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Spatiotemporal Gait Parameter Comparison for Parkinson's Disease, Multiple System Atrophy, and Other Parkinsonism Diseases

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HIGHLIGHTS

- The patients with Parkinson's disease (PD) showed more laterally deviated gait parameter compared to the multiple system atrophy patients at the early stage of the diseases.
- The gait velocity has a borderline significance in between PD and other Parkinsonism diseases, indicating that it might differ at the early stage of diseases.

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Spatiotemporal Gait Parameter Comparison for Parkinson's Disease, Multiple System Atrophy, and Other Parkinsonism Diseases

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Conflict of Interest
The authors have no potential conflicts of interest to disclose.

ABSTRACT

The aim of this study was to compare and quantify the spatiotemporal and gait parameters obtained by foot pressure analysis during the gait in a group of Parkinson's disease (PD) patients compared with other Parkinsonism diseases, especially multiple system atrophy (MSA). Thirty-seven out of ninety-three patients who visited the center of neurology or rehabilitation with features of Parkinsonism were recruited. Spatiotemporal gait parameters were collected using gait analysis system. The results did not differ in terms of the stride length, step width, double stance phase, stride time, cadence, velocity, gait line and single support line differences, anterior-posterior position of center of pressure, and maximal gait line velocity; the lateral symmetry showed a significant difference between the PD and the MSA groups (p < 0.05). The study evaluated the differences in terms of spatiotemporal parameters between the PD and MSA along with other Parkinsonism diseases; it showed that the PD patients had a gait tendency to deviate laterally compared to the MSA patients. The result suggests conducting the gait foot pressure analysis might help distinguish PD from other Parkinsonism diseases in early stage, aiding the early decision for the treatment plans.

Keywords: Parkinsonism; Parkinson's disease; Multiple system atrophy; Gait

INTRODUCTION

Parkinson's disease (PD) is a progressive and neurodegenerative disorder characterized clinically by bradykinesia, rigidity, tremor, and postural instability. Disability occurs at all stages of the disease and the severity of disability usually increases with disease duration. Patients frequently experience gait disturbance, difficulty in linking movements together smoothly, and episodes of freezing [1].

Of these cardinal motor features, gait disturbance is one of the most disabling characteristics of the disease since it not only reduces the patient's mobility, but also leads to increased fall frequency; the overall quality of life diminishes with aggravating gait disturbance. It is estimated that more than 70% of patients fall during the course of the disease and such events often result in fractures, often leading to another morbidity. To improve the quality of life for

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patients with PD, many research studies have evaluated the underlying mechanisms that cause gait disturbance and have focused on evaluating different intervention strategies [2].

Patients with PD often walk with a reduced gait speed, shorter stride length, reduced arm swing, and decreased postural stability [1,2]. Previous study on the gait evaluation of the PD patients suggested that reductions in gait velocity result from diminished stride length in persons with PD, whereas cadence is typically unaffected; the PD patients often develop a strategy to increase dynamic stability known as festinating gait; it is characterized by rapid, hypometric steps that minimize displacement of the center of gravity relative to the base of support and increase double-limb support time [2,3].

Parkinsonism diseases include the atypical Parkinsonian disorders of multiple system atrophy (MSA), dementia with Lewy bodies (DLB), progressive supranuclear palsy (PSP), and corticobasal syndrome, as well as secondary causes of Parkinsonism [4]. It is a challenge to distinguish PD from other Parkinsonism diseases because they share similar symptoms, despite of differences in etiology and treatment plans. Although the classic PD has the clinical features most commonly associated with Parkinsonism, there is a broader spectrum of diseases represented by a collection of phenotypically-similar neurodegenerative conditions that mimic many of the core features of PD, including gait pattern. Because of the similar clinical gait presentations, it is necessary to consider relevant disorders when diagnosing PD [5].

There is growing interest in having an objective assessment of these diseases using technology-based devices capable of providing unbiased measurements in clinical practice. Treadmill gait analysis is an attractive example, as it requires little space and allows for the use of harness support systems; several studies have found that the use of treadmill in training the patients with PD may improve clinically relevant gait parameters such as gait speed and stride length [1,6].

The gait parameters were often studied and analyzed in order to evaluate the gait patterns of specific disease group or patient at specific age. In the PD patients, Blin et al. [7] analyzed previous gait parameter studies and showed that kinematic gait parameters are different, yet the relationships between the parameters are unchanged. Gait parameters were used to describe the patterns or the effect of specific treatment so far, yet there was no attempt to make comparison between similar, but different diseases so far in our knowledge. Therefore, we hypothesized that the gait parameters are different in the PD and other Parkinsonism diseases, especially the parameters of MSA; the MSA has several subtypes in which MSA-Parkinson type (MSA-P) has the similar balance and gait disturbance shown in the PD.

The aims of this study were to compare the spatiotemporal parameters of gait in PD patients and other Parkinsonism patients, using such gait analysis treadmill platform.

MATERIALS AND METHODS

Subjects
Ninety-three patients who visited the center of neurology or rehabilitation with features of Parkinsonism were recruited from a single university hospital. Among the visitors, the patients with the following criteria were excluded: 1) had a past medical history of

neurological conditions other than Parkinsonism, such as stroke, 2) previously diagnosed with PD or other Parkinsonism diseases, and 3) had a history of orthopedic or other conditions affecting walking ability. A fundamental requirement for inclusion in the study was the ability to walk for 30 seconds on a floor, then on a treadmill without stopping, walking aids, or other forms of assistance. Also, the patients with previous underlying diseases were excluded because of the potential effects of the existing gait disturbance on the results. The disease duration was not clear among the patients, yet we selected the patients, who had no previous visit to hospital with the Parkinsonism symptoms, for evaluation. This prospective study's protocol was approved by the Ethics Committee of Ewha Womans University Medical Center (IRB No. 2018-05-058-001).

The age and sex of each patient were obtained. The level of functional disability was determined using the unified Parkinson's disease rating scale (UPDRS) motor section and the Hoehn and Yahr (H&Y) scale scored by a neurologist. We identified patients with the diagnosis of PD and other Parkinsonism in the Neurology department out-patient service by neurologic specialists of Parkinsonism. Once the initial diagnosis was made to the patients, they were categorized into 3 groups: PD, MSA, and other Parkinsonism diseases; the MSA group was separated from the Parkinsonism disease group because the MSA, especially MSA-P subtype, has the similar balance and gait disturbance. In this selecting process, patients diagnosed with other than PD or Parkinsonism diseases, such as ataxia, dystonia, depression, and etc., were excluded.

Foot pressure analysis

Foot pressure analysis during the gait was performed on the instrumented force platform (Zebris® gait analysis, Zebris Medical GmbH, Isny im Allgau, Germany). The spatiotemporal parameters of gait were estimated from the vertical pressures on the treadmill analysis system (Fig. 1). The instrumented force analysis system comprises a capacitance-based, foot pressure platform housed within a treadmill. The pressure platform has a sensing area of 150 × 50 cm and the sensor unit has 5,370 pressure/force sensors. Foot pressure analysis provided not only the pressure change patterns in both feet during the gait, but also the spatiotemporal gait parameters associated with the gait.

All experiments were conducted while the patients were in an initial "Dopamine-OFF" stage. The selected patients were capable of walking at least for 30 seconds at their comfortable gait velocity. The subjects stood barefoot on the force platform for a few seconds before initiating gait at a self-selected speed. One or two practice trials were performed before the experimental trials. In order to reflect the gait patterns of early disease stage, patients who could not walk properly on the treadmill or those with gait velocity below 1.0 km/hr were excluded from our analysis.

Outcome measures

We gathered and analyzed the following temporal and spatial gait parameters: the stride length (cm), step width (cm), double stance phase (%, double support as percentage of stride time), stride time (seconds), cadence (steps/min), gait velocity (km/hr), gait line and single support line differences between right and left legs (mm), anterior-posterior position of center of pressure (mm), center of pressure (COP) lateral symmetry of the patients during the gait (mm), and maximal gait line velocity (cm/sec). Parameters that were taken from a single side (e.g., swing phase of left lower leg, transit time from heel to toe of right foot, etc.) were excluded from analysis since each patient had different gait/limping patterns and there was no
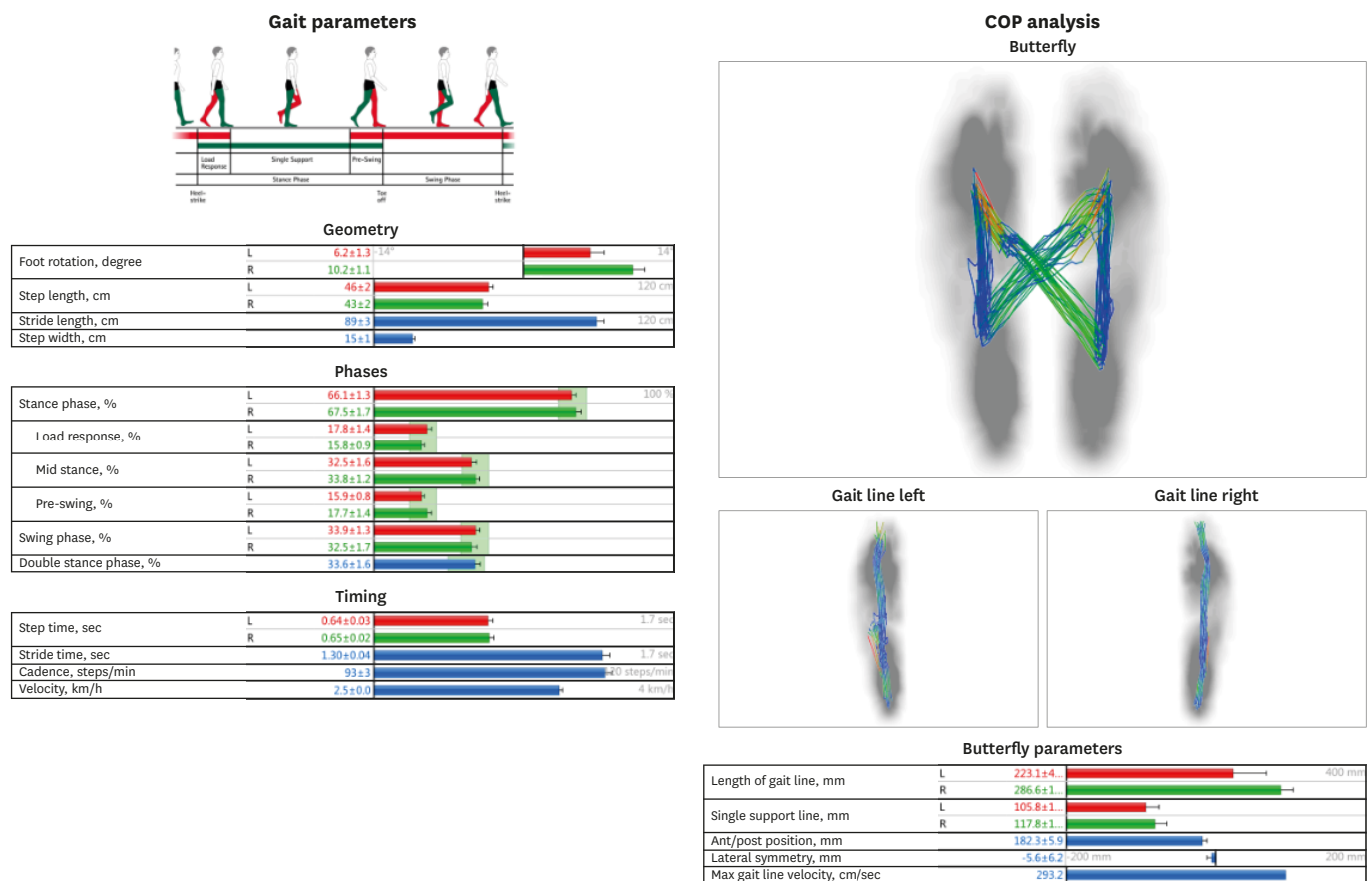
Fig. 1. Gait parameter analysis from a patient.

report that PD or other Parkinsonism patients developed a specific limping side as the diseases progressed. The pressure data were excluded from the analysis because we focused on the difference in the spatiotemporal parameters representing the differences in gait pattern.

Statistics

Age, sex, UPDRS, and H&Y scale of the patient pool were analyzed to compare demographic and functional characteristics. Kruskal-Wallis test was conducted to the gait parameters described above. Then, Mann-Whitney U-test was conducted between the groups (PD vs. MSA, PD vs. other Parkinsonism diseases, and MSA vs. other Parkinsonism diseases), and obtained p values from 3 Mann-Whitey tests were adjusted using Bonferroni method for multiple testing correction. Kruskal-Wallis and Mann-Whitney tests were utilized because our patient groups were composed of a small number, in which we could not assume for normal distribution. All statistical analyses were performed using the SPSS program ver. 23.0 (SPSS Inc, Chicago, IL, USA). A p value ≤ 0.05 was considered statistically significant with a confidence interval (CI) of 95%.

RESULTS

Demographic and clinical characteristics

Among ninety-three patients, total of thirty-seven patients were recruited for analysis: sixteen PD, eleven other Parkinsonism, and ten MSA patients (Table 1). Each group's

Table 1. Demographic characteristics

Characteristics	PD	MSA	Parkinsonism	p value
Subjects (No. of omitted)	16	10	11	-
Sex (male/female)	8/8	9/1	7/4	0.366
Age (yr)	63.1 ± 8.7	66.9 ± 7.5	70.4 ± 10.4	0.144
UPDRS motor score	20.75 ± 13.64	29.38 ± 10.75	20.75 ± 14.01	0.122
H&Y scale	1.8 ± 0.77	2.4 ± 0.74	2.0 ± 0.62	0.157

Values are mean ± standard deviations.
There was lost data: 2 patients from the MSA group and 1 patient from other Parkinsonism group in UPDRS motor score and H&Y scale.
PD, Parkinson's disease; MSA, multiple system atrophy; UPDRS, unified Parkinson's disease rating scale; H&Y, Hoehn and Yahr.

patients' mean ages were as following: 63.1 ± 8.7 for PD, 66.9 ± 7.5 for MSA, and 70.4 ± 10.4 for other Parkinsonism diseases. Thirteen out of thirty-seven patients (35.1%) were females in this study: 8 out of sixteen in the PD, one out of ten in the MSA, and 4 out of eleven in Parkinsonism patients. No significant differences were found between the IPD group and the Parkinsonism other than IPD group in terms of age and gender distribution. The mean values of the level of functional disability obtained using UPDRS motor scores was 20.75 ± 13.64 in the PD group, 29.38 ± 10.75 in the MSA group, and 20.75 ± 14.01 in the other Parkinsonism group. The onset duration of the disease was omitted from the analysis, because the onset recording was not.

Gait analysis: spatiotemporal parameters

The spatiotemporal parameters of the 3 groups and each group's median value and 25%–75% interquartile values are shown in Table 2. Kruskal-Wallis test was used to compare the 3 groups; it showed that the velocity and the lateral symmetry had borderline significances, with p values of 0.090 and 0.071, respectively (Table 2). When comparing 3 independent groups all together, no single factor had successfully described the difference in gait patterns among the patients.

Thus, we compared each independent group with one another to check whether there was significant difference among the spatiotemporal parameters using Mann-Whitney test and Bonferroni adjustment. The results showed that the PD and MSA groups (total n = 26, PD = 16, and MSA = 10) did not show a meaningful difference between the 2 groups in terms of velocity, but it showed a significant difference in terms of the lateral symmetry during the gait (p = 0.048). As shown in the Table 2, the median value of PD group's lateral symmetry was 11.77 mm with interquartile range from 4.22 mm to 24.17 mm, and the MSA with the median of 2.45 mm and the interquartile from 1.34 mm to 9.32 mm. The analysis indicated that such difference had a statistical meaning; the PD patients indeed had more tendency to laterally deviate than the MSA patients (Fig. 2). However, the difference in the COP lateral symmetry during the gait between the MSA and other Parkinsonism disease groups was not statistically meaningful (Table 2).

Analyses between 2 independent groups was conducted as well, and the analysis between the PD and other Parkinsonism disease groups showed that gait velocity had a borderline significance; with the Bonferroni adjustment, however, it did not show statistical significance with p value 0.162. The similar result was shown in terms of velocity between the MSA and other Parkinsonism disease groups (adjusted p value = 0.171). Thus, velocity could not describe the gait pattern differences between the groups as lateral symmetry did, yet it showed the possibility that velocity might be another distinguishing spatiotemporal parameter in terms of describing the gait pattern difference. The comparison between other

Table 2. Spatiotemporal parameter distribution in each group

Parameters	Group	Median	Interquartile		p value
Stride length (cm)	PD	52.47	39.60	66.81	0.232
	MSA	46.82	42.56	50.67	
	Parkinsonism	38.48	32.81	49.22	
Step width (cm)	PD	16.72	15.51	18.75	0.945
	MSA	16.67	14.55	17.27	
	Parkinsonism	16.37	14.19	18.57	
Double stance phase (%)	PD	40.08	37.02	46.06	0.786
	MSA	40.03	38.79	43.47	
	Parkinsonism	44.60	36.87	49.79	
Stride time (sec)	PD	0.995	0.878	1.085	0.919
	MSA	0.992	0.868	1.072	
	Parkinsonism	1.000	0.914	1.110	
Cadence (steps/min)	PD	120.75	110.80	137.20	0.899
	MSA	121.40	112.30	138.80	
	Parkinsonism	120.20	108.35	131.75	
Velocity (km/hr)	PD	1.98	1.39	2.22	0.090*
	MSA	1.77	1.48	2.10	
	Parkinsonism	1.24	1.23	1.80	
Gait line diff. (mm)	PD	15.55	3.10	27.35	0.784
	MSA	15.70	9.50	19.40	
	Parkinsonism	13.40	8.20	18.35	
Single support line diff. (mm)	PD	11.34	5.20	16.36	0.283
	MSA	6.21	4.83	7.59	
	Parkinsonism	6.25	2.70	9.43	
Ant-post position (mm)	PD	188.85	165.95	196.60	0.924
	MSA	189.20	178.20	201.40	
	Parkinsonism	188.60	183.50	192.65	
Lateral symmetry (mm)	PD	11.77[†]	4.22	24.17	0.071*
	MSA	2.45[†]	1.34	9.32	
	Parkinsonism	8.35	3.62	17.76	
Max. gait line velocity (cm/sec)	PD	569.90	543.05	605.30	0.265
	MSA	622.15	600.30	796.00	
	Parkinsonism	654.30	390.90	684.40	

Number of patients in each group: PD 16, MSA 10, other Parkinsonism 11.
PD, Parkinson's disease; MSA, multiple system atrophy; Diff, differences; Max, maximum.
*The p value < 0.10 in Kruskal-Wallis test; [†]Subgroup analysis between the PD and the MSA using Mann-Whitney test, corrected by Bonferroni adjustment, showed p value of 0.048.
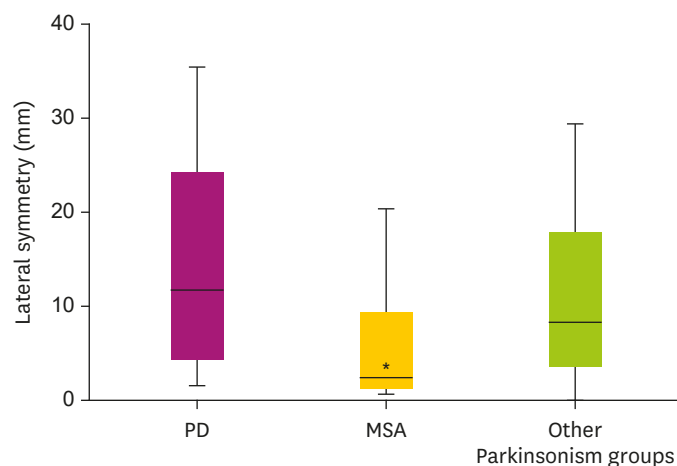

Fig. 2. Lateral symmetry comparison between PD, MSA, and other Parkinsonism groups.
PD, Parkinson's disease; MSA, multiple system atrophy.
*p value < 0.10 in Kruskal-Wallis test; Subgroup analysis between the PD and the MSA using Mann-Whitney test, corrected by Bonferroni adjustment, showed statistically significant difference.

parameters did not significantly differ in terms of the stride length, step width, double stance phase, stride time, cadence, gait line and single support line differences between right and left legs, anterior-posterior position of COP, and maximal gait line velocity.

DISCUSSION

The gait pattern in PD can be described characteristically and has been well studied in previous studies [7,8]. The steps are short and variable whereas the cadence is mostly normal, except for in later stages with severe akinesia [9]. The step width and foot rotation angles are normal [10]. In later stages of the disease the foot to floor clearance is reduced and the patient begins to shuffle over the ground. In our study, all 3 groups had decreased step lengths, approximately 15 cm, and increased step width, approximately by 5 cm, compared to the values found in control (normal) group in a study conducted by Bello et al. [11].

PD refers to a clinical condition: progressive Parkinsonism of undetermined cause without features suggestive of an alternative diagnosis responding to dopaminergic treatment. Although a diagnosis of PD as defined above can be a straightforward clinical exercise in patients with typical presentation of cardinal signs and excellent response to levodopa treatment, the differential diagnosis versus other forms of Parkinsonism can be challenging, especially early in the disease when the signs and symptoms of the different forms of Parkinsonism have the greatest overlap. The correct diagnosis of PD is important for prognostic and therapeutic reasons and is also essential in clinical research. Investigations of the diagnostic accuracy for PD and other forms of Parkinsonism in community-based samples of patients taking antiparkinsonian medication confirmed a diagnosis of Parkinsonism in only 74% of patients and clinically probable specific PD in only 53% of patients [12]. The gold standard for definite diagnosis for other Parkinsonism diseases, such as MSA, PSP, CBD, and DLB remains to be pathology [13].

For this reason, various researches are actively being conducted to distinguish PD from other types of Parkinsonism. Typically, studies that distinguish PD from other Parkinsonism use imaging techniques [14,15]. One of these studies analyzed exhaled volatile organic compounds with a breath test to distinguish between PD and other Parkinsonian syndromes [16]. Still, to the best of our knowledge, no previous studies have used foot pressure analysis, especially the spatiotemporal parameters obtained from the analysis, to compare PD with other Parkinsonism, though one study has tried to compare the gait disturbance in PD and normal pressure hydrocephalus; according to Stolze et al., [17] normal pressure hydrocephalus patients displays hypokinetic gait pattern similar to that of the PD patients, but with enlarged step width and increased step length compared to the PD patients.

The freezing of gait, commonly seen in advanced PD, has been classified as its fifth cardinal feature. However, its presence frequently leads to a misdiagnosis of PD, as the freezing is in fact more common in atypical Parkinsonism [18,19]. We examined PD and other Parkinsonism diseases in terms of spatiotemporal parameters from foot pressure analysis. In this study, we found that there was a statistically significant difference in the lateral symmetry during the gait (Table 2, Fig. 2); the median value of the lateral symmetry was higher in the PD group than in the MSA group, indicating that the PD patients tend to show more lateral deviation than the MSA patients. Freezing of gait in the PD is known to be associated with the disease severity [18], yet the PD patients had more lateral deviation during the gait compared

to other disease groups. Such difference is may be due to different disease pathophysiologic characters. Due to the dopaminergic pathway dysfunction, the PD develops progressive loss of the decreased ability to internally control the center of mass during self-directed activities [2]. The decreased control leads to deficits in gait initiating, which requires a voluntary shift in the COP from a 2-leg stance to an alternating single-leg stance. Along with such character, the PD often shows unilateral symptom onset on either the dominant or non-dominant of the body [4]; it may also affect the tendency of having more lateral deviation during the gait.

Other gait parameters did not have significant differences among the 3 groups. Although the gait velocity seemed to have certain degree of clinically meaningful difference, the results did not show statistically meaningful difference within 95% CI. It implies that distinguishing PD from other Parkinsonism by the spatiotemporal parameters we obtained from the foot pressure analysis is not reliable for clinical use yet.

There were several limitations in this study. First, there might be differences in the measured parameters between treadmill walking and ground walking. There are several studies had compared the differences in gait kinematic parameters between treadmill walking and ground walking in PD, and they reported that a reduced gait variability and an increased step length were observed during treadmill walking [20-22]. Second, there was a relatively small sample size of 3 groups; we could not assume for normal distribution among the groups, which forced our team to use non-parametric tests for data analyses. Third, the Parkinsonism other than PD group was made of heterogeneous diseases, including vascular Parkinsonism and drug-induced Parkinsonism. The heterogeneity in one of the groups might distorted the data analyses. Fourth, the onset of disease symptom duration was unclear for our patients. We evaluated the patients who visited the neurology and rehabilitation departments of the hospital, yet the patients did not have exact memory of the disease onset. Our evaluation was intended for the early stage patients, yet our patient pool might have the patients in various stages. Lastly, our analyses were made based on the first diagnosis given to the patients, which might have been inaccurate; the future study should be conducted with the longer period clinical follow-up along with the gait spatiotemporal parameter studies.

In our knowledge, there is no previous study that have analyzed the gait parameter differences between the PD and the MSA group using foot pressure analysis during the gait. Our study showed possibility that there may be the meaningful difference in terms of the gait parameters in the early stage of the diseases, such as lateral symmetry of the center of the pressure, which have shown a meaningful difference between the PD and the MSA groups.

CONCLUSION

This study showed the differences in spatiotemporal parameters among PD, Parkinsonism diseases, and MSA using foot pressure analysis during the gait; there was a statically significant difference in lateral symmetry of gait patterns between the PD and the MSA groups in the early stage of the diseases. The PD patients showed more lateral deviation during the gait compared to the MSA group. The data also suggest that there might be other spatiotemporal parameters with meaningful difference among the groups, such as gait velocity. These results support the approach of conducting foot pressure analysis, or other gait analysis programs capable of analyzing the spatiotemporal parameters, to aid distinguishing PD from other Parkinsonism diseases.

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