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Backward Gait is Associated with Motor Symptoms and Fear of Falling in Patients with *De Novo* Parkinson's Disease

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Background and Purpose Many previous studies have investigated forward gait (FG), backward gait (BG), and dual-task gait (DG) in patients with Parkinson's disease (PD). However, it remains uncertain whether gait parameters are implicated in motor symptoms or the risk of falling, especially in patients with *de novo* PD.

Methods Demographic and clinical characteristics including the Fear of Falling Measure (FFM) were assessed in patients with *de novo* PD and in healthy subjects. A computerized gait analysis using the GAITRite system was performed for FG, BG, and DG. The Unified Parkinson's Disease Rating Scale Part III was assessed in patients with PD.

Results This prospective study included 24 patients with *de novo* PD and 27 controls. Compared with controls, patients with *de novo* PD showed a slower gait and shorter stride in all three gaits. Patients with *de novo* PD also exhibited increases in the stride-to-stride variability in the stride time and stride length of the gait for BG, increased length for DG, and no increase for FG. Moreover, the BG speed in *de novo* PD patients was significantly associated with their motor symptoms (bradykinesia, postural instability, gait difficulty, and total motor score) and negatively correlated with the FFM score.

Conclusions The BG dynamics were more impaired and more closely related to motor symptoms and fear of falling than were the FG or DG dynamics in patients with *de novo* PD, indicating that BG parameters are potential biomarkers for the progression of PD.

Key Words Parkinson's disease, gait, fear of falling, backward gait.

INTRODUCTION

The gait impairment in patients with Parkinson's disease (PD) is characterized by increases in the stride-to-stride variability in the stride length and stride time of the gait along with reductions in the gait speed, stride length, and step width.[1-3] Many studies of gait analysis in PD have focused on the usual or comfortable walking in a forward direction, perhaps because forward gait (FG) is the most common and important type of gait in humans regardless of the presence of PD. Among the few studies that have investigated the dynamics of backward gait (BG) in patients with PD, Hackney and Earhart[4] found that BG is more impaired than FG in patients with PD, and Bryant et al.[5] reported that BG was improved similarly to FG after levodopa administration. Conversely, the dual-task gait (DG), such as walking while performing a cognitive task, has been extensively investigated in patients with PD in the context of cognitive impairment. Compared with the single-task gait, patients with PD performing DG exhibit more-severe deficits in gait speed, stride length, gait asymmetry, and stride-to-stride variability.[6] Moreover, DG was more impaired in PD patients who exhibit the freezing of gait, which is considered to be associated with a high risk

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of falling.[7,8]

Most gait studies have investigated patients in the advanced stages of PD rather than the early stages of PD, because alterations of gait parameters are closely related to the progression of motor symptoms in PD patients. This focus has resulted in a dearth of information on the characteristics of gait dynamics in early-stage PD. However, some researchers have reported that even patients with *de novo* PD exhibited a slow gait with reductions in stride length and stride time.[9,10] Our group recently showed that the slow gait in patients with *de novo* PD was related to a reduction in the stride length rather than the stride time; furthermore, after levodopa administration, their slow gait was improved by increasing the walking cadence; that is, shortening the stride time rather than increasing the stride length.[11]

In the present study we aimed to determine the type of gait (FG, BG, or DG) that is most strongly associated with pathophysiological changes reflecting motor symptoms or the risk of falling in patients with *de novo* PD. We hypothesized that DG is more closely related to motor symptoms and the risk of falling in PD patients because mild cognitive impairment is not uncommon in the early stages of PD,[12,13] and such cognitive difficulties could exert a greater impact on DG in patients with *de novo* PD.[14] However, it was found that the results did not fully support this hypothesis.

METHODS

Participants

Drug-naïve patients with a clinical diagnosis of *de novo* PD[15] and healthy controls were recruited prospectively from the Parkinson's Disease Center of Korea University Guro Hospital between 2014 and 2015. Patients who had PD for shorter than 5 years and were 50–75 years old participated in the study. Subjects who found it difficult to properly perform various gaits during the analysis were excluded, and hence none of the included subjects had any significant musculoskeletal condition or comorbidity of neurological disorder including dementia or vestibulopathy. In addition, to minimize the possibility of atypical parkinsonism, we excluded any PD patient with poor levodopa responsiveness after a levodopa trial, defined as an improvement in motor symptoms of less than 20% at 1 hour after receiving levodopa.[16]

After obtaining informed consents, initially 30 patients with PD and 30 age- and sex-matched healthy subjects were recruited. After applying the exclusion criteria, 24 patients with PD and 27 controls were included in the final analysis. The present study had a prospective design and was approved by the Institutional Review Board of Korea University Guro Hospital (IRB No. KUGH13034). A subset of the data reported here has been published previously.[11]

Clinical assessments

Clinical PD was diagnosed in all patients by a single movement-disorder specialist (S.-B.K.). All of the participants (both the PD patients and controls) were assessed by another movement disorder specialist (K.-Y.K.) applying the inclusion and exclusion criteria for subjects in the study. Clinical demographics and scores on the Korean version of the Montreal Cognitive Assessment were measured. The fear of falling was evaluated using the Fear of Falling Measure (FFM) with permission from the authors, for which the maximum score is 38.[17] In addition to the Unified Parkinson's Disease Rating Scale (UPDRS) Part II, patients with PD were evaluated using UPDRS Part III (motor symptoms) at baseline and 1 hour after administering levodopa/carbidopa (100 mg/25 mg). The subscore for motor symptoms was derived as follows: the tremor score was calculated as the sum of UPDRS Part III items 3–9; the rigidity score was calculated as the sum of UPDRS Part III items 10–14; the bradykinesia score was calculated as the sum of UPDRS Part III items 15–22 and 27; and the postural instability and gait difficulty (PIGD) score was calculated as the sum of UPDRS Part II items 13–15 and UPDRS Part III items 25 and 26.

Gait studies were performed using the GAITRite system (CIR Systems Inc., Franklin, NJ, USA) with a 4.6-m-long walkway mat. FG, BG, and DG (which involved walking while subtracting serial 7s) were randomly assessed in each patient in order to minimize possible learning effects. Each of the three gaits was tested 10 times while walking at a comfortable speed. Participants were asked to start two steps before the mat and stop two steps after the mat in order to avoid acceleration and deceleration effects. The following spatiotemporal gait parameters were measured: speed (cm/s), cadence (steps/min), stride time (s), stride length (cm), swing phase (%), double-support phase (%), and step width (cm). The following gait parameters were also calculated: coefficient of variation (defined as 100×SD/mean) of any given variable, and the gait asymmetric index [defined as 100/ln (short-swing time/long-swing time)]. The parkinsonian motor symptoms and FG, BG, and DG parameters were only analyzed at baseline (before levodopa administration), although evaluation of motor symptoms and gait tests were also conducted after levodopa administration.

Statistics

Comparisons between the PD patients and controls were performed using Student's *t*-test. Spearman's rank correlation was used for correlation analyses. A p value of <0.05 was considered statistically significant. Statistical analyses were conducted using SPSS (version 20.0, IBM Corp., Armonk, NY, USA).

RESULTS

Between-group comparisons of FG, BG, and DG

The clinical characteristics of the study participants are listed in Table 1. The follow-up period of the PD patients was 4.09±1.03 years (mean±SD), and the condition of all of them had altered since the initial diagnosis of PD. There were no significant differences in their baseline demographics, with only the FFM score being lower in patients with PD than in the normal controls (p=0.002). Table 2 presents the spatiotemporal, gait variability, and gait asymmetry-associated parameters for the three gaits (FG, BG, and DG) in the healthy controls and the patients with *de novo* PD. Compared with controls,

Table 1. Demographic and clinical characteristics of the participants

Characteristic	Healthy controls (n=27)	Drug-naïve PD patients (n=24)	p
Females	11 (40.7)	9 (37.5)	0.813
Age at examination, years	61.41±6.70	63.96±6.27	0.168
Height, cm	164.00±8.04	163.04±7.85	0.669
Weight, kg	61.19±9.23	61.10±8.91	0.975
Body mass index, kg/m^2	22.64±2.15	22.91±2.37	0.663
Education, years	10.52±5.00	10.46±4.94	0.966
MoCA-K score	24.70±4.61	25.00±2.75	0.785
Fear-of-falling measure	1.67±1.62	4.54±4.18	0.002*
Disease duration, years	n.a.	1.13±1.45	
UPDRS Part II	n.a.	5.46±4.11	
UPDRS Part III (motor symptoms)	n.a.	17.13±6.40	
Tremor score	n.a.	4.42±2.99	
Rigidity score	n.a.	3.46±2.30	
Bradykinesia score	n.a.	6.75±3.33	
PIGD score	n.a.	1.54±1.74	
Hoehn & Yahr stage	n.a.	1.88±0.40	

Data are n (%) or mean±SD values. Modified from the original version of Kwon et al. Gait Posture 2017;58:1-6.[11]
*p<0.05.
MoCA-K: Korean version of the Montreal Cognitive Assessment, n.a.: not applicable, PD: Parkinson's disease, PIGD: postural instability and gait difficulty, UPDRS: Unified Parkinson's Disease Rating Scale.

Table 2. Comparison of FG, BG, and DG parameters between healthy controls and patients with *de novo* PD

Variable	FG		p	BG		p	DG		p
	Control	*De novo* PD		Control	*De novo* PD		Control	*De novo* PD	
Spatiotemporal parameters									
Walking speed, cm/s	116.50±9.92	107.72±14.48	0.014*	83.50±13.54	66.76±18.80	0.001*	99.43±12.54	86.73±14.90	0.004*
Cadence, steps/min	111.93±9.08	114.35± 6.17	0.276	110.60±11.19	111.31±13.54	0.839	103.17±10.12	103.53±12.94	0.910
Stride time, s	1.08±0.09	1.05±0.05	0.196	1.09±0.12	1.09±0.13	0.966	1.17±0.13	1.17±0.16	0.990
Stride length, cm	125.62±8.75	113.35±14.19	0.001*	90.87±11.09	72.56±18.88	<0.001*	114.81±10.51	101.15±14.42	<0.001*
Swing phase, %	38.67±0.87	37.74±1.38	0.008*	35.79±1.81	34.78±3.00	0.162	37.52±1.66	36.20±1.79	0.009*
Double-support phase, %	22.97±1.69	24.45±2.87	0.028*	28.07±3.19	30.70±5.01	0.049*	25.34±2.85	28.15±3.58	0.003*
Step width, cm	8.24±2.44	7.53±2.05	0.270	16.17±4.22	15.50±3.43	0.546	8.56±2.99	8.02±2.16	0.469
CV, %									
Stride time	2.86±0.95	3.11±0.99	0.363	4.71±1.82	6.18±2.61	0.024*	5.29±2.97	5.72±3.05	0.615
Stride length	3.40±1.05	3.88±1.68	0.236	7.32±2.74	10.45±3.00	<0.001*	4.92±1.79	6.06±2.15	0.044*
Asymmetry of gait									
Gait asymmetry index	2.37±1.60	3.36±2.59	0.103	3.26±3.30	5.22±4.31	0.085	2.81±2.03	4.38±3.62	0.068
Gait CV asymmetry	21.01±13.40	24.48±24.93	0.547	17.76±17.60	17.99±15.22	0.960	25.82±16.52	22.36±16.92	0.464

Data are mean±SD values. Student's t-test used for comparisons of control vs. PD groups.
*p<0.05.
BG: backward gait, CV: coefficient of variation, DG: dual-task gait, FG: forward gait, PD: Parkinson's disease.

patients with *de novo* PD showed a slower gait (p=0.014, p=0.001, and p=0.004 in FG, BG, and DG, respectively), a shorter stride (p=0.001, p<0.001, and p<0.001), and an increased double-support phase (p=0.028, p=0.049, and p=0.003) in all three gaits. However, compared with the controls, the patients with *de novo* PD exhibited different results regarding the variabilities in stride time and stride length among the three gaits (Fig. 1). BG revealed both increased variability in both stride time (p=0.024) and stride length (p< 0.001). DG revealed only altered stride-length variability (p= 0.044), and between-group differences in stride-time and stride-length variability were not observed for FG. In addition, there were no between-group differences in any parameters associated with gait asymmetry.

As a post-hoc analysis, comparisons between gait tasks (FG vs. BG vs. DG) in the same group were evaluated (Supplementary Tables 1 and 2 (in the online-only Data Supplement) for healthy controls and patients with *de novo* PD, respectively). Most of the gait-task parameters differed significantly not only in the control group but also in the PD group. The findings of the within-group comparisons were similar in all groups.

Correlations between FG, BG, and DG speeds and motor symptoms in patients with *de novo* PD

We investigated whether gait speed in each gait condition was correlated with motor symptoms in patients with *de novo* PD. The results in Table 3 indicate that the BG speed was negatively correlated with bradykinesia score (r_s=-0.469, p= 0.021), PIGD score (r_s=-0.452, p=0.027), and total motor score (r_s= -0.473, p=0.020). Whereas, the DG speed was negatively correlated with the bradykinesia score (r_s=-0.455, p=0.025) and the total motor score (r_s=-0.428, p=0.037). Unexpectedly, the tremor score was positively correlated with the FG speed (r_s= 0.477, p=0.019).

Associations of fear of falling with FG, BG, and DG parameters in controls and patients with *de novo* PD

The fear of falling is a risk factor for falling in patients with PD,[18,19] and so we investigated the correlation between gait speed and FFM score (Fig. 2). Notably, the FFM score in patients with *de novo* PD was negatively correlated with the BG speed but not with the FG or DG speed. Conversely, no correlation between FFM score and gait speed was observed in the control group for all three gaits.

DISCUSSION

To the best of our knowledge, this is the first study to investigate the differences in gait parameters among three gaits (FG, BG, and DG) between patients with PD and normal controls. This study investigated drug-naïve patients with *de novo* PD to determine the earliest association between motor symptoms and gait dynamics based on gait. Furthermore, we assessed the correlations between gait speed and FFM score in patients with *de novo* PD and in healthy controls. The obtained results will help to improve the understanding of the

Table 3. Correlation of gait speed and motor features for FG, BG, and DG in patients with *de novo* PD

Motor feature	FG	BG	DG
Tremor score	0.477 (0.019)	0.258 (0.224)	0.198 (0.353)
Rigidity score	-0.004 (0.985)	-0.369 (0.076)	-0.242 (0.254)
Bradykinesia score	-0.193 (0.367)	-0.469 (0.021)*	-0.455 (0.025)*
PIGD score	-0.380 (0.067)	-0.452 (0.027)*	-0.125 (0.560)
Total motor score	-0.075 (0.729)	-0.473 (0.020)*	-0.428 (0.037)*

Data are Spearman's r_s (p) values. Walking speed was normalized to the height of each patient.
*p<0.05.
BG: backward gait, DG: dual-task gait, FG: forward gait, PD: Parkinson's disease, PIGD: postural instability and gait difficulty.

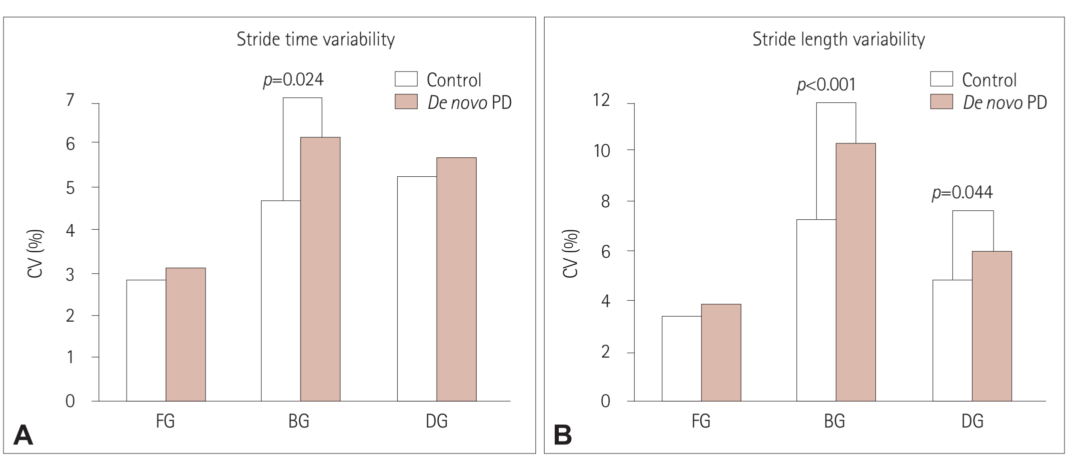

Fig. 1. Stride-to-stride variability in stride time (A) and stride length (B) in FG, BG, and DG in patients with *de novo* PD and healthy controls. BG: backward gait, CV: coefficient of variation, DG: dual-task gait, FG: forward gait, PD: Parkinson's disease.

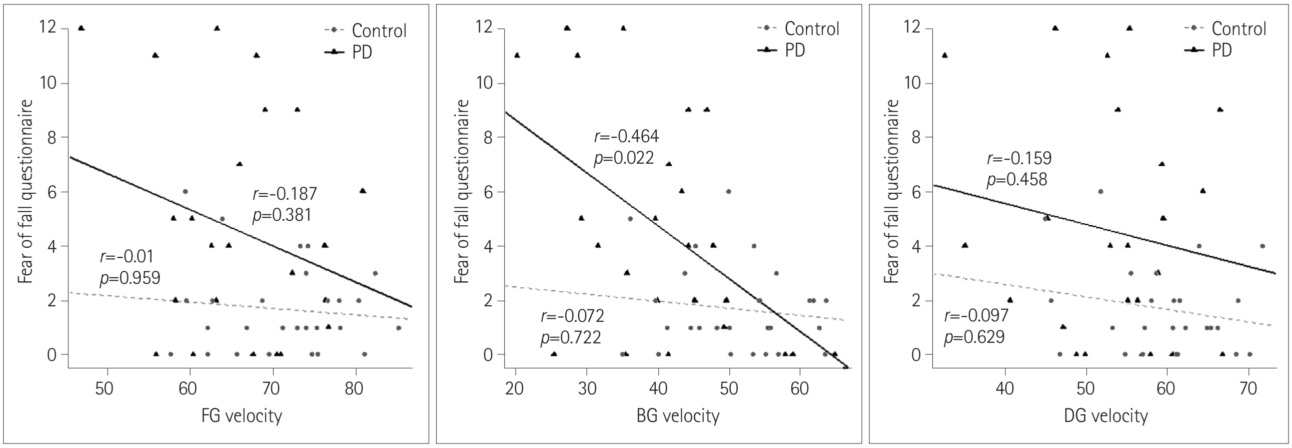

Fig. 2. Associations between fear of falling and FG, BG, and DG speeds in patients with *de novo* PD and healthy controls. BG: backward gait, DG: dual-task gait, FG: forward gait, PD: Parkinson's disease.

detailed clinical relationship between gait parameters among FG, BG, and DG and motor symptoms or fear of falling in the early stages of PD.

The patients in this study with *de novo* PD showed a slower gait and shorter stride in FG, BG, and DG compared with normal controls. However, the stride-to-stride gait variability results differed among the three gaits (Table 2, Fig. 1): compared with the healthy controls, the patients with *de novo* PD showed no difference in the variabilities of stride length and stride time in FG, an increased variability in both stride length and stride time in BG, and an increased variability in stride length in DG. These results indicate that slow walking with a short stride is a clear feature of *de novo* PD regardless of the gait task being performed, and the earliest alterations of gait variability may first become apparent in BG, followed by DG and then FG.

The exact reason why the stride-to-stride variability is more impaired in BG than in FG or DG in patients with *de novo* PD remains unclear. The stride-to-stride variability of BG in patients with PD has not been fully investigated, although one study found no significant differences between patients in advanced stages of PD and controls.[4] Accordingly, further well-designed studies of stride-to-stride variability in different gait types (including BG) need to be performed in patients with PD to determine the clinical relevance or pathomechanisms of disease progression. Conversely, in agreement with the results obtained in the present study, the stride-to-stride variability of DG has been reported to be greater than FG in patients with PD with a moderate disease severity.[20] In addition, although asymmetric limb symptoms are a key feature of PD, the degree of gait asymmetry was not altered in any of the gaits in patients with *de novo* PD compared with normal controls in the present study, which implies that gait asymmetry is a relatively late change in the gait dynamics.

Various factors (including motor symptoms) can affect the gait speed in patients with PD. We investigated whether parkinsonian motor symptoms were correlated with the walking speed in FG, BG, and DG. As indicated in Table 3, the BG speed was associated with a wider range of motor symptoms. Notably, the BG speed was negatively correlated with PIGD score in patients with *de novo* PD. Our findings indicate that the BG speed is a potential surrogate marker for the progression of motor symptoms or gait impairment in PD. Since there has been relatively few studies of BG in PD, the exact reason for the BG speed being mostly closely related to motor symptoms in patients with *de novo* PD remains unclear. The basal ganglia are known to function primarily to control and regulate voluntary movements more smoothly. FG could be influenced by visual information, and DG might be affected by the degree of cognitive impairment. BG might be the simplest type of gait among the three gait tasks. In other words, BG might be more closely linked to the function of the basal ganglia in relation to the locomotor system compared to FG or DG. It is therefore reasonable to infer that BG reflects the primary function of the basal ganglia better than does FG or DG, especially in the early stages of PD. Conversely, the tremor score was positively correlated with the FG speed in patients with *de novo* PD. This result does not imply that tremor accelerated the walking speed, but that patients with less tremor might belong to the non-tremor-dominant or PIGD type, thereby indicating that non-tremor-dominant PD patients exhibited a slower gait than tremor-dominant PD patients. Similarly, several other studies have found that the reductions in gait speed were more pronounced in non-tremor-dominant PD patients than in tremor-dominant PD patients.[11,21,22]

The risk factors for falling in patients with PD include a previous history of falls, disease duration, disease severity, dyskinesia, freezing of gait, stride-time variability, fear of falling, and postural instability.[23-26] Falls can occasionally occur even in the early stages of PD, which has prompted several researchers to investigate the risk of falling in early-stage PD, including the *de novo* state.[27-29] However, those studies have not produced consistent results. Moreover, meaningful comparisons of the fall history between controls and patients with *de novo* PD could not be performed in the present study since the number of participants with a history of a recent fall was very small in both groups (data not shown). Instead, the fear of falling was correlated with the BG speed, but not the FG or DG speed in patients with *de novo* PD; however, a similar association was not found for any of the three gaits in healthy normal controls (Fig. 2). Lord et al.[27] recently reported that a slower gait was an independent risk factor for falling in *de novo* PD patients, and Son et al.[30] demonstrated that freezing of gait in patients with PD was associated with slower walking in BG than in FG. Together these findings indicate that the BG speed is more strongly associated with the risk of falling than are the FG or DG speed in the early stages of PD. Future studies should investigate the relationship between the BG speed and falls in patients with PD.

This study was subject to several limitations. First, it was conducted in a single hospital and included a relatively small number of participants, and so the findings should be interpreted with caution. Nevertheless, significant results could be obtained since it was a prospectively designed case–control study. Second, the measurements using the GAITRite system for evaluating each gait did not accurately represent real walking conditions. However, several efforts were made not only to reduce the learning effect, but also to minimize the effects of acceleration and deceleration on the gait, as described in the Methods.

In summary, patients with *de novo* PD exhibited a slower gait and shorter stride in FG, BG, and DG compared with normal controls. However, the stride-to-stride gait variability was more impaired in BG than in FG or DG. Furthermore, the BG speed was more closely related to motor symptoms and fear of falling than were the FG and DG speeds in patients with *de novo* PD. Our findings suggest that more clinically relevant studies of BG are required in patients with PD.

Supplementary Materials

The online-only Data Supplement is available with this article at https://doi.org/10.3988/jcn.2019.15.4.473.

Author Contributions

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Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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