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Impacts of freezing of gait on forward and backward gait in Parkinson's disease

Minji Son[a], Sang-Myung Cheon[b,*], Changhong Youm[c], Youkyung Kim[a], Jae Woo Kim[b]

[a] Biomechanics Laboratory, College of Health Sciences, Dong-A University, Busan, Republic of Korea
[b] Department of Neurology, School of Medicine, Dong-A University, Busan, Republic of Korea
[c] Department of Health Care and Science, College of Health Sciences, Dong-A University, Busan, Republic of Korea

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ABSTRACT

Freezing of gait (FOG) is a major risk factor for falls and fall-related injuries in patients with Parkinson's disease (PD). The characteristics of gait in PD patients with FOG have been studied but remain controversial. To investigate gait characteristics of FOG in PD, this study analyzed the forward and backward walking of patients with PD. Twenty-six patients with PD were recruited [age: 71.0 ± 6.2 years, Hoehn and Yahr stage: 2–3 (median 2.5)]. Based on responses to the New Freezing of Gait Questionnaire, we classified patients into either the "freezer" or "non-freezer" group. Spatiotemporal and kinematic analyses of forward and backward walking were completed using a three-dimensional motion analysis system over an 8 m walkway in the defined "off" state. There was no difference in demographic and clinical characteristics between the freezers (n = 10) and non-freezers (n = 16). Analysis of forward walking revealed no between-group differences, except for faster walking speed among the non-freezers. During backward walking, the freezers exhibited slower walking speed, shorter stride length, and increased asymmetry of step length. Kinematic analysis of backward walking revealed smaller range of motion in hip and ankle joints and lower step height in freezers. Further investigations of backward walking might expand our understanding of the pathophysiology of FOG in patients with PD.

1. Introduction

Freezing of gait (FOG) is defined as suddenly stopping or decreased stepping in spite of the intention to continue walking. It frequently occurs in patients with Parkinson's disease (PD), with an estimated point prevalence of 30–60% [1,2]. FOG is related to postural instability and balance impairment and is a major risk of falling while walking [3,4]. Falls resulting from FOG can cause serious trauma and impose considerable social burden [5]. FOG can be provoked at the start of gait, turning, passing narrow paths or obstacles, approaching target destinations, or under stressful conditions [6,7]. Patients with PD often experience gait adjustment difficulties in response to environmental changes or complex directional control [8], and FOG can be provoked by such conditions.

Walking is the key component of human locomotion, and walking backward is a natural, but complex variation of forward walking [9]. Backward walking is an essential component of numerous daily activities including changing clothes or turning in narrow spaces. It is frequently associated with backward sway or perturbation and frequently causes falls in elderly people [8,10,11]. Patients with PD demonstrate impairments in gait control during complex locomotive tasks, including turning, and gait analysis in patients with PD should include multi-directional walking tasks [8].

Compared to normal elderly people, patients with PD are more dependent on visual feedback to control posture and gait, which can be contributed by defective proprioception in PD [12–14]. Those visual dependence in PD are shown to be excessive in patients with FOG, resulting in FOG events at confronting obstacles or narrow paths [13–15]. Because backward walking is usually performed without visual information and is complex locomotive task, PD patients with FOG might have greater difficulty in backward walking.

Several studies have characterized backward walking in patients with PD. Some studies have indicated that patients with PD walk slower, in both forward and backward directions, than control subjects [8,16]. Compared to forward walking, backward walking in the "off" state was slower with shorter stride length. However, there are no differences between forward and backward walking in the "on" state [17]. Patients with PD having FOG exhibited slower forward and backward walking, with shorter stride length and higher gait asymmetry during backward walking than those without FOG [10].

* Corresponding author at: 26, Daesingongwon – ro, Seo – gu, Busan, 49201, Department of Neurology, School of Medicine, Dong – A University, Republic of Korea.
E-mail address: smcheon@dau.ac.kr (S.-M. Cheon).

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Although past studies have described some characteristics of backward walking in patients with PD, they studied only the two-dimensional analysis of gait. Comprehensive characterization of backward walking using three-dimensional kinematic analysis has not been done in patients with PD. And the influence of FOG on backward walking in patients with PD was also not fully investigated. Therefore, this study analyzed forward and backward walking in patients with PD to investigate the impact of FOG using a three-dimensional kinematic analysis system. Our hypothesis is that PD patients with FOG have greater impairments in walking than those without FOG, especially at backward walking.

2. Methods

2.1. Participants

Twenty-six patients with PD participated in this study. Patients were grouped as freezers (n = 10) or non-freezers (n = 16), according to their responses to the New Freezing of Gait Questionnaire (NFOGQ) [18]. The inclusion criteria were patients with idiopathic PD according to UK Brain Bank criteria [19,20]; mild-to-moderate stage of PD (Hoehn and Yahr stage: 2–3); currently taking anti-parkinsonian medication; and able to walk unassisted. Exclusion criteria included cognitive impairment, which was defined as a Korean version of Mini-Mental State Examination (K-MMSE) score of less than 24 points [21]; any other neurological, visual, vestibular, or muscular disorder; or injury, which could disturb gait, within the six months preceding the study. The regional Institutional Review Board approved all experimental protocols, and all patients gave written informed consent prior to participation.

2.2. Procedures

Gait assessments were done in the defined “off” state of patients. The Unified Parkinson's Disease Rating Scale (UPDRS), Hoehn and Yahr scale, NFOGQ, K-MMSE, disease duration, and L-Dopa equivalence dose (LED) were obtained from each patient for clinical measurement. During the forward and backward walking task, all patients wore Lycra shorts and a T-shirt, and completed the test with bare feet. The Plug-in-gait model was used with 39 reflective markers. The markers were attached on the clavicle, sternum, 7th cervical vertebrae, 10th thoracic vertebrae, scapular medial border, and bilaterally on the front and back of the head, shoulder, lower third of the upper arm, lateral humeral epicondyle, lower third of the forearm, medial and lateral styloid processes of the wrist, 3rd metacarpal head, anterior superior iliac spine, posterior superior iliac spine, lower third of the lateral thigh, lateral femoral epicondyle, lower third of the lateral shank, calcaneus, lateral malleolus, and the second metatarsal head. The markers were secured with athletic tape to reduce motion artifacts

2.3. Apparatus

The gait of all patients was captured using six infrared cameras (Vicon, MX-T10, UK) on an 8 m walkway. A global coordinate system was established, with the positive X-axis to the right, positive Y-axis facing anteriorly, and the Z-axis defined as the cross-product between the X-axis and the Y-axis, with the positive Z-axis facing superiorly.

2.4. Data analysis

The sampling frequency for kinematic data was set at 100 Hz, with the collected data low-pass filtered (second-order Butterworth filters) at 6 Hz. Capture of motion data and post-processing of marker trajectories were performed using Nexus software (version 1.83, VICON, UK). Three successive complete trials were recorded for each patient. The two steps immediately following the third step from the start of walking in each direction were captured for the analysis of forward and backward walking. The side of each step was labeled as the more affected side (MAS) or less affected side (LAS). The MAS was defined as the side exhibiting a greater magnitude of PD symptoms during an examination.

All spatiotemporal and kinematic variables of gait were measured over the three trials, and the average score was obtained for each. The spatiotemporal variables of gait were cadence, walking speed, step time, and step length during both walking tasks. Range of motion (ROM) in joints of lower extremities in the sagittal plane and toe clearance height were analyzed as kinematic analysis of gait. The ROM was defined as difference between the maximum and minimum joint angles during each stride. The toe clearance height was measured as the maximum vertical height of the toe marker during the swing phase of each step. Asymmetry of each variables were measured as the asymmetry index, defined as the ratio of observed asymmetry between the MAS and the LAS step [22].

$$\frac{\text{maximum amplitude} - \text{minimum amplitude}}{\text{maximum amplitude}} \times 100$$

The maximum anti-phase was calculated as the maximum angle between the pelvic vector (from left to right marker of the anterior superior iliac spine) and shoulder vector (from left to right marker of the shoulder) in the horizontal plane during the forward and backward walking.

2.5. Statistical analyses

All statistical analyses were performed using SPSS (version 21.0; SPSS. Inc., Chicago, IL). Descriptive statistical analysis using mean and standard deviation were used to describe the characteristics of each variable. All variables were tested for normality using the Shapiro–Wilk test. A repeated-measures two-way analysis of variance (ANOVA) was used to examine interactions and main effects between groups and within steps during the forward and backward walking. Moreover, independent and paired samples *t*-tests were used to determine significant differences. The statistical significance was set at $p < .05$.

3. Results

During gait analysis, FOG rarely occurred and we were unable to count the actual number of FOG events. All data were normally distributed. There was no significant between-group differences with regard to physical and clinical characteristics, with the exception of the NFOGQ score (Table 1). Forward walking showed that walking speed of LAS step was the only significant between-group difference (Table 2). The freezers were slower than the non-freezers at the LAS step. Marked

Table 1
Clinical characteristics of the patients.

	Freezers (n = 10)	Non-freezers (n = 16)	p-value
Sex (M:F)	7:3	11:5	–
Age (Years)	70.24 ± 6.21	71.52 ± 6.34	.619
Height (cm)	162.70 ± 7.88	157.75 ± 10.34	.220
Body mass (kg)	60.99 ± 6.03	60.28 ± 10.24	.846
K-MMSE	28.40 ± 3.27	27.31 ± 1.54	.261
Symptom duration (years)	4.60 ± 1.07	4.52 ± 1.23	.865
Treatment duration (years)	3.43 ± 1.43	3.68 ± 1.43	.567
Off UPDRS (Part3)	35.95 ± 9.97	35.69 ± 7.60	.940
Off UPDRS (Total)	51.80 ± 14.47	48.59 ± 10.45	.518
Off Hoehn and Yahr stage	2.60 ± 0.51	2.23 ± 059	.110
LED (mg/day)	588.75 ± 217.31	494.19 ± 263.01	.351
NFOGQ*	10.60 ± 5.99	0	.000

All data are expressed as mean ± standard deviation. K-MMSE: Korean Mini-Mental State Examination, UPDRS; Unified Parkinson’s disease rating scale, LED: L-Dopa equivalent dosage, NFOGQ: New Freezing of Gait Questionnaire.

* Significant difference ($p < .05$).