

Postural Sway and Falls in Parkinson's Disease: A Regression Approach

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Abstract: A population-based study was designed to evaluate the clinical associates of postural sway and to identify the risk factors for falls in Parkinson's disease (PD). From a total population of 205,000 inhabitants, 215 PD patients were identified of which 120 home-dwelling cases were finally included in the study. Medical data were collected and patients were clinically examined and tested for static balance using an inclinometric device. Recent falls occurred in 40 (33%) of the subjects and 27 (23%) subjects were recurrent fallers. The fallers had a significantly larger sway area ($P = 0.021$) and a larger maximum deflection in anterior–posterior ($P = 0.016$) and lateral directions ($P = 0.006$) than the nonfallers. A significant correlation was found between the sway measures and

the UPDRS total score, motor subcore and UPDRS “bradykinesia” item. A higher UPDRS total score (OR: 1.04, 95% CI: 1.01–1.07) and an increased sway area (OR: 1.25, 95% CI: 1.02–1.54) were independent risk factors for recent falling in PD. In addition, the duration and severity of PD, antiparkinsonian medication, recent falling and the use of a walking aid were associated with increased sway measures. The results can be used to identify PD patients who are at a risk of falling. Both antiparkinsonian medication and nonmedical treatment should be optimized to reduce falls in PD. © 2007 Movement Disorder Society

Key words: Parkinson's disease; postural sway; balance impairment; falls.

Parkinson's disease (PD) is a common neurodegenerative disease in the elderly population. Balance impairment is one of the cardinal symptoms of PD, placing patients at an increased risk of falling.¹ Falls often lead to injuries, fractures, increased dependency, and fear of falling, and thereby to a decreased quality of life.^{2–6}

Several components of postural control, including the latencies and amplitudes of postural response, visual, proprioceptive, and vestibular control of postural responses, biomechanical properties of muscles and joints, and dynamic control, may be affected in PD patients.⁷ Impairment of postural reflexes reduces the limits of stability and is associated with difficulty in executing and

timing responses to external challenges and unexpected perturbations.⁸ Measurement of postural sway can be used to quantify postural balance impairment. Postural sway, especially in lateral directions, appears to be significantly greater in PD patients than in healthy controls, and to correlate with the duration and severity of the disease.⁹ Several previous reports also state that body sway is an important risk factor for falling.^{10–14} The pathophysiological background of balance disturbance in PD remains unknown, but it may be partly nondopaminergic in origin.¹⁵

In retrospective studies 38 to 64% of PD patients have reported falls.^{8,16,17} However, recent prospective studies suggest that even a higher proportion (51–68%) of PD patients experience falls.^{5,6,18} Previous falls, fear of falling, dementia, disease duration, and loss of arm swing have been identified as independent risk factors for falls in PD.^{5,6}

Using a regression approach the present study aimed to identify the clinical determinants of increased postural sway and falling in PD.

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TABLE 1. Characteristics of the study patients (N = 120)

	All patients (N = 120)	Fallers (N = 40)	Nonfallers (N = 80)	P
Gender (M/F)	79/41	24/16	55/25	0.341 ^a
Mean age, yrs (SD)	68.2 (10.1)	70.5 (8.3)	67.1 (10.8)	0.055
Mean duration of PD, yrs (SD)	5.7 (4.6)	7.6 (6.2)	4.8 (3.2)	0.010
Height, cm (SD)	168.5 (9.3)	168.1 (9.1)	168.7 (9.5)	0.731
Weight, kg (SD)	75.0 (13.1)	74.0 (13.6)	75.5 (12.9)	0.566
BMI, kg/m ² (SD)	26.4 (4.1)	26.2 (4.4)	26.5 (3.9)	0.727
Mean UPDRS total score (SD)	44.5 (18.4)	53.7 (20.1)	39.9 (15.7)	<0.001
Mean UPDRS ADL score (SD)	13.5 (6.2)	17.0 (6.1)	11.8 (5.5)	<0.001
Mean UPDRS motor score (SD)	24.8 (10.7)	28.5 (12.8)	22.9 (9.1)	0.015
Hoehn & Yahr stage (SD)	2.2 (0.6)	2.4 (0.7)	2.1 (0.6)	0.018
Motor fluctuations present, n (%)	57 (47.5%)	24 (60.0%)	33 (41.3%)	0.053 ^a
Dyskinesia present, n (%)	21 (17.5%)	12 (30.0%)	9 (11.3%)	0.011 ^a
Freezing present, n (%)	18 (15.0%)	10 (25.0%)	8 (10.0%)	0.030 ^a
PIGD type PD	88 (73.3%)	37 (92.5%)	51 (63.8%)	0.001 ^a
MMSE (SD)	26.5 (2.8)	26.1 (2.8)	26.7 (2.9)	0.323
BDI (SD)	5.2 (4.5)	6.5 (5.4)	4.5 (3.8)	0.018
Levodopa, n (%)	97 (80.8%)	35 (87.5%)	62 (77.5%)	0.190 ^a
Mean levodopa dose, mg/day (SD)	403.8 (344.6)	543.8 (436.7)	333.8 (264.3)	0.007
Dopamine agonist, n (%)	55 (45.8%)	18 (45.0%)	37 (46.3%)	0.897 ^a
Selegiline, n (%)	63 (52.5%)	20 (50.0%)	43 (53.8%)	0.698 ^a
Entacapone, n (%)	25 (20.8%)	11 (27.5%)	14 (17.5%)	0.204 ^a
Fear of falling, n (%)	73 (60.8%)	32 (80.0%)	41 (51.3%)	0.002 ^a
Walking aids, n (%)	42 (35.0%)	24 (60.0%)	18 (22.5%)	<0.001 ^a

P between fallers and nonfallers.

^aχ² test.

All other: unpaired *t* test.

PD, Parkinson's disease; BMI, body mass index; UPDRS, Unified Parkinson's Disease-Rating Scale; ADL, activities of daily living; PIDG, postural instability and gait difficulty; MMSE, Mini-Mental State Examination; BDI, Beck Depression Inventory.

SUBJECTS AND METHODS

Subjects

Patients with idiopathic PD, diagnosed according to the United Kingdom Parkinson's Disease Society brain bank criteria¹⁹ and having follow-up contacts with the Department of Neurology of the local University Hospital, were invited to participate in this population-based study. Patients in institutional care were excluded. From the total population of approximately 205,000 inhabitants, 215 potential cases were identified and 162 of them agreed to participate in the study. Of these 162, 36 patients were excluded as they were not able to stand unsupported during the sway measurements; one patient was excluded because of a severe concurrent disease; and five further patients were excluded because of severe dyskinesia or other motor complications related to PD. The remaining 120 patients were included in the study.

The mean age of the patients was 68.2 years (SD 10.1, range 45–88) and 79 (65.8%) of the patients were men. The mean duration of PD was 5.7 years (SD 4.6). The mean total score on the Unified Parkinson's Disease Rating Scale (UPDRS)²⁰ was 44.5 (SD 18.4) and the mean total on the motor subscore was 24.8 (SD 10.7). The mean Mini-Mental State Examination (MMSE)²¹

score was 26.5 ranging from 17 to 30. The other main clinical characteristics of the patients are summarized in Table 1.

Table 2 shows the antiparkinsonian treatment of the study patients. Thirty-five patients were on monotherapy and 83 were on combination therapy. Six PD patients had either undergone thalamotomy surgery or had a deep brain stimulator.

Table 3 shows the concomitant medical conditions and medications of the study patients. The concomitant diseases were in a stable state.

TABLE 2. Antiparkinsonian treatment of the study patients (N = 120)

Antiparkinsonian treatment	N
No medication	2
Monotherapy	35
Levodopa	24
Selegiline	4
Dopamine agonist	7
Combination therapy	83
Levodopa + selegiline/entacapone	35
Levodopa + dopamine agonist + selegiline/entacapone	38
Dopamine agonist + selegiline	10
Thalamotomy or deep brain stimulator	6

TABLE 3. Concomitant medical conditions and medications of the study patients (N = 120)

	N (%)
Concomitant medical conditions	
Cardiovascular disease	62 (52)
Obstructive pulmonary disease	10 (8)
Musculoskeletal disease	28 (23)
Hypothyreosis	11 (9)
Adult-onset diabetes mellitus	13 (10)
Concomitant medications	
Nitrates	17 (14)
Diuretics	17 (14)
Beta-blockers	40 (33)
Calcium channel blockers	11 (9)
ACE inhibitors	18 (15)
ATII receptor blockers	5 (4)
Thyroxine	11 (9)
Hypnotics	29 (24)
Opioid derivatives	6 (5)
Antipsychotics	6 (5)
Antidepressants	14 (12)

ACE inhibitors, Angiotensin converting enzyme inhibitors; ATII receptor blockers, Angiotensin II receptor blockers.

The study was carried out in the Department of Neurology, in a University Hospital, with the approval of the local ethics committee. Informed consent was obtained from all participants.

Methods

Questionnaires

Medical data relating to disease duration, concomitant medical conditions and current medication were collected by interviewing the patients and by reviewing their patient charts. Patients filled in a questionnaire on lifetime physical activity^{22,23} and daily living conditions, and were asked if they had any fear of falling and if they used any walking aid. The presence of depression was assessed with the Beck Depression Inventory (BDI) questionnaire²⁴ and cognitive functioning was evaluated using the MMSE.

Recording of Falls

Patients were asked to recall the number of falls indoors and outdoors during the preceding three months. For further analyses the patients were grouped into fallers (N = 40) and nonfallers (N = 80). A fall was defined as an unexpected event when a person came to rest unintentionally on the ground or another lower level. A faller was defined to have at least one fall either indoors or outdoors during the preceding three months.

Clinical Examination

All patients were clinically examined and tested for balance during the "on" phase. The severity of the PD

symptoms and signs was assessed using the UPDRS and the Hoehn and Yahr's staging (H&Y).²⁵ Visual acuity was measured using the Snellen chart.

Measurement of Postural Sway

The static balance was measured using an inclinometric instrument, which has been described in detail before (see Fig. 1).⁹

The postural sway measurements were performed after device calibration without any prior practice sessions under standardized conditions and were recorded twice during normal standing, each time with eyes open and with eyes closed. The duration of each recording was 60 s. The mean values of two successive recordings were used in the analyses. During the measurements the patients stood with no shoes on, with their feet together and their arms by their sides. In the eyes open test, the



FIG. 1. The inclinometric single-link pendulum device for assessing postural sway consists of a belt fastened firmly to a subject at the level of the sacrum, an inflexible measuring rod, an inclinometric module, and a joint structure lying on the ground connected with a power unit and a computer. The movement of the measuring rod ($D_{x,y}$) is calculated separately in lateral (x) and antero-posterior (y) directions at the level of the estimated height (h) of the center of gravity, α being the measured inclination.

patients were asked to look straight ahead at a mark on the wall facing them.

Statistical Methods

The data were analyzed using the SPSS for Windows software, version 12.0. The baseline variables were compared between the fallers and nonfallers using the unpaired *t* test for the continuous data and the Chi-square test for the categorical data. For the statistical analyses UPDRS “bradykinesia” was defined as UPDRS item 31 and UPDRS “postural stability” as UPDRS item 30. UPDRS “tremor” was defined as a sum of UPDRS items 20 (a)–(e) and UPDRS “rigidity” as a sum of UPDRS items 22 (a)–(e). Furthermore patients were categorized into different motor subtypes according to the method proposed by Jankovic and colleagues.^{26,27} The subtypes are referred as tremor dominant, postural instability and gait difficulty (PIGD), or indeterminate. To assess how well the various measured risk factors could predict different sway parameters, multiple linear regression analysis was performed using all the variables associated with the sway parameters reaching the level of statistical significance in univariate analyses. In the exploratory analyses Pearson correlation coefficients were used for normally distributed continuous variables, and Spearman correlation coefficients were used to assess the data that either had ordered categories or were not normally distributed. Intercorrelations of measures were checked for collinearity.

A multiple logistic regression analysis was performed to calculate odd ratios (ORs) and 95% confidence intervals (CIs) for falling. Forward stepwise regression procedures were used to select the most predictive variables. The significant risk factors in the final multivariate model are reported using ORs and their 95% CIs. The level of significance for all tests was set at $P < 0.05$.

RESULTS

Forty patients (33.3%) reported at least one fall (either indoors or outdoors) during the preceding 3 months, and 27 patients (22.5%) reported two or more falls. Three subjects reported over 50 falls. Eighty-eight patients were classified as having a PIGD type PD, seventeen were tremor dominant, and 15 patients were indeterminate.

The fallers had a longer disease duration than the nonfallers ($P = 0.010$), and they tended to be older (Table 1). The fallers also had higher UPDRS total scores ($P < 0.001$), motor subscores ($P = 0.015$), activities of daily living (ADL) subscores ($P < 0.001$), and H&Y stages ($P = 0.018$) than the nonfallers. Dyskinesia and freezing were present more often among the fallers

($P = 0.011$ and 0.030 respectively), but there was no difference in the prevalence of motor fluctuations between the fallers and the nonfallers. Most fallers had a PIGD subtype of PD. Fear of falling was more common among the fallers than nonfallers, and the fallers used walking aids more frequently.

With eyes open the fallers had a significantly larger sway area than the nonfallers ($P = 0.021$), and a larger maximum deflection both in the anterior–posterior directions (Δy) ($P = 0.016$) and in the lateral directions (Δx) ($P = 0.006$) (Table 4). The sway measures also differed significantly between the fallers and nonfallers in the eyes closed condition ($P = 0.042$, 0.008 , and 0.025 respectively). The total UPDRS scores and UPDRS motor subscores correlated significantly with almost all the sway measures (Table 5). The UPDRS ADL subscores, tremor and rigidity scores were significantly associated with several sway measures, but overall the correlation coefficients were low. The UPDRS “bradykinesia” score also correlated significantly with all the sway measures, but none of the sway measures correlated significantly with the UPDRS “postural stability” score.

Table 6 shows all correlation coefficients and R^2 s from univariate linear regression analyses between the possible risk factors and postural sway variables. Using multiple linear regression the final models explained 13.7% of the eyes-open sway area variance, 13.1% of the maximum deflection in the anterior–posterior direction (Δy) variance, and 20.5% of the maximum deflection in the lateral direction (Δx) variance. In the eyes-closed condition the final models explained 17.0% of the sway area variance, 15.4% of the maximum deflection in the anterior–posterior direction (Δy) variance and 28.5% of the maximum deflection in the lateral direction (Δx) variance. From the exploratory analyses six variables (UPDRS total score, history of falls during the past 3 months, number of falls indoors during the past 3 months, duration of PD, use of dopamine agonists and use of a walking aid) emerged which in different combinations significantly predicted the postural sway (Table 7).

Finally, a multivariate model of risk factors for recent falling in PD was created. Table 8 shows the univariate ORs and 95% CIs for all the possible risk factors for falling, and multivariate ORs and 95% CIs for the statistically significant variables within each category used in the final model. The UPDRS total score (OR: 1.04, 95% CI: 1.01–1.07) and the sway area in the eyes-open test (OR: 1.25, 95% CI: 1.02–1.54) were independent risk factors for falling in the final logistic regression analysis.

TABLE 4. Postural sway in Parkinson's disease patients

Variable	Patients (N = 120)	Fallers (N = 40)	Non-fallers (N = 80)	P	Tremor dominant type PD (N = 17)	PIGD type PD (N = 88)	P
Eyes open							
Area (cm ²)	2.7 (3.0)	3.8 (4.0)	2.2 (2.2)	0.021	1.8 (1.9)	3.0 (3.3)	0.161
Velocity (cm/s)	0.56 (0.35)	0.64 (0.32)	0.52 (0.36)	0.081	0.55 (0.31)	0.56 (0.37)	0.876
Length (cm)	33.4 (20.7)	38.1 (18.8)	31.0 (21.2)	0.078	32.8 (18.4)	33.7 (21.8)	0.864
Length y (cm)	18.2 (11.9)	20.8 (10.4)	17.0 (12.4)	0.096	19.3 (13.7)	18.2 (12.1)	0.733
Length x (cm)	23.2 (15.8)	26.1 (13.6)	21.7 (16.6)	0.153	23.5 (16.1)	23.4 (16.4)	0.978
Δ y (cm)	2.3 (1.0)	2.7 (1.3)	2.1 (0.8)	0.016	2.0 (0.7)	2.4 (1.1)	0.145
Δ x (cm)	2.4 (1.2)	2.8 (1.3)	2.2 (1.1)	0.006	2.0 (1.1)	2.5 (1.3)	0.140
Eyes closed							
Area (cm ²)	4.2 (4.9)	5.5 (5.7)	3.6 (4.3)	0.042	2.4 (1.7)	4.7 (5.4)	0.084
Velocity (cm/s)	0.72 (0.41)	0.82 (0.43)	0.68 (0.40)	0.077	0.67 (0.42)	0.74 (0.43)	0.535
Length (cm)	43.9 (24.8)	49.1 (25.9)	41.5 (24.0)	0.117	40.9 (25.2)	45.3 (26.1)	0.525
Length y (cm)	25.1 (13.7)	28.6 (15.9)	23.4 (12.2)	0.076	22.4 (11.8)	25.6 (14.7)	0.379
Length x (cm)	28.3 (18.3)	31.7 (17.6)	26.5 (18.4)	0.143	27.4 (20.4)	29.1 (18.9)	0.739
Δ y (cm)	2.9 (1.4)	3.3 (1.6)	2.6 (1.2)	0.008	2.3 (0.8)	3.0 (1.5)	0.062
Δ x (cm)	2.8 (1.5)	3.2 (1.6)	2.6 (1.4)	0.025	2.2 (0.9)	3.0 (1.6)	0.061

Values are expressed as means (SD).

Length y indicates path length in anterior-posterior direction.

Length x indicates path length in lateral direction.

Δ y indicates maximum anterior-posterior deflection.

Δ x indicates maximum lateral deflection.

Significance for postural sway parameters between the fallers and non-fallers and between the tremor and PIGD types PD using the unpaired *t* test. PIGD, postural instability and gait difficulty.

DISCUSSION

The present study aimed to identify the clinical correlates of postural sway in patients, and to assess the risk factors for falls in PD. High UPDRS total scores and increased sway areas are independent risk factors for falling in PD. Furthermore, disease duration and severity, recent falling, use of dopamine agonists and use of a

walking aid are significant predictors of sway measures. The negative predictive effect of the use of dopamine agonists on sway is probably due to the present treatment guidelines where dopamine agonists are recommended as the first-line antiparkinsonian treatment for relatively young PD patients. Age itself was not significant enough to be included in the final models. The results can be

TABLE 5. Pearson correlation coefficients between the different sway measures and UPDRS items

Variable	UPDRS total score	UPDRS motor score	UPDRS ADL score	UPDRS tremor	UPDRS rigidity	UPDRS bradykinesia	UPDRS postural stability
Eyes open							
Area (cm ²)	0.287**	0.284**	0.235**	0.098	0.244**	0.333**	0.169
Velocity (cm/s)	0.215*	0.208*	0.168	0.354**	0.045	0.269**	0.096
Length (cm)	0.220*	0.213*	0.171	0.347**	0.050	0.276**	0.097
Length y (cm)	0.227*	0.216*	0.178	0.286**	0.075	0.242**	0.062
Length x (cm)	0.178	0.175	0.125	0.328**	0.040	0.238**	0.089
Δ y (cm)	0.315**	0.280**	0.313**	0.104	0.219**	0.341**	0.141
Δ x (cm)	0.293**	0.272**	0.242**	0.118	0.204**	0.366**	0.176
Eyes closed							
Area (cm ²)	0.288**	0.291**	0.239**	0.118	0.251**	0.265**	0.119
Velocity (cm/s)	0.319**	0.324**	0.242**	0.339**	0.173	0.292**	0.126
Length (cm)	0.299**	0.310**	0.221*	0.327**	0.163	0.287**	0.098
Length y (cm)	0.352**	0.368**	0.276**	0.330**	0.202**	0.324**	0.123
Length x (cm)	0.262**	0.264**	0.191*	0.328**	0.128	0.237**	0.116
Δ y (cm)	0.332**	0.331**	0.310**	0.104	0.275**	0.362**	0.167
Δ x (cm)	0.302**	0.266**	0.272**	0.164	0.201**	0.325**	0.147

The tremor score is the sum of the UPDRS items 20(a)–(e).

The rigidity score is the sum of the UPDRS items 22(a)–(e).

For abbreviations see Tables 1 and 4.

**P* < 0.05.

***P* < 0.001.

TABLE 6. Univariate R^2 s from linear regression analyses between the possible risk factors and postural sway variables in PD patients ($N = 120$)

	Eyes open			Eyes closed		
	Sway area	Δy	Δx	Sway area	Δy	Δx
Continuous variables						
Age	0.037*	0.026	0.084*	0.017	0.030	0.101*
Duration of disease	0.033*	0.036*	0.087*	0.030	0.029	0.122*
UPDRS ADL score	0.055*	0.098*	0.059*	0.057*	0.096*	0.074*
UPDRS motor score	0.081*	0.079*	0.074*	0.085*	0.109*	0.071*
UPDRS total score	0.082*	0.099*	0.086*	0.083*	0.110*	0.091*
H&Y stage	0.049*	0.043*	0.080*	0.049*	0.056*	0.076*
MMSE score	0.003	0.006	0.020	0.002	0.009	0.008
BDI score	0.059*	0.062*	0.030	0.083*	0.059*	0.037*
Visual acuity	0.021	0.011	0.057*	0.000	0.006	0.037*
L-dopa dosage	0.047*	0.072*	0.073*	0.069*	0.077*	0.087*
Number of falls indoors	0.001	0.006	0.007	0.057*	0.061*	0.045*
Number of falls outdoors	0.010	0.022	0.023	0.019	0.033*	0.023
Dichotomized variables						
Sex	0.003	0.037*	0.001	0.019	0.042*	0.000
Dyskinesia	0.008	0.014	0.011	0.010	0.008	0.026
Fluctuation	0.029	0.013	0.036*	0.013	0.002	0.020
Freezing	0.004	0.022	0.007	0.012	0.017	0.015
Deep brain stimulator or thalamotomy	0.027	0.045*	0.069*	0.007	0.013	0.042*
Use of dopamine agonists	0.032	0.009	0.071*	0.031	0.022	0.075*
Measures taken to prevent falling	0.069*	0.038*	0.079*	0.026	0.042*	0.050*
Subjective inconvenience with visual acuity	0.003	0.002	0.003	0.001	0.002	0.001
Use of a walking aid	0.057*	0.090*	0.066*	0.062*	0.076*	0.111*
Fear of falling	0.068*	0.051*	0.083*	0.037*	0.053*	0.097*
Other CNS disorder	0.002	0.001	0.004	0.000	0.000	0.003
Psychiatric disorder	0.043*	0.050*	0.021	0.049*	0.041*	0.015
Obstructive pulmonary disease	0.000	0.002	0.010	0.006	0.014	0.032
Cardiovascular disease	0.030	0.018	0.017	0.017	0.012	0.018
Adult-onset diabetes mellitus	0.026	0.038*	0.008	0.012	0.018	0.005
Musculoskeletal disease	0.000	0.001	0.013	0.026	0.022	0.058*
Use of benzodiazepines	0.021	0.016	0.005	0.033*	0.043*	0.033*
Use of opiates	0.004	0.000	0.010	0.000	0.000	0.001
Use of antipsychotics	0.017	0.020	0.015	0.040*	0.022	0.012
Use of antihypertensive agents	0.000	0.001	0.001	0.000	0.000	0.000
Use of antidepressants	0.028	0.034*	0.006	0.045*	0.044*	0.021
Falls during the past 3 months	0.064*	0.069*	0.062*	0.035*	0.058*	0.042*

*Statistical significance at level $P < 0.05$.

UPDRS, Unified Parkinson's Disease Rating Scale; ADL, Activities of Daily Living; H&Y, Hoehn&Yahr; MMSE, Mini-Mental State Examination; BDI, Beck Depression Inventory; CNS, central nervous system.

used to identify those PD patients who are at risk of falling.

The current regression models predicted between 13.1% and 28.5% of the postural sway variance. Toole et al.⁷ were able to explain a larger amount of variability. The difference between these studies may be due to different device used to assess postural sway and variables used in the regression models. Although the majority of the variability in sway remained unexplained, the models predicted almost third of the variability. In our data, sway area was a significant risk factor for falling. Simple and practical tools for predicting increased sway and postural impairment might help to identify patients at risk for future falling. Information on walking aid, recent falling, antiparkinsonian medication

and duration and severity of PD are easy to achieve, and no complex measuring equipment are required.

Balance disturbances in PD patients have previously been assessed by recording ground reaction forces.^{28,29} These studies have revealed an association between balance impairment and abnormal postural reflexes in the lower extremities of PD patients. Several studies have confirmed the abnormality of postural reflexes in PD and also shown that postural sway is increased in PD.^{15,30} We have earlier shown that postural sway, especially in lateral directions, is increased in PD patients compared to healthy controls.⁹ Until now, however, there have been no studies focusing on the role of body sway regulation as a factor of falls in PD. Our study shows that the amount of sway and maximum deflection in the anterior–

TABLE 7. Significant predictors of different sway measures in stepwise multiple linear regression analysis in PD patients (N = 120)

Variable	Regression coefficient (95% CI)	SE	P
Eyes open			
Sway area: Model R ² = 0.137, Standard Error of the Estimate = 2.653, P < 0.001			
UPDRS total score (per one point increment)	0.040 (0.011–0.068)	0.014	0.006
Falls during the past 3 months vs. none (referent)	1.299 (0.203–2.395)	0.553	0.021
Δ y: Model R ² = 0.131, Standard Error of the Estimate = 0.931, P < 0.001			
UPDRS total score (per one point increment)	0.015 (0.005–0.025)	0.005	0.004
Falls during the past 3 months vs. none (referent)	0.404 (0.020–0.787)	0.194	0.039
Δ x: Model R ² = 0.205, Standard Error of the Estimate = 1.056, P < 0.001			
Duration of disease (per one year increment)	0.069 (0.025–0.113)	0.022	0.002
Use of dopamine agonist vs. none (referent)	–0.697 (–1.088––0.306)	0.197	0.001
Falls during the past 3 months vs. none (referent)	0.524 (0.094–0.954)	0.217	0.017
Eyes closed			
Sway area: Model R ² = 0.170, Standard Error of the Estimate = 4.253, P < 0.001			
Use of any walking aid vs. none (referent)	2.050 (0.359–3.742)	0.854	0.018
Number of falls indoors during the past 3 months (per one fall increment)	0.124 (0.033–0.215)	0.046	0.008
Use of dopamine agonist vs. none (referent)	–1.867 (–3.463––0.272)	0.805	0.022
Δ y: Model R ² = 0.154, Standard Error of the Estimate = 1.150, P < 0.001			
Use of any walking aid vs. none (referent)	0.785 (0.337–1.234)	0.227	0.001
Number of falls indoors during the past 3 months (per one fall increment)	0.033 (0.008–0.057)	0.012	0.009
Δ x: Model R ² = 0.285, Standard Error of the Estimate = 1.221, P < 0.001			
Duration of disease (per one year increment)	0.106 (0.056–0.157)	0.025	<0.001
Use of dopamine agonist vs. none (referent)	–0.869 (–1.325––0.412)	0.231	<0.001
Use of any walking aid vs. none (referent)	0.674 (0.183–1.165)	0.248	0.008

Δ y indicates maximum anterior-posterior deflection.

Δ x indicates maximum lateral deflection.

posterior and lateral directions are significantly greater in PD patients with a history of recent falling than in those without. Moreover, it has been shown earlier that body sway is a significant risk factor for falling in the general population.^{10–14}

Wood et al.⁶ described previous falls, loss of arm swing, duration of PD and dementia as independent predictors of falling in PD. Disease duration and presence of complications related of PD (freezing, dyskinesia, walking, and postural difficulties), existence of postural hypotension, and daily intake of alcohol have been demonstrated to be risk factors for falling in PD.¹⁸ Bloem et al.⁵ concluded that prior falls, disease severity, and the Romberg test were the best diagnostic predictors for falling whereas recurrent falls were best predicted by disease severity and prior falls. We found that in addition to disease severity, an increased postural sway area is a significant risk factor for falling in PD.

Only a few studies have quantified postural sway and examined its clinical associates in PD. Toole et al.⁷ have introduced a regression approach to examine the multicomponent nature of balance in persons with parkinsonism. The effect of levodopa on postural sway in PD has also been studied earlier.³¹ Our previous study⁹ showed that the amount of postural sway is significantly increased in severe PD, and the amount

of postural sway correlates with the severity of the disease and some UPDRS items. The present results show that most postural sway measures correlate with the UPDRS total and motor scores, and with the UPDRS “bradykinesia” score and interestingly, that the UPDRS “tremor” and “rigidity” scores correlate with the different sway measures. Tremor correlated with sway velocity, total path length and the path length in lateral and anterior–posterior directions whereas rigidity correlated with the sway area and maximum deflection in the lateral and anterior–posterior directions, the same variables that distinguished the fallers and nonfallers from each other. In our study the postural sway parameters did not correlate with the UPDRS “postural stability” scores supporting the concept that the assessment of balance requires more accurate tests than the traditionally used retro-pulsion test.^{5,6}

The reported proportion of fallers among PD patients has ranged from 38 to 68%.^{5,6,8,16–18,32,33} In our study 33.3% of patients had fallen during the past 3 months. The number of patients with recurrent falling (two or more falls) was 23% in this study and has ranged from 25 to 51% in previous studies.^{5,6} The recall-based study method may underestimate the true incidence of falls.³⁴

TABLE 8. Risk factors for falling in PD patients (N = 120)

	Univariate OR (95% CI)	Multivariate OR (95% CI)
Statistically significant variables in the final model		
UPDRS total score	1.05 (1.02–1.07)	1.04 (1.01–1.07)
Sway area (in the eyes open test)	1.21 (1.04–1.41)	1.25 (1.02–1.54)
Nonsignificant variables in the final model		
Age	1.04 (1.00–1.08)	
Sex	1.47 (0.67–3.23)	
Duration of disease	1.16 (1.05–1.28)	1.08 (0.95–1.22)
UPDRS ADL score	1.17 (1.08–1.26)	
UPDRS motor score	1.05 (1.01–1.09)	
H&Y stage	2.18 (1.12–4.23)	0.96 (0.33–2.84)
Dyskinesia	3.38 (1.28–8.91)	1.45 (0.36–5.80)
Fluctuation	2.14 (0.99–4.63)	
Freezing	3.00 (1.08–8.34)	
Levodopa dosage	1.002 (1.001–1.003)	0.999 (0.997–1.001)
Use of dopamine agonists	0.95 (0.44–2.04)	
Stimulator or thalamotomy	4.33 (0.76–24.76)	
BDI score	1.11 (1.01–1.21)	1.00 (0.87–1.16)
MMSE score	0.93 (0.81–1.07)	
BMI	0.98 (0.89–1.08)	
Visual acuity	0.55 (0.20–1.56)	
Current level of physical activity	0.54 (0.36–0.80)	0.95 (0.55–1.65)
Fear of falling	3.81 (1.56–9.27)	2.20 (0.76–6.15)
Use of any walking aid	5.17 (2.27–11.75)	
Measures taken to prevent falling	0.23 (0.10–0.53)	
Subjective inconvenience with visual acuity	0.29 (0.12–0.69)	
Other CNS disorders	2.14 (0.58–7.89)	
Psychiatric disease	3.48 (1.21–9.99)	3.35 (0.67–16.63)
Obstructive pulmonary disease	3.35 (0.89–12.66)	
Cardiovascular disease	2.27 (1.04–4.98)	1.66 (0.65–4.26)
Adult-onset diabetes mellitus	1.29 (0.39–4.22)	
Musculoskeletal disease	1.71 (0.72–4.09)	
Use of antihypertensive agents	1.54 (0.72–3.30)	
Use of opiates	0.99 (0.17–5.63)	
Use of antipsychotics	4.28 (0.75–24.44)	
Use of benzodiazepines	1.05 (0.44–2.54)	
Use of antidepressants	1.11 (0.35–3.57)	
Δy (in the eyes open test)	1.85 (1.17–2.94)	1.01 (0.37–2.76)
Δx (in the eyes open test)	1.55 (1.11–2.15)	0.96 (0.39–2.40)

UPDRS, Unified Parkinson's Disease Rating Scale; ADL, Activities of Daily Living; H&Y, Hoehn&Yahr; BDI, Beck Depression Inventory; MMSE, Mini-Mental State Examination; BMI, body mass index; CNS, central nervous system; Δy , Maximum anterior-posterior deflection; Δx , maximum lateral deflection.

Univariate OR's and 95% CI's for all possible risk factors for falling are presented. Multivariate OR's and 95% CI's are presented for the statistically significant variables within each category of risk factors. The UPDRS total score and the sway area in the eyes-open test were independent risk factors for falling in the final analysis.

We identified dyskinesia as being associated with falls, as has also been reported earlier^{18,35} but contrasting with others⁶ the wearing-off phenomenon was not significant in this regard. Fear of falling was more common among the fallers than the nonfallers, a fact that has been identified also earlier.^{5,6,35} Fallers suffer more often from depression than nonfallers, a result consistent with previous reports with smaller study populations.^{6,8}

We acknowledge some limitations concerning the present study. Several consecutive unpaired *t* tests or Chi Square tests were performed between the fallers and nonfallers. The level on statistical significance was set at $P < 0.05$. However, the use of a more conservative Bonferroni adjustment would have altered the criteria for

statistical significance thus reducing the chance of a Type I error. A self report was used to assess the frequency of falls during the past 3 months. The registration of falls concerning the past 3 months has been shown to be reliable.³⁶ Although the highest number of reported falls may be rough estimates rather than the true incidence of falls, the results were not biased because of misclassification since the patients were classified into fallers and nonfallers. No neurophysiological testing was performed to assess peripheral neuropathy.

In conclusion, the present study shows that high UPDRS total scores and increased postural sway are risk factors for falling in PD. Furthermore, disease duration and severity, recent falling and use of a walking aid are

predictors of postural sway. The UPDRS total score and the degree of postural sway can be used to identify PD patients who are at risk of falling. Both antiparkinsonian medication and nonmedical treatment should be optimized to reduce fall incidence in PD.

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