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Postural Control While Sitting and Its Association with Risk of Falls in Patients with Parkinson's Disease

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1. Introduction

Abnormal postures and falls in patients with Parkinson's disease (PD) have been well recognized from the time of its earliest clinical description (Parkinson, 1817). Abnormal postures in PD are observed in the entire body, including flexion to the anterior, lateral, or anterolateral direction of the trunk, neck flexion, flexion of the extremities, and abnormal postures of the hands, fingers, and toes. A lateral deviation of the spine and a corresponding tendency to lean to one side was reported (Duvoisin and Marsden 1975; Hayashi et al., 2010). These postural abnormalities cause postural instability and falls. In a recent study, approximately 50% of the PD patients had fallen, compared to about 15% of healthy elderly subjects, and approximately 75% of falls in PD patients occurred during activities associated with daily living, such as turning around, standing up, and bending forward (Bloem et al., 2001). Postural instability is caused by an inability to adjust the center of gravity quickly enough to account for perturbations in the environment (Shivitz et al., 2006). Maki and colleagues (1994) have suggested that increased lateral sway is associated with increased risk of falling in elderly persons. Several studies have quantified postural stability during quiet stance in patients with PD and revealed that PD patients have more difficulty in controlling lateral postural sway than anteroposterior sway (Mitchell et al., 1995; Rocchi et al., 2002).

In the standing position, postural adjustments can be accomplished with responses at the ankle, knee, hip, and trunk joints, independently or combined (Hodges et al., 2002; Krishnamoorthy et al., 2005) and these complex structures consisting of multiple linked segments must be maintained in a stable position on a relatively narrow support base formed by the feet. Lee and coworkers (1995) studied preparatory postural adjustments associated with a lateral leg-raising task in parkinsonian patients with postural instability. In the sitting position, the influence of hip joints and lower extremities can be minimized to study the postural control of the trunk. Van der Burg and coworkers (2006) studied the postural control of the trunk during unstable sitting in PD patients and revealed that PD patients showed difficulty in truncal control. They suggested that these changes may be related to postural instability and fall risk.

In this study, the body movement in PD patients during sitting was investigated by measuring center of pressure (COP) excursions and trunk deviations under two conditions: 1) sitting at rest for two minutes, 2) raising his/her arm laterally to 90 degrees. An additional aim was to study differences in trunk control between patients who had a history of falling (fallers) and patients who did not have a history of falling (non-fallers). The aim of this study is also to test the hypothesis that postural abnormality in a lateral direction may, or would be a high risk factor for falling during the daily activities of PD patients and further attempts to formulate the pattern of muscle tone abnormalities that may underline this disturbance.

2. Patients and methods

2.1 Patients

17 consecutive idiopathic PD patients and 8 age-matched normal controls were studied. These 17 patients received regular outpatient treatment every month over the course of a one-year follow-up period. All patients satisfied the following inclusion criteria: Hoehn and Yahr stage II or higher while off medication (II=1, III=11, IV=5), a clear history of significant responsiveness to levodopa and an absence of other neurologic diseases including significant dementia or autonomic dysfunction. The patients' clinical data are given in Table 1. All patients (mean age ± sd: 72±6 years) did not have any neurological or other diseases that might affect their postural stability or ability to perform the experimental tasks.

Patient	Sex	Age (years)	Hoehn & Yahr	Duration (years)	Number of falls (per year)
1	F	70	3	12	more than 5
2	F	65	3	12	under 5
3	M	65	4	8	under 5
4	F	77	3	7	more than 5
5	F	64	3	11	0
6	M	75	3	6	under 5
7	F	67	3	11	0
8	M	78	3	13	under 5
9	F	75	2	4	0
10	F	75	4	11	under 5
11	M	71	3	6	0
12	M	75	4	8	under 5
13	F	81	3	6	0
14	F	79	4	11	more than 5
15	F	62	3	25	0
16	M	78	4	6	more than 5
17	F	69	3	11	more than 5

Table 1. Clinical characteristics of PD patient

This study was approved by the Okaya City Hospital Committee for Research on Human Subjects, and informed consent was obtained from all test subjects.

2.2 Experimental setup and procedure

A stable stool was placed on a force platform (Kistler platform type 9281CA, Winterthur, Switzerland). The stool was high enough so that each subject's legs could hang down without touching the platform (Fig. 1). Subjects sat on the stool at ease. At that time, if subjects presented a tilt of the trunk away from the vertical position, they were not asked to correct their trunk to the vertical position. Subjects were asked to maintain a sitting posture on the stool for 1) 2 minutes at rest, and 2) 30 seconds with a lateral arm raised alternatively up to 90 degrees with their legs hanging down and their hand placed on each thigh except for a raising arm. Subjects were also asked to keep their eyes open and to focus on the target point in front of them.

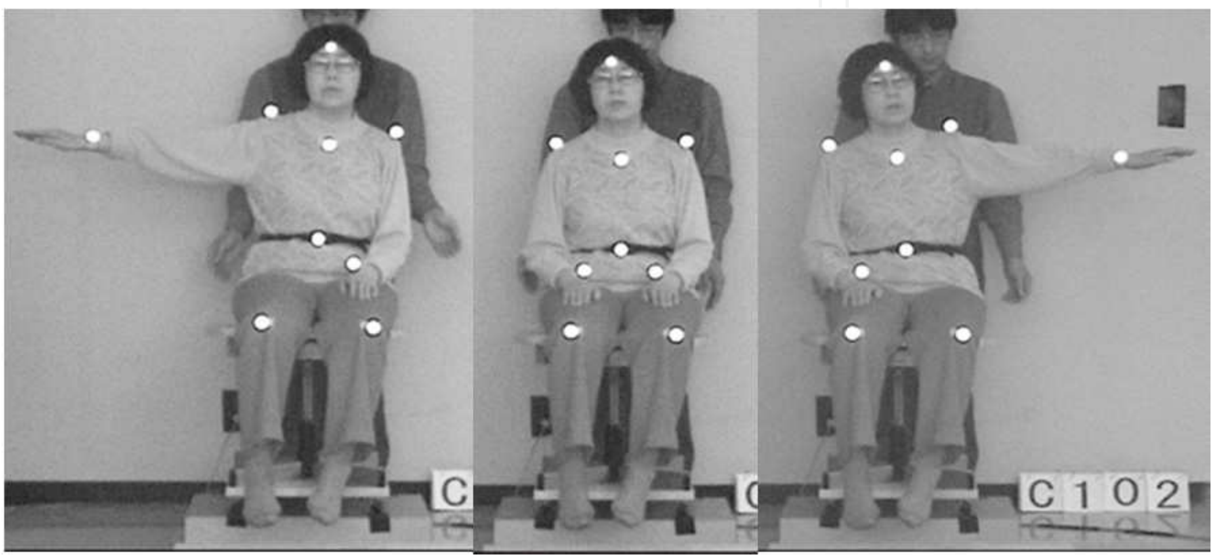

Fig. 1. Example of postural changes both during sitting on a stool at resting posture and during the raising of each arm.

Using the forced plate with a sampling frequency of 500Hz, the excursion of the centre of pressure (COP) was measured. The position of the body segments was also measured using a video image processing system, with the images being developed in our laboratory. Nine reflective markers (1 cm in diameter) were placed on the forehead, the upper part of the sternum, shoulders, wrists, knees, and the level of the umbilicus, and reflections from the markers were recorded with a sampling rate of 30 Hz.

2.3 Evaluation of truncal inclination at rest

Both COP excursions and the body-marker displacement were recorded simultaneously for 2 minutes. Values for the initial 10 seconds and the last 10 seconds were averaged, and the difference was calculated for each trial. The values obtained by the two trials for each subject were averaged.

2.4 Evaluation of truncal inclination while raising arm

After evaluation of truncal inclination at rest, the patient was studied when each of their arms were raised laterally up to 90 degrees two times in the following sequence: at rest for

30 seconds, raising the right arm for 30 seconds, at rest for 30 seconds, then raising the left arm for 30 seconds.

2.5 Statistical analysis

For each posturographic parameter and clinical measurement, Student's t-test or an analysis of variance (ANOVA) was used to compare group means between normal controls and PD patients. Correlation between the degree of COP displacement and the degree of body displacement was evaluated with Spearman's rank correlation coefficient.

3. Results

3.1 Clinical features

On examination, in all 17 patients, the side of initial symptoms was also the side of dominant clinical signs. Over the one-year follow-up period, 6 of 17 patients (35%) experienced no falls. The remaining 11 patients (65%) fell at least two times. Five of patients experienced more than 5 falls during the one-year follow-up, and these patients were described as "frequent fallers" in this paper. Patients who experienced less than 5 falls were described as a "less frequent fallers." This study found a strong correlation between disease severity and frequency of falls. The mean value with standard deviation of the Hoehn and Yahr stage in non-fallers and "less frequent fallers" was 2.8±0.4, and that of the "frequent fallers" was 3.5±0.5 ($p<0.02$). There was no significant difference between "frequent fallers" and "non-fallers" and "less frequent fallers" in age or duration of illness (73.3±5.2 years versus 70.0±7.0 years, $p=0.3$ in age; 9.5±2.6 years versus 10.5±7.7 years, $p=0.7$ in duration).

3.2 Body inclination during sitting

A consistency in lateral displacement was observed in all 17 patients. Table 2 shows the values of two parameters of body inclination in each group. There was a tendency toward increased values of both lateral COP displacement and trunk displacement in a group of PD patients compared with controls. However, there was no significant difference in these parameters between that of the control group and the PD-patient group. When each parameter obtained by "frequent fallers" is compared with controls, there was a significant difference in each parameter (lateral COP displacement $p=0.01$, trunk displacement $p=0.01$).

	Control	PD		
		all	non-fallers & fallers (under 5)	Fallers (more than 5)
	n=8	n=17	n=12	n=5
Lateral COP displacement	2.0 ± 1.7	6.2 ± 7.0 (p=0.11)	3.5 ± 2.5 (p=0.16)	12.9 ± 12.9 (p=0.01)
Trunk displacement	7.1 ± 4.8	17.3 ± 18.2 (p=0.14)	10.1 ± 7.7 (p=0.35)	34.5 ± 34.5 (p=0.01)

unit: mm

Table 2. This data represents the mean value with one standard deviation of each parameter of body inclination in control subjects and in PD patients at rest for 2 minutes. Each mean value was calculated using an absolute value of each parameter obtained from each subject.

Fig. 2 shows the relationship between changes of lateral COP displacement and trunk displacement obtained from all 17 patients. The amount of lateral COP displacement was correlated significantly with that of trunk displacement ($r=0.94$, $p<0.0001$).

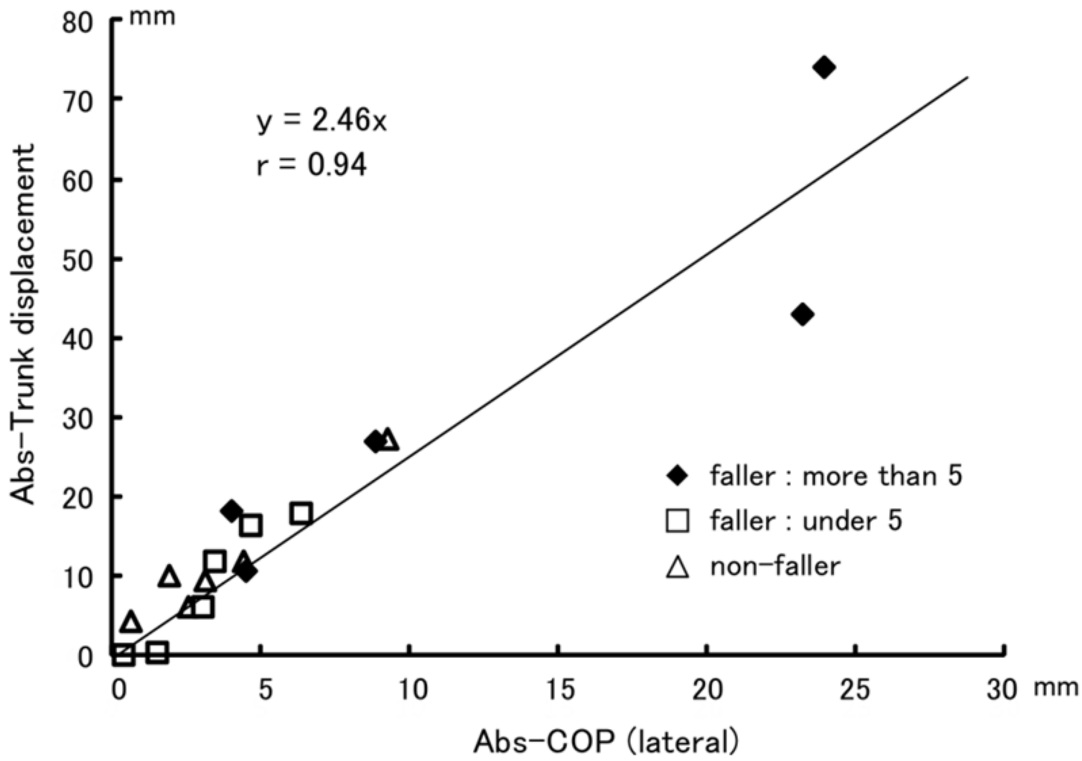

Fig. 2. The relationship between the absolute value of lateral COP displacement (Abs-COP) and the absolute value of trunk displacement (Abs- trunk displacement) obtained from 17 patients at rest.

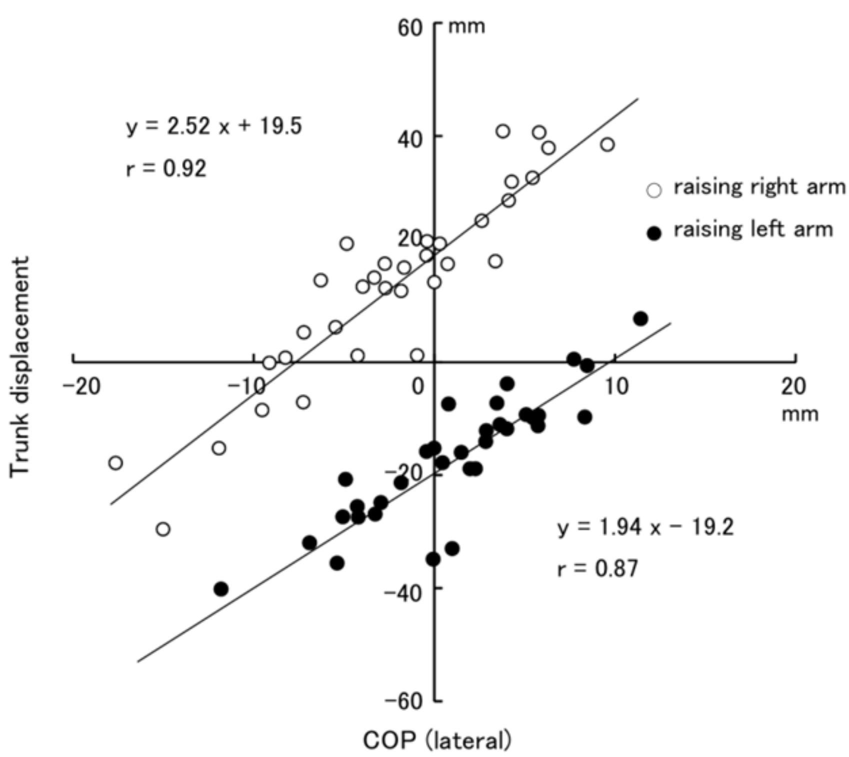

Fig. 3. The relationship between the value of lateral COP displacement (COP) and the value of trunk displacement obtained from 17 patients during arm-raising examination.

3.3 Postural change during arm raising

Two patients, who were "frequent fallers" and showed a large lateral inclination, had difficulty in keeping their sitting posture for more than 10 seconds and had to be supported by experimenters to prevent them from falling during arm-raising test. Therefore, the following was analyzed: 1) the relationship between the lateral COP displacement and the trunk displacement using the value observed at 1 second after raising the arm to 90 degrees for all 17 patients, and 2) changes of the body axis during the arm-raising for 15 patients.
A postural change observed from one patient during the arm-raising test is shown in Figure 1. When the patient raised her arm laterally up to 90 degrees, the trunk marker shifted to the opposite side. In Figure 3, the relationship between the lateral COP displacement and the trunk displacement obtained from all 17 patients is shown.

	Control	PD		
		all	non-fallers & fallers (under 5)	Fallers (more than 5)
	n=8	n=17	n=12	n=3
Raising right arm	4.4 ± 1.6	4.5 ± 2.1 (p=0.5)	4.3 ± 2.0 (p=0.9)	5.1 ± 2.8 (p=0.6)
Raising leftt arm	3.7 ± 0.9	5.3 ± 2.7 (p=0.2)	4.4 ± 2.3 (p=0.4)	5.3 ± 1.5 (p=0.3)

unit: degree

Table 3. The absolute mean value with one standard deviation of each change of body inclination in control subjects and in PD patients when each subject raised each arm 90 degrees.

A positive relationship with a high correlation coefficient was observed, which was the same as the relationship observed during maintaining sitting posture at rest, only the shift of the initial position of the trunk marker. Table 3 shows the change of body axis associated with the arm-raising in each group. There was no significant difference between both the control group and the PD patient group, or between the control group and the "frequent faller" PD patient group.
In this test, R was defined as the following equation under a hypothesis that the relationship between the lateral COP displacement (ΔG) and the trunk displacement (ΔL) obtained during the sitting condition also applied to the lateral arm raising condition. In the sitting test, the relationship between ΔL and ΔG is expressed as following equation; $\Delta L=2.46*\Delta G$ (cf. Figure 2).

$$R=\Delta L -2.46*\Delta G$$

Figure 4 shows each parameter obtained from one subject during the arm raising test and the calculated results applied using the equation above. The calculated data showed a square change during the arm-raising phase (Figure 4B). The square change associated with the arm raising was observed in all patients except two patients who had fallen.

3.4 Estimation of trunk muscle tone

In this paper, we proposed a simulation model (cf. Figure 7) and an estimation of trunk muscle tone was made using patient's data under following conditions: 1) to mimic a sitting posture at rest and 2) to mimic a sitting posture with an arm raising. A detail of the model and a calculation procedure are described in the Appendix of this paper. Each body segment

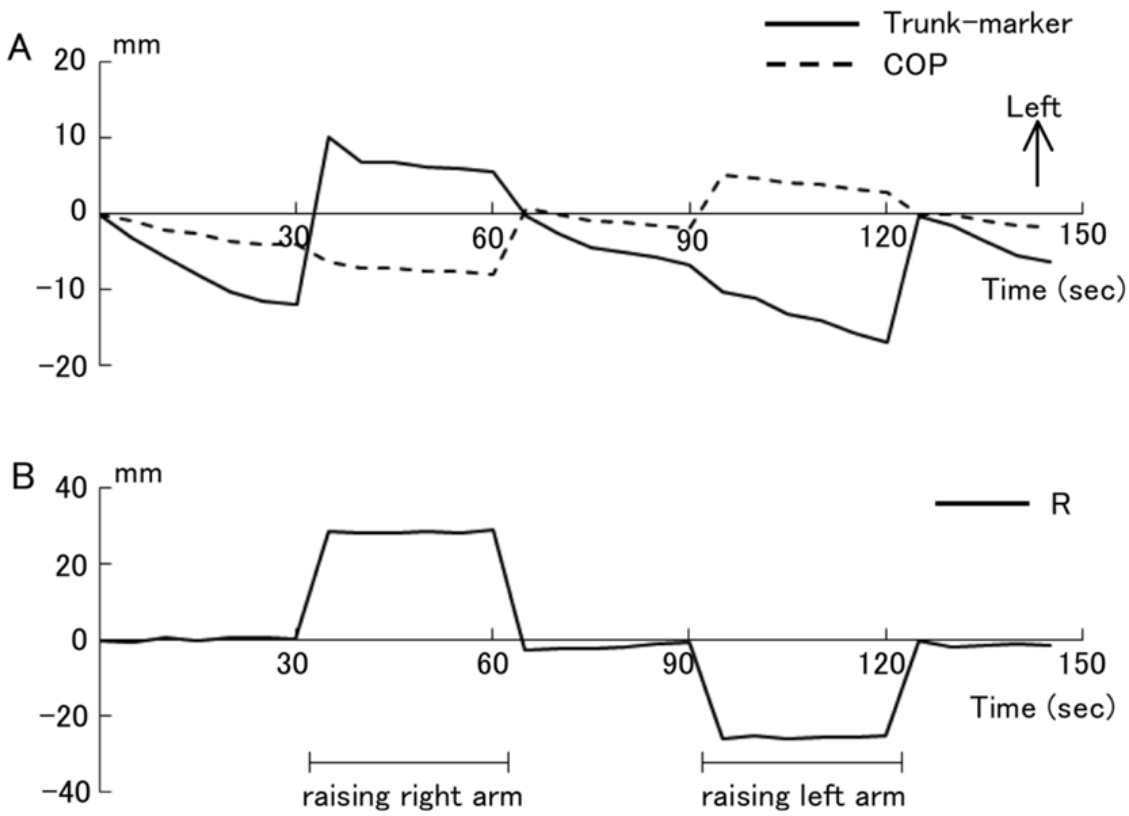

Fig. 4. A: A sequential change of lateral COP displacement (COP) and the value of trunk displacement (Trunk-marker) when one patient raised her arm alternatively. B: The R value change, which was calculated by our proposed equation (see Text).

Patient	Weight (kg)	Sitting height (cm)	Shoulder biacromial breadth (cm)	Bicristal breadth (cm)	Arm length (cm)	Torque (Nm) at rest	Torque (Nm) arm raising
1	46.0	70.0	32.9	23.6	55.0	5.87	39.1
2	60.0	73.6	32.9	26.4	62.9	5.02	44.4
3	44.0	73.6	33.6	28.6	61.4	3.54	42.4
4	37.5	64.3	28.6	25.7	54.3	3.13	37.8
5	48.0	72.9	32.1	28.6	60.0	2.37	42.4
6	61.0	72.9	33.6	25.7	64.3	0.11	43.6
7	43.0	74.3	32.1	26.4	62.1	0.94	43.8
8	60.0	70.0	30.7	25.7	62.9	0.05	43.4
9	44.0	72.9	29.3	25.7	61.4	1.31	43.3
10	47.0	64.3	30.7	27.1	61.4	1.22	43.3
11	57.0	73.6	38.6	27.9	55.7	2.65	38.7
12	54.0	70.0	37.9	27.9	62.9	2.89	43.2
13	44.0	64.3	27.9	26.4	62.1	2.23	43.8
14	34.0	64.3	30.7	21.4	58.6	1.68	41.7
15	51.6	67.9	34.3	26.4	60.7	6.33	45.3
16	45.0	76.4	31.4	27.1	62.1	9.78	42.8
17	65.0	72.9	32.1	27.1	58.6	22.51	41.5

Table 4. Each body segment size or body weight, which were used to estimate the torque, and the estimated value of torque both at rest and arm-raising.

size or body weight, which was used to estimate the torque, is shown in Table 4. There was a tendency toward increased value of the torque in PD patients who experienced falling frequently. The mean value with standard deviation of the torque at rest in non-fallers and less frequent fallers was 2.4 Nm±1.9 Nm, and that of the frequent fallers was 8.6 Nm±8.4 Nm ($p<0.03$). In Figure 5, the relationship between the value of trunk displacement and the estimated torque for each patient is shown. An estimated torque value was calculated using an averaged data value of all 17 patients when our model leaned. The data suggested that the trunk muscle tone was larger in the patients with high falling risk than the patients with less falling risk. In a simulation of the arm-raising, there was no significant difference between the non-fallers (42.9±2.3 Nm) and the fallers (42.1±2.0 Nm) ($p>0.47$).

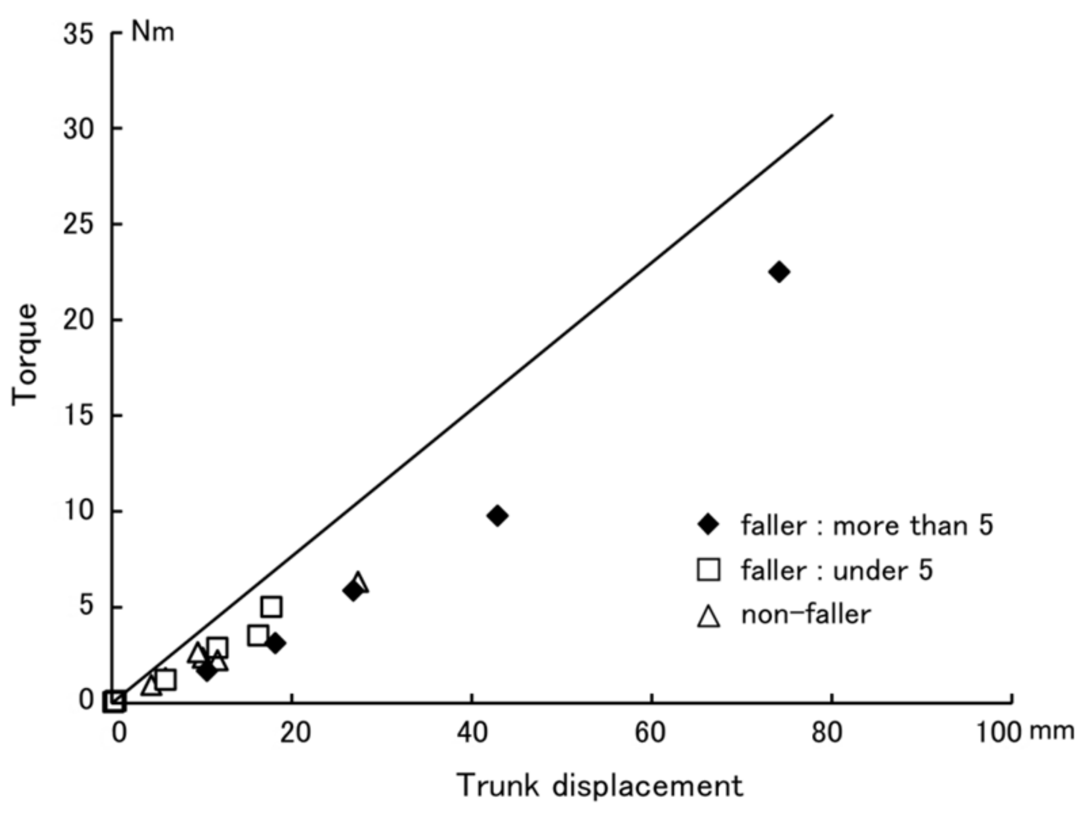

Fig. 5. Relationship between the value of trunk displacement and the estimated torque for each patient. An estimated torque value to the trunk displacement is shown as a straight line: a simulation was conducted using each of the following parameters calculated by averaging the data obtained from each of our 17 patients; body weight (except legs): 49.5 kg; arm weight 3.2 kg; sitting height 70.5 cm; shoulder biacromial breadth 32.3 cm; bicristal breadth 26.3 cm; arm length 60.4 cm.

In Figure 6, both the trunk displacement and the COP displacement were shown when the arm segment of the model was raised up to 90 degrees. Although we observed a transient response when the arm segment moved from a resting posture to a 90-degree arm raising posture or when the arm segment moved from the 90-degree position to the initial position, a constant value was observed when the arm segment was held at the 90-degree position or at the rest position.

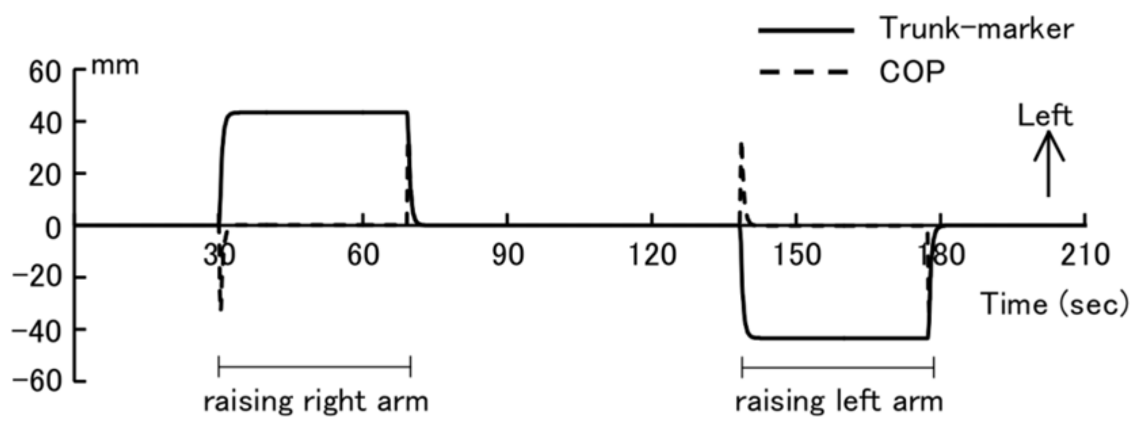

Fig. 6. Simulation representing an arm-raising test. A sequential change of lateral COP displacement and the value of trunk displacement when the model raised an arm alternately. A simulation was conducted using each of the following parameters calculated by averaging the data obtained from each of our 17 patients; body weight (except legs): 49.5 kg; arm weight 3.2 kg; sitting height 70.5 cm; shoulder biacromial breadth 32.3 cm; bicristal breadth 26.3 cm; arm length 60.4 cm.

4. Discussion

In this study, we demonstrated that PD patients who fell frequently tended to have 1) a value of lateral COP displacement greater than the value of control subjects, 2) a geometrical relationship between the arm and the trunk was preserved in PD patients, the same as in control subjects, and 3) a significant difference in postural muscle tone between frequent fallers and non-fallers or less frequent fallers. These results suggest that the measurement of both lateral COP displacement during sitting and arm-raising would be useful in predicting the risk of falling and predicting the trunk rigidity in PD patients.

4.1 Body inclination during sitting and in relation to falling frequency

Postural instability is one of the major symptoms of Parkinson's disease, and the instability in the control of upright stance and posture in PD often results in falling (Bloem et al., 2001; Wood et al., 2002; Grimbergen et al., 2004; Bloem et al., 2006). Several studies reported that postural sway patterns during quiet stance in PD patients are different compared to those of healthy elderly subjects, with PD patients displaying larger lateral excursion compared with anteroposterior excursion (Mitchell et al., 1995; Morris et al., 2000; Van Wegen et al., 2001; Van der Burg et al., 2006). In our study, the same tendency of postural sway pattern during sitting was observed and the excursions in the lateral direction in PD patients were larger than those of control subjects. Regarding postural control during standing, several authors suggested that instability in the anterior-posterior direction was compensated for by increasing excursion in the lateral direction in PD patients (Schieppati et al., 1994; Mitchell et al., 1995; Van Wegen et al., 2001). These mechanisms might be working during sitting and would have eventually increased the lateral inclination. Van Emmerik et al. (1999) also suggested that lateral impairment in postural control in patients with PD might be a reflection of axial rigidity.

Several studies suggested that increased lateral sway is associated with increased risk of falling in both elderly subjects (Maki et al., 1994) and patients with PD (Mitchell et al., 1995; Rocchi et al., 2002). Our study also showed that the degree of lateral inclination during sitting was significantly larger in PD patients with history of falls than PD patients without history.

Based on these results, we suggest the risk of falls would increase when compensation in the anterior-posterior body sway with the lateral body sway is difficult. Measurement of postural change in the lateral direction during sitting for a relatively long time, 2 minutes in this study, is a simple and effective method that can be used in daily clinical examinations to evaluate the risk of falling.

4.2 Postural change associated with a lateral arm-raising task

A large number of human motor actions cause potential displacement of the body center of gravity (COP) and it is well known that voluntary movement is preceded and accompanied by postural muscular activities. Several studies which fall into this category include activation of posterior trunk and leg muscles when the arms are raised in front of the body (Traub et al., 1980; Zattare & Bouisset, 1988) or when a leg is raised while standing (Lee et al., 1995).

There are several reports that postural adjustments of the upper extremities may also be disrupted in Parkinson's disease. Abnormalities in the timing or amplitude of anticipatory postural adjustments, which occur when rapid voluntary arm movements are made while in the standing position, have been reported in parkinsonian subjects (Dick et al., 1986). Lee and coworkers (1995) studied the preparatory postural adjustments associate with a lateral leg raising task in parkinsonian patients and described the amplitude of the initial displacement of COP was markedly reduced and the interval between the earliest force changes and the onset of leg elevation was prolonged. These authors focused on the initial phase of the preparatory postural adjustments in parkinsonian patients with postural instability. On the other hand, in our study, the postural change after elevating and holding the arm was examined. We found no significant difference in the trunk inclination, associated with arm-raising between normal controls and PD patients, or between raising the right arm and the left arm test in PD patients. These test results indicated that the postural controls during the arm raising were preserved in PD patients we studied.

Adopting an appropriate body orientation, and maintaining this posture to the displacing effects of gravity or external forces is essential for postural control. Patients with Parkinson's disease had difficulty in postural control, especially the control of body vertically (Vaugoyeau et al., 2007; Hayashi et al., 2010). Steiger et al. (1996) reported that PD patients had difficulty in coordinating the orientation of the axial segments along the spinal axis. Several investigators also reported that the proprioceptive feedback information to the static position and movement perception processing decreased in PD patients (Zia et al., 2002; Keijsers et al., 2005; Vaugoyeau et al., 2007). In this study, the body inclination was observed during the arm-raising test, and the R-value was constant. These results suggested that a geometric relationship between the raised arm and the trunk was preserved during the arm-raising phase even though the trunk inclined.

4.3 Estimation of postural muscle tone in the body axis

Rigidity is a continuous and uniform increase in muscle tone, felt as a constant resistance throughout the range of passive movement of a limb or a neck, and is a cardinal symptom of Parkinson's disease. Clinically, rigidity is usually assessed by passively flexing and extending a patient's limb. Objectively, most previous investigators examined rigidity in the muscles in PD patients, using either torque motor or isokinetic dynamometer (Nuyens et al., 2000; Hayashi et al., 2001). A few studies have done quantitatively to measure of postural muscle tone in the body axis of healthy test subjects (Kumar 2004; Gurfinkel et al., 2006) or to measure of trunk rigidity in parkinsonian patients (Mak et al., 2007). In these studies, the measurement procedures were different; each estimated value of muscle tone was close. Gurfinkel et al. (2006) reported that the value was 2 Nm to 9 Nm in standing, 40 Nm to 80 Nm in sitting (Kumar, 2004). Mak and coworkers (2007) reported PD patients had a significantly higher trunk muscle tone when compared with normal controls in the standing position, in both passive trunk flexion (17-22 Nm・deg in the control group, 27-40 Nm・deg in PD patients) and passive trunk extension (21-26 Nm・deg in the control group, 28-45 Nm ・deg in PD patients).

In this paper, we estimated the postural muscle tone in the body axis based on our model and showed that the positive relationship between the trunk displacement and the estimated torque value at rest condition. The estimated torque value in the high risk PD patients for falls was larger than that of lower risk PD patients. These results were consistent with that reported by Mak and coworkers (2007). In their study, it was reported that unstable PD patients had a tendency to have high trunk muscle tone.

5. Conclusion

Based on these results, we conclude that a measurement of body inclination for an extended period of 2 minutes as in this study is a valuable predictor for the risk of falling and is a simple and easy method to estimate the trunk muscle tone. This study also demonstrates that even PD patients with high falling risk are capable of controlling their postural geometry between the raised arm and the trunk.

6. Appendix

The proposed model, which simplified a sitting posture on a chair, was developed using an ODE (Open Dynamic Engine) simulator. This model is composed of the following 7 parts, including the upper part of the trunk, arm part, shoulder hinge joint, impedance joint set under the upper part, waist hinge joint, lower part of the trunk and the hip hinge joint. Body segment parameters used at the simulator are given by general physical data obtained from our patients, and an estimation value of each body segment was made based on the previous reports (Jensen et al., 1994, Okada et al., 1996).

The unique point of our model is using an "impedance joint", which consist of two parts: "elastic property" and "viscous properties" to artificially reproduce the muscles encompassing the waist.

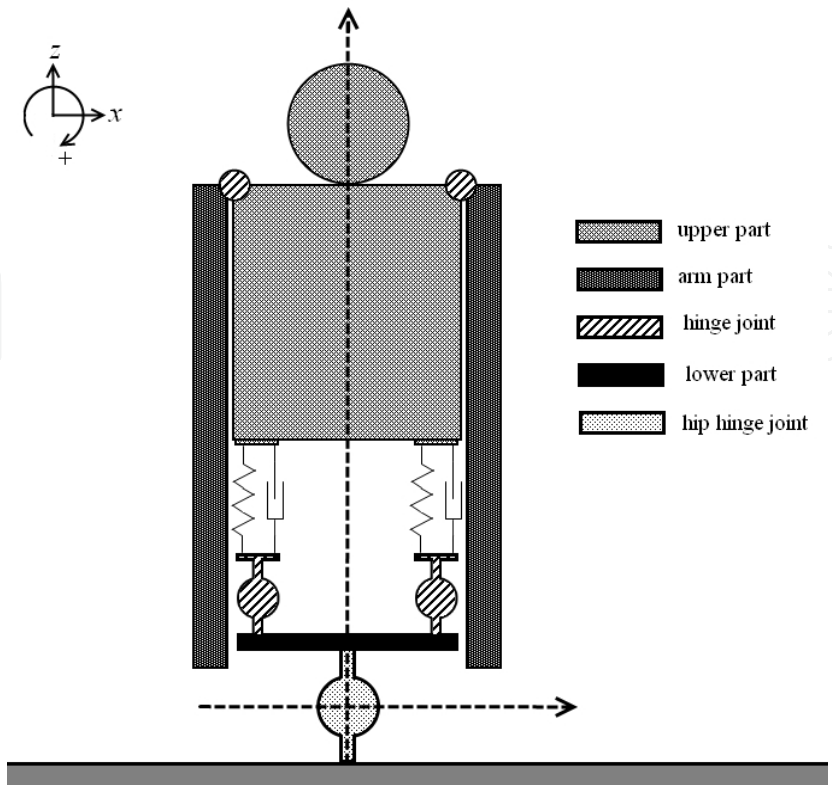

Fig. 7. A proposed model

The mathematical expression of the each impedance joint is shown as:

$$I\ddot{\theta} = \tau - d\dot{\theta} - k\theta$$

where I is the fictitious force, θ is the angle of the joint, τ is the muscle torque around the waist, d is the elastic property and k is the viscous property. By using this impedance joint, it becomes very easy to simulate the behavior of the body. The hinge joints work as an actuator, rotation sprig or a torque motor; which are used in the shoulder, waist and hip joint. It is also possible to obtain the data of each part and the whole body's barycentric coordinates using this simulator.

The procedure of the simulation is thus illustrated as follows: first, each parameter of the model such as weight or height et al. was estimated based on the previous Japanese reports (Okada et al., 1996) and our patients (cf. Table 4). Then a condition was imposed on the model to remain stable while a small disturbance to the body was applied. During this procedure the torque exerted on each of the joints was calculated, and using this data we were able to calculate the optimal solution of the stiffness for each joint.

At the next step, a stiffness condition was imposed on the model, which was evaluated from the previous simulation and then, set the same condition for the model to stay stable. This time, instead of applying a small disturbance, we requested the model to raise their arm up to the 90-degree position in 1 second. Through simulation, we gave careful consideration of the body sway by using the impedance joint and the hinge joints. Tuning the two impedance joints and the stiffness joints through the numerical simulations, we estimated an identified torque, which is needed to maintain posture maintenance.

Winter et al. (1998) reported that a relationship between COP and COM (center of mass or barycenter) was expressed in the following equation in a stiffness control of balance in the quiet standing position.

$$COP - COM = -\frac{I}{mgh}\ddot{x}$$

Where I is the inertial around the mass, m is the mass of the object, g is the acceleration due to gravity, h is the length from the origin coordinates and $\ddot{x}$ is the second derivative of *COM*. At this simulation, thereafter the arm is raised up to the 90-degree position, the body will be stationary; thereby we can consider $\ddot{x} = 0$.
The barycentric coordinate of the full body (P_{tx}, P_{tz}) will be expression as:

$$\begin{aligned} P_{tx} &= (M_{un} \cdot P_{un\_x} + M_{up} \cdot P_{up\_x} + M_{la} \cdot P_{la\_x} + M_{ra} \cdot P_{ra\_x}) / (M_{un} + M_{up} + M_{la} + M_{ra}) \\ P_{tz} &= (M_{un} \cdot P_{un\_z} + M_{up} \cdot P_{up\_z} + M_{la} \cdot P_{la\_z} + M_{ra} \cdot P_{ra\_z}) / (M_{un} + M_{up} + M_{la} + M_{ra}) \end{aligned} .$$

Where $M_{un}, M_{up}, M_{la}, M_{ra}$ is the mathamatical representation of "lower part of the trunk (21.5% of body weight)", "upper part of the trunk (28.5% of body weight)", "left arm (6.5% of body weight)", "right arm (6.5% of body weight)", and $P_{un\_x}, P_{up\_x}, P_{la\_x}, P_{ra\_x}, P_{un\_z}, P_{up\_z}, P_{la\_z}, P_{ra\_z}$ is the barycentric position of each part where x and z represent the horizontal component and the vertical component, respectively.
The angle between "barycentric position" and "hip hinge joint" will be expression as:

$$\text{angle} = \arctan(P_{tx} / (P_{tz} - P_h)) .$$

Where P_h is the length from the home position.

1. to mimic a sitting posture at rest
   The torque applied to the hip hinge joint will be express as:

   $$\text{torque}_h = G_{Dh}(0 - R_{Vh}) + G_{Ph}(0 - R_{Ah}) ,$$

   where G_{Dh}, G_{Ph} are a derivative gain and a proportional gain of the torque.
   And R_{Vh}, R_{Ah} are a displacement and an angular rate of the body.
2. to mimic a sitting posture with the right arm raising, we used the right arm hinge torque and the hip hinge torque.
   Right arm hinge torque can be represented excellently by:

   $$\text{torque}_{ra} = -G_{Da}(B_{Va} - R_{Va}) - G_{Pa}(B_{Aa} - R_{Aa})$$

   where G_{Da}, G_{Pa} are a derivative gain and a proportional gain of the torque.
   And R_{Va}, R_{Aa} are a displacement and an angular rate and B_{Va}, B_{Aa} are the target trajectories of the arm.

7. References

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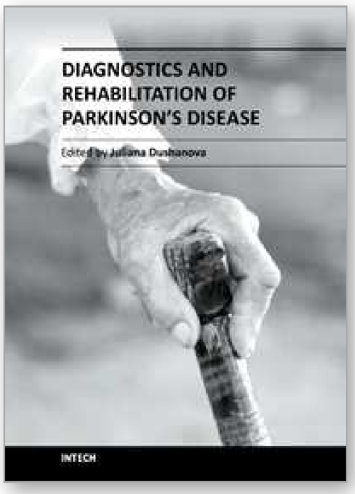

Diagnostics and Rehabilitation of Parkinson's Disease

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Diagnostics and Rehabilitation of Parkinson's Disease presents the most current information pertaining to news-making topics relating to this disease, including etiology, early biomarkers for the diagnostics, novel methods to evaluate symptoms, research, multidisciplinary rehabilitation, new applications of brain imaging and invasive methods to the study of Parkinson's disease. Researchers have only recently begun to focus on the non-motor symptoms of Parkinson's disease, which are poorly recognized and inadequately treated by clinicians. The non-motor symptoms of Parkinson's disease have a significant impact on patient quality of life and mortality and include cognitive impairments, autonomic, gastrointestinal, and sensory symptoms. In-depth discussion of the use of imaging tools to study disease mechanisms is also provided, with emphasis on the abnormal network organization in parkinsonism. Deep brain stimulation management is a paradigm-shifting therapy for Parkinson's disease, essential tremor, and dystonia. In the recent years, new approaches of early diagnostics, training programmes and treatments have vastly improved the lives of people with Parkinson's disease, substantially reducing symptoms and significantly delaying disability. Written by leading scientists on movement and neurological disorders, this comprehensive book should appeal to a multidisciplinary audience and help people cope with medical, emotional, and practical challenges.

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