The Egyptian Journal of Otolaryngology

ORIGINAL ARTICLE Open Access

Assessment of postural instability in Parkinson's disease patients

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Abstract

Background: Parkinson's disease (PD) is a degenerative, progressive, neurological condition that influences the control of a person's body movements. Computerized dynamic posturography (CDP) is a clinical tool intended to evaluate the integration of visual, vestibular, and somatosensory inputs to maintain postural gait. Posturography can be used to measure postural instability in PD patients. So, the aim of this study was to evaluate the postural control and elaborate on the pathophysiology of the balance impairment in PD patients in the "on" state.

Results: All antero-posterior (AP) and medio-lateral (ML) sensory balance scores, except vestibular ones, were significantly lower in the study group compared to the control group. AP and ML sway were generally higher in the study group at all frequencies, with AP being mostly greater compared to ML sway in PD subjects. Global sensory scores were shown to deteriorate with increased durations of the disease and treatment.

Conclusions: PD patients have higher postural instability in comparison to controls with AP sway being higher compared to ML.

Keywords: Parkinson's disease, Computerized dynamic posturography, Sensory organization test, Postural control

Background

Parkinson's disease (PD) is a progressive and chronic degenerative CNS disorder. Patients with PD demonstrate more difficulty in producing simultaneous and sequential movements versus simple movements; thus, they need to finish production of one movement before initializing the next [1]. In 2013, there were up to 1,000,000 PD patients in the USA, and the prevalence is expected to reach double that number in 2040 [2]. The incidence of PD in USA is about 50,000 yearly [3].

Patients at later stages and with longer duration of the disease have a higher tendency to fall [4]. Progression of the disease is associated with an abnormal gait called festination, characterized by lower speed and shorter stride, where the patient seems to chase his center of gravity, with an affinity to fall forward.

Posturography is a clinical tool intended to evaluate the integration of visual, vestibular, and somatosensory systems to maintain postural gait [5]. It can measure postural instability in PD patients. In addition, it can assist in the investigation of the functional aspects of dysfunctions causing the body imbalance [6] and complement conventional vestibular tests for diagnosis, staging, treatment, and prognosis in PD [7].

Several studies have been conducted to assess the balance inputs in PD patients using posturography. They included both case-control studies [8] and interventional studies [9–11].

Balance deficits in PD patients are multifactorial. Sensory Organization Test (SOT) has been utilized to objectively quantify postural deficits in PD subjects [12–14]. The eyes closed condition has been verified as a valuable clinical observation to recognize postural sway. Results from computerized dynamic posturography (CDP) imply PD

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patients of Hoehn and Yahr stages 2 to 4 had poorer scores than norms for composite, vestibular, and visual inputs, representing higher reliance on visual information [15].

In summary, posturography has been found to be a very useful tool in clinical assessment of postural control in PD patients. Yet, more posturographic tests could be conducted to elaborate on the pathophysiology of balance impairment in PD patients in the "on" state.

Methods

The protocol of the current case control study was approved by the Ethics Committee of Faculty of Medicine, Alexandria University, Egypt. All participants provided written an informed consent after receiving a detailed explanation of the study. All the tests were performed in Audio-vestibular Medicine Unit, Otorhinolaryngology department of Alexandria main university hospital.

Participants

Fifteen subjects of both genders diagnosed as having PD for a minimum of 1 year earlier by a neurologist were included according to the following criteria:

i. History of first complaint (tremor, inability to control, and abnormal movement …to specify the duration of the disease)
ii. Family history
iii. History of head trauma
iv. History of medications (with the duration of treatment of PD using levodopa included)
v. Full neurological examination
vi. Investigation: CT and MRI to exclude any abnormality in brain structure.

Fifteen gender- and age-matched controls, who had no history of neurological deficits, also participated in the study.

All subjects who participated in the study had the following exclusion criteria:

a) External and/or middle ear disorders
b) Those with psychiatric disorders
c) History of otological surgery
d) Those unable to comprehend and follow simple verbal instructions
e) Those unable to stay upright unassisted
f) Severe uncorrected diminution of visual acuity
g) Limitation of movement due to orthopedic disorders
h) Subjects with prosthetic legs who were enrolled in a body balance rehabilitation program in the 6 months prior to CDP examination

Patients with PD were examined during their "on" period, 40 min to 2 h after levodopa was given, when they showed improved motor performance [16].

Sensory organization test (SOT)

SOT was performed using the Synapsys Posturography System (SPS), posturography system (SYNAPSYS SA 58 rue Paul Langevin, 13013, Marseille, France).

The subject's overall balance was assessed using sensory organization test. The limits of stability (LoS) was first evaluated on a static platform. LoS measures the maximum distance an individual's center of gravity moves in a certain direction without one taking a step or losing balance. The patients' eyes were open and they moved as far as they could in all directions while maintaining their body straight and without relocating their feet or falling. This way, balance is preserved using the ankle strategy (upside down pendulum). The limits of stability are used by the software to later assess the AP and ML sway in the SOT, thus the sensory balance scores.

Static posturography was assessed using the static platform. A foam platform, imposing a dynamic balance task, was used in dynamic posturography. The foam platform was positioned on the static Synapsys Posturography System (SPS) platform. Eyes opened, eyes closed, and deceptive vision trials were performed on the static and dynamic support surfaces creating six conditions. These are:

1. Static support, eyes open (EO): none of the afferents are manipulated.
2. Static support, eyes closed (EC): the visual inputs are suppressed. Only the somatosensory and vestibular information is available.
3. Static support, vision erroneous (VE): the visual information is inaccurate through the "sway referencing" of the visual surroundings. The somatosensory and vestibular information is not manipulated
4. Dynamic support, EO: the somatosensory information provided from the feet and joints is erroneous; the visual and vestibular inputs are not manipulated.
5. Dynamic support, EC: the somatosensory information is erroneous; the visual afferences are suppressed. Only the vestibular information is available.
6. Dynamic support, VE: the somatosensory and visual information is erroneous; the vestibular afferences are not manipulated.

For each test condition, the barefooted subjects were instructed to stand straight on the platform and were

requested to look at a picture located on an LCD screen in front of them. The patients were instructed to keep their balance without standing stiffly or moving their feet. To protect against falls, subjects were instructed to hold on to the security support if they were about to fall. Two trials of 20 s were recorded in each test condition. The antero-posterior (AP) and medio-lateral (ML) center of pressure (CoP) sway were recorded separately for each of the six test conditions. The following sensory balance scores were calculated in the antero-posterior (AP) and medio-lateral (ML) movements: somatosensory, visual, vestibular, preferential, and global.

The somatosensory, visual, and vestibular scores inform us of the patient's ability to use somatosensory, visual, and vestibular afferences respectively. The preferential score indicates the patient's ability to ignore incorrect visual information. The lobal score is a weighted average of balance scores on the 6 conditions. It characterizes the coverall balance level.

Somatosensory score = static support, EC/static support, EO
Visual Score= Dynamic support, EO/static support, EO
Vestibular score=Dynamic support, EC/static support, EO
Preferential = Static support, VE+ dynamic support, VE/static support, EC+ dynamic support, EC

Fast Fourier transform energies of the CoP displacement in both AP and ML planes in each of the six conditions were recorded. The Fourier transforms are divided into 3 areas: low frequency area [0–0.5 Hz], medium frequency area [0.5–2 Hz], and high frequency area [2–20 Hz]. For each of the areas, the program calculates the energy expended by the patient in the corresponding frequency band and its distribution compared to the total energy.

Statistical analysis

Data were analyzed using IBM SPSS software package version 20.0. (Armonk, NY, IBM Corp). Chi-square test was used to test homogeneity among proportions. Monte Carlo correction was used for correction of chi-square since more than 20% of the cells had expected count less than 5. Mann-Whitney test was used for comparison between the control and study groups, since the normality of variance assumption was rejected. Wilcoxon signed-rank test was used for comparing two related samples, matched samples, or repeated measurements on a single sample to assess whether their population mean ranks differ (paired difference test). Spearman's correlation coefficient was used to study the correlation between variables, given that the normality of variance assumption was rejected

Results

A total number of 30 subjects were examined in this study, who were divided into a control group (15 subjects) (three females and 12 males; mean age 53.07 ± 11.71 years) and a study group (15 subjects) (three females and 12 males; mean age 51.40 ± 12.29 years). The groups were comparable as regards gender (χ^2 = 0.409, FEp=0.682) and age (U = 103.0, p = 0.692). Characteristics of the study group are shown in Table 1.

Results of the SOT are shown in Tables 2 and 3. All antero-posterior sensory balance scores, except vestibular, were lower in the study group compared to the control group. The difference was statistically significant in somatosensory ($p \leq 0.001$), visual ($p = 0.022$), preferential ($p < 0.001$), and global scores ($p < 0.001$). No statistically significant difference was found in vestibular score (p=0.058) (Table 2). All medio-lateral sensory balance scores, except vestibular, were lower in the study group compared to the control group. The difference was statistically significant in somatosensory ($p \leq 0.001$), visual ($p = 0.014$), preferential ($p < 0.001$), and global ($p < 0.001$). No statistically significant difference was found in vestibular score ($p = 0.169$) (Table 3).

Table 1 Comparison between the two studied groups according to age, gender, duration of disease, duration of treatment, and etiology of the disease

	No. (%)
Age (years)	
<60	7 (46.7%)
≥60	8 (53.3%)
Median (Min.–Max.)	60 (45–66)
Mean ± SD.	58.7 ± 6.1
Sex	
Male	12 (80%)
Female	3 (20%)
Duration of disease (years)	
<5	9 (60%)
≥5	6 (40%)
Median (Min.–Max.)	4 (1.5–10)
Mean ± SD.	4.3 ± 2.6
Duration of treatment	
<4	8 (53.3%)
≥4	7 (46.7%)
Median (Min.–Max.)	4 (1.5–10)
Mean ± SD.	4.3 ± 2.6
Causes	
Idiopathic	13 (86.7%)
Trauma	2 (13.3%)

Table 2 Comparison of antero-posterior sensory balance scores of complete static sensory organization test between control and study groups (n = 30)

Antero-posterior	Cases (n = 15)	Control (n = 15)	U	p
Somatosensory				
Min.–Max.	3.0–90.0	84.0–100.0	21.0*	<0.001*
Median and quartile	80.0 (73–90)	100.0 (90–100)		
Visual				
Min.–Max.	4.0–100.0	82.0–100.0	58.50*	0.022*
Median and quartile	82.0 (82–100)	97.0 (87–100)		
Vestibular				
Min.–Max.	60.0–100.0	82.0–100.0	2.008	0.058
Median and quartile	84.0 (72–99)	96.0 (87–96)		
Preferential				
Min.–Max.	0.0–100.0	67.0–91.0	26.0*	<0.001*
Median and quartile	50.0 (28–65)	74.0 (70–77)		
Global				
Min.–Max.	14.0–66.0	60.0–74.0	25.50*	<0.001*
Median and quartile	44.0 (29–59)	66.0 (60–73)		

U, Mann-Whitney test, *p* *p* value for comparing between the two groups
*Statistically significant at $p \leq 0.05$

Table 3 Comparison of medio-lateral sensory balance scores of complete static sensory organization test between control and study groups (n=30)

Medio-lateral	Cases (n=15)	Control (n=15)	U	P
Somatosensory				
Min.–Max.	0.0–97.0	97.0–100.0	12.0*	<0.001*
Mean ± SD.	69.47 ± 36.97	98.87 ± 1.30		
Median and quartile	80.0 (68–97)	99.0 (98–100)		
Visual				
Min.–Max.	0.0–94.0	80.0–100.0	54.0*	0.014*
Mean ± SD.	70.33 ± 30.52	90.60 ± 7.89		
Median and quartile	82.0 (71–86)	89.0 (82–99)		
Vestibular				
Min.–Max.	0.0–100.0	81.0–100.0	79.50	0.169
Mean ± SD.	72.73 ± 31.39	88.13 ± 5.88		
Median and quartile	84.0 (74–92)	85.0 (85–91)		
Preferential				
Min.–Max.	0.0–81.0	60.0–91.0	32.0*	0.001*
Mean ± SD.	45.20 ± 32.20	80.33 ± 10.42		
Median and quartile	50.0 (10–74)	86.0 (70–89)		
Global				
Min.–Max.	1.0–73.0	70.0–88.0	5.50*	<0.001*
Median and quartile	50.0 (41–70)	74.0 (74–81)		

U, Mann-Whitney test, *p*, *p* value for comparing between the two groups
*Statistically significant at $p \leq 0.05$

For the FFT of the CoP displacement, in all static conditions, FFT of AP and ML displacement was significantly higher at all frequencies in the study group compared to controls. On the other hand, in foam conditions (eyes open and vision erroneous), FFT of AP and ML displacement of CoP was significantly higher at all frequencies in the study group compared to controls. In eyes closed condition, FFT of AP displacement of CoP was significantly higher only at high frequencies in the study group while the FFT of ML displacement was significantly higher at all frequencies in the study group compared to controls (Figs. 1 and 2).

Comparison between FFT energy of AP and ML displacement of CoP in the study group in the static condition showed that the AP displacement was higher than ML in all static conditions at all frequencies except eyes closed condition where the AP was lower than ML at low frequency. A statistically significant difference was found only in Servo-controlled condition at low frequency (p<0.002), mid frequency (p<0.004), and high frequency (p<0.011) (Figs. 3 and 4).

The AP and ML global sensory balance scores were correlated with the duration of the disease and treatment. Both AP and ML global sensory balance scores were significantly correlated with the duration of the disease and treatment. For the AP score, the correlation was strong with both the duration of the disease and treatment (r_s = 0.736, p = 0.002*) and (r_s = 0.690, p = 0.004*) respectively. The correlation of ML score was moderate with both the duration of the disease and treatment (r_s = 0.634, p = 0.011*) and (r_s = 0.549, p = 0.034*) respectively (Fig. 5).

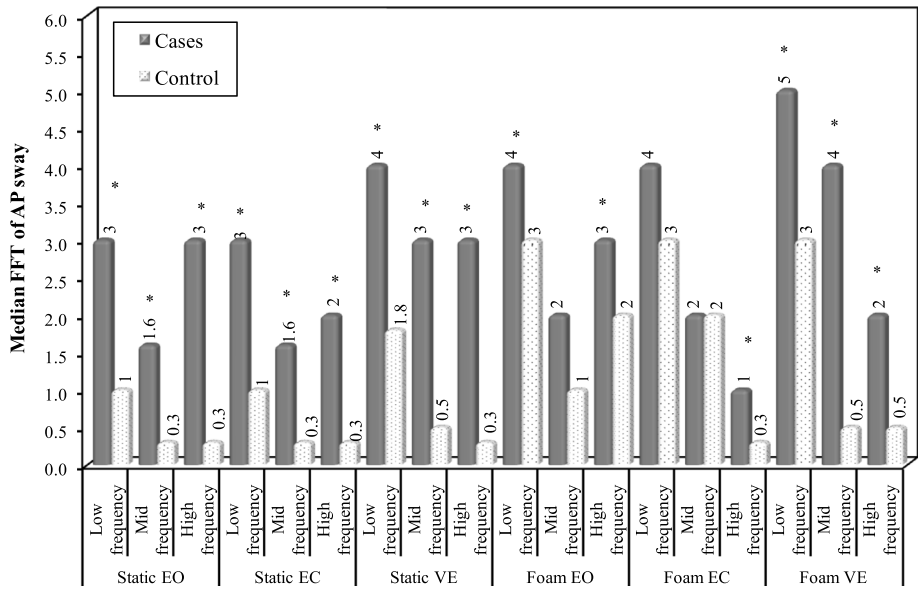

Fig. 1 Comparison of FFT of AP sway between cases and controls

Discussion

The purpose of this study was to evaluate the postural control in patients with PD in comparison to age- and gender-matched controls and elaborate on the pathophysiology of the balance impairment in PD patients in the "on" state. This was accomplished by the CDP.

Our results show that the cases showed more statistically significant decrease in all sensory balance scores except vestibular compared to controls.

Our results with global SOT are similar to a study by Rossi et al. [13], who confirmed that patients with abnormal balance (global SOT ≤ 69) have pathological integration of sensory inputs of balance. Nevertheless, Landers et al. [14] demonstrated that a global SOT cut-off score of 68.5 was not reliable in differentiating PD patients into fallers and non-fallers. Insensitivity of global SOT to categorize PD patients into fallers and non-fallers might be accredited to non-sensory balance deficits in people with PD, which can go unnoticed by SOT [17].

In contrast to our results in vestibular equilibrium, somatosensory, and preferential scores, results from a

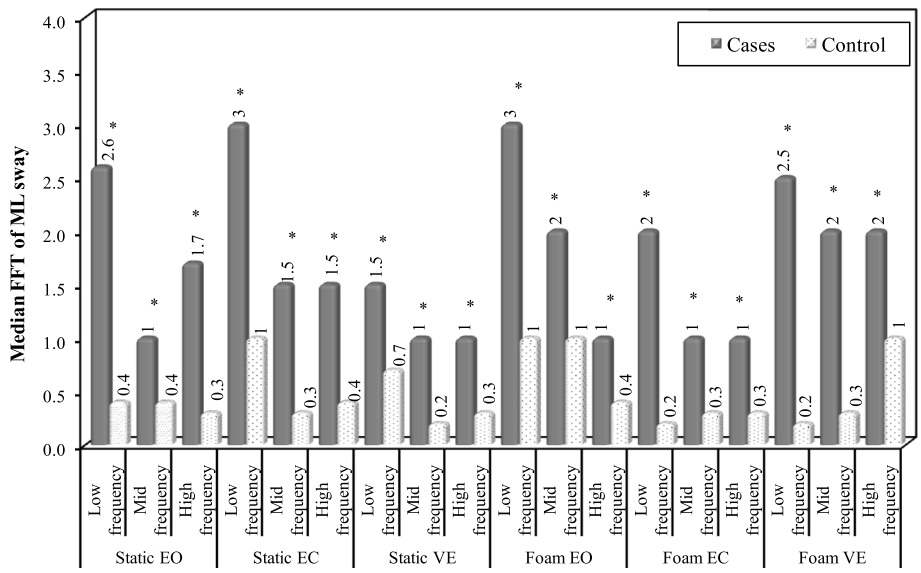

Fig. 2 Comparison of FFT of ML sway between cases and controls

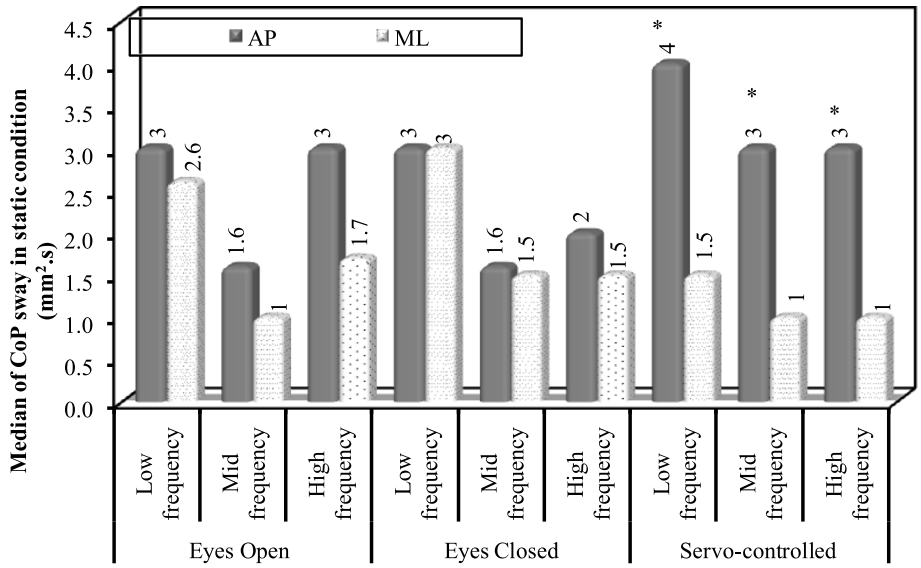

Fig. 3 Comparison of FFT of AP and ML sway in the study group in the static conditions

study by Rossi et al. [13], Huh et al. [18], and Colnat-Coulbois et al. [19] showed impaired vestibular and normal somatosensory and preferential balance scores in PD patients in comparison to controls. Rossi et al. [13] study investigated the postural control of PD patients (Hoehn and Yahr Stages 2 to 4) and control subjects using the SOT. In that study, the investigators noticed that even Hoehn and Yahr stage 2 patients demonstrated deficits in postural control in circumstances where information from the vestibular system is needed whereas the preferential and somatosensory scores were not significantly different from controls. The somatosensory input of patients with PD, despite not being significantly poorer than that of controls, was inversely correlated with duration of the disease as well as duration of treatment. The authors concluded that the defective processing of vestibular information is not dependent on the stage of PD and may be due to a central vestibular lesion. Huh et al. [18] found that PD patients with FOG showed poorer postural sensory processing in relation to those without FOG. In particular, the inability to employ the vestibular information and impaired control over the disturbed somatosensory inputs significantly contributed to FOG. Similar to Rossi et al., the authors concluded that the vestibular deficits may stem from a failure in the central processing of vestibular feedback. Colnat-

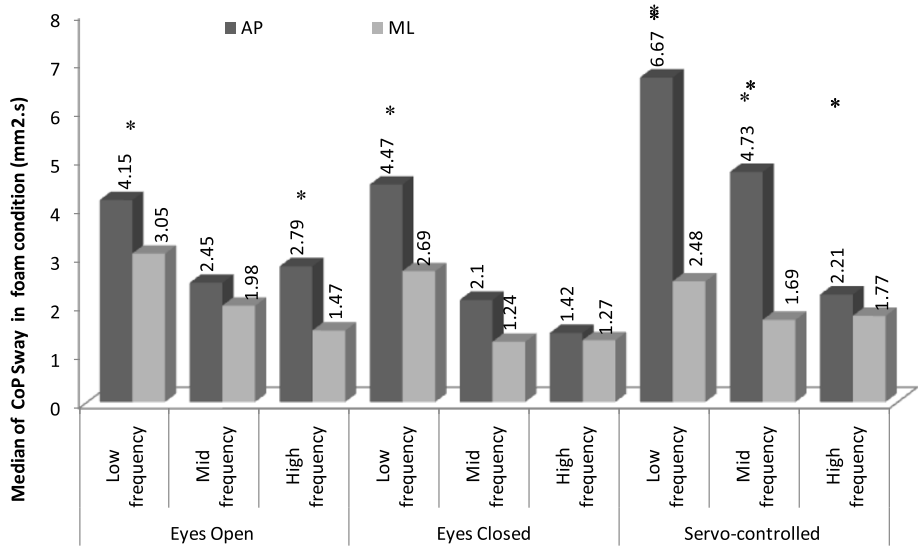

Fig. 4 Comparison of FFT of AP and ML sway in the study group in the foam conditions

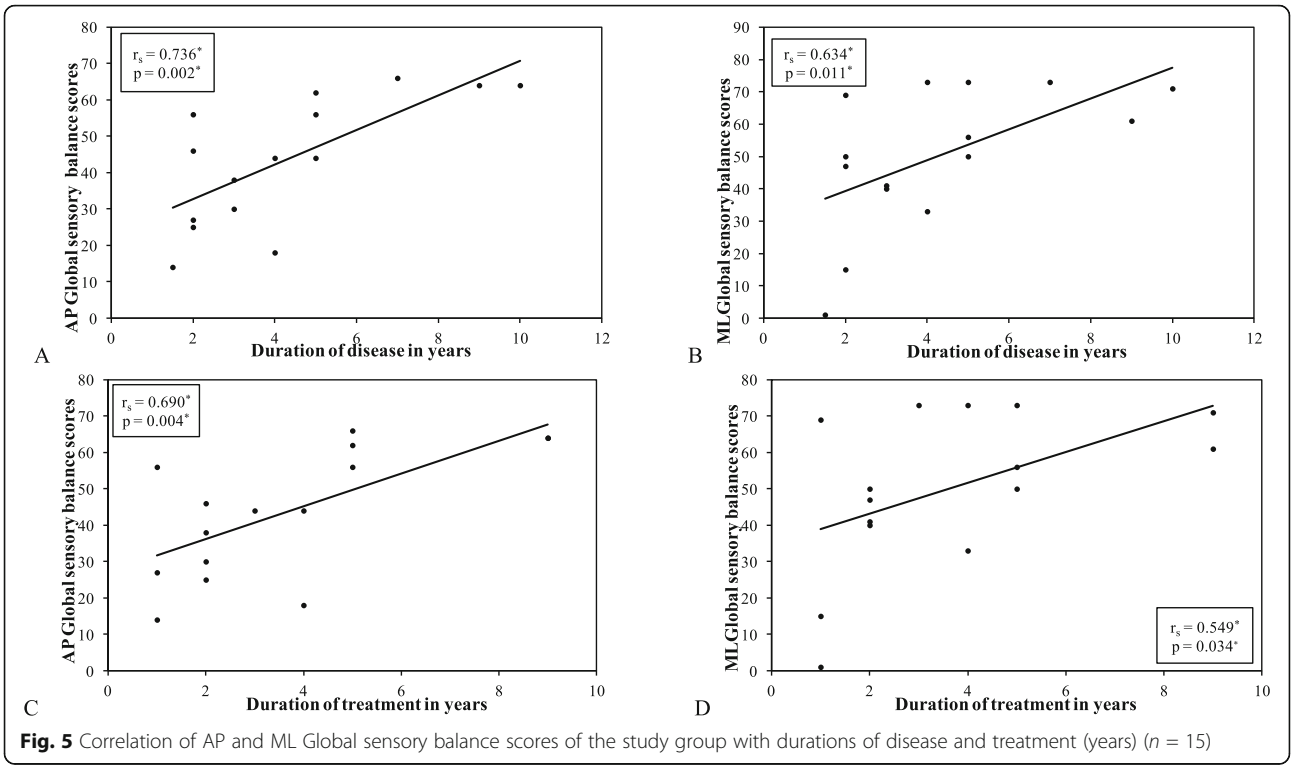

Fig. 5 Correlation of AP and ML Global sensory balance scores of the study group with durations of disease and treatment (years) (n = 15)

Coulbois et al. [19] found that patients in late stages of PD show impairment of all scores except somatosensory and preferential scores. The controversy in our results in the vestibular score with previous studies may be attributed to a few factors. In the study of Rossi et al. [13], although their study group received their medication prior to CDP examination similar to the cases in the current study, their PD patients were much older (mean age 70.4 years and ranged from 46 to 82 years versus mean age 53.07 and ranged from 29 years to 65 years) respectively. Visual and vestibular inputs of balance control are influenced by aging [20–23]. The study by Colnat-Coulbois et al. [19] investigated the SOT in late stage PD where the duration of disease was (median = 11 years, interquartile range 4.3 years). In our study subjects, the median duration of disease was 4 years. Huh et al. [18] investigated the postural sensory deficits in PD patients with FOG in their off medication state and the patients were unable to utilize vestibular cues to maintain posture, thus a chief contributor to FOG. The authors concluded that this might be ascribed to failure of central processing of vestibular feedback, similar to other studies [19, 24, 25]. Abnormal vestibulocollic responses have also been recognized in PD patients having moderate to severe motor disability [26]. However, levodopa has been found to increase the amplitudes of cVEMPs in PD patients [27]. The decrease of the somatosensory input in our PD subjects compared to controls may be attributed to the medication since our patients were tested in their (On) state. Sridharan et al. [28] investigated the effects of dopaminergic medication on cortical somatosensory inputs in PD using magnetoencephalography (MEG). They found a higher positive effect of dopaminergic medications on the induced gamma augmentation compared to other treatment options. Also O'Suilleabhain et al. [29] established that levodopa impairs somatosensation of people with PD and pointed out that the drug might induce dyskinesia. However in another study, patients with PD showed an SOT condition 1 performance comparable to norms which is inconsistent with dyskinetic swaying [13].

In our study subjects, FFT of AP and ML displacement of CoP was significantly higher at all frequencies in all static and foam conditions except at low and mid frequencies in foam eyes closed condition (condition 5) in the AP plane compared to controls. Comparison of AP than ML sway within the study group showed that AP sway was higher than ML in static conditions at all frequencies except eyes closed condition where the AP was lower than ML. The difference was statistically significant in Servo-controlled eye condition. The AP sway was also higher in all foam conditions at all frequencies. The difference was statistically significant at low and high frequencies in eyes open condition, low frequency in eyes closed condition, and low and mid frequencies in Servo-controlled condition.

There have been many efforts to specify the operating frequency ranges used by vestibular, visual, and

somatosensory systems sustain an upright position. The results of different studies were contradictory. For the visual system, Nashner et al. [30] hypothesized that it operates below 0.1 Hz, while Mauritz et al. [31] suggested that it is put into action below 1.0 Hz, and Dichgans and Brandt [26] concluded that it works below 1.2 Hz. Nashner [32] postulated that, regarding the vestibular system, the semicircular canals detect sway at above 0.1 Hz, while the otolith organs sense acceleration below this frequency. The somatosensory system may function between 0.3 and 1.2 Hz [30]. Thus, the definite frequency range where each system operates has not yet been specified [33]. Consequently, increased high frequency sway in condition 5 in our cases, which is equivalent to the vestibular sensory balance score, may be attributed to impaired somatosensory input in this condition since our cases showed AP and ML vestibular scores comparable to controls. These findings are also supported by the considerable decline in the somatosensory score in PD patients as opposed to control subjects. This decrease of the somatosensory input may be attributed to the medication since our patients were tested in their (On) state.

Resembling our results, a study by D'Andréa Greve et al. [34] also reported significantly higher AP sway compared to the ML in PD patients in the "on" state. Greater AP sway may be accounted for by the PD-induced postural deficits, due to over activation of trunk flexor muscles and anterior relocation of the center of gravity. Conversely, Mitchell et al. [35] recognized an increased sway range in the mediolateral direction alone.

PD patients had more deterioration of global sensory score with increased durations of disease and treatment. The increased duration of treatment with levodopa could impair somatosensation of patients and induce dyskinesia leading [29, 36, 37] to increased global SOT. In contrast to our results, one study found no correlation between global SOT with neither duration of disease nor that of treatment [13].

Conclusions

Parkinson's disease patients tend to sway more compared to controls in all test conditions of SOT. AP sway is higher compared to ML. These results might provide a better understanding of pathological mechanisms of balance deficits in PD and thus help planning suitable rehabilitative therapies for PD patients.

Abbreviations

AP: Antero-posterior; CDP: Computerized dynamic posturography; CNS: Central nervous system; CoP: Center of pressure; CT : Computerized tomography; cVEMPs: Cervical vestibular evoked myogenic potentials; EC: Eyes closed; EO: Eyes open; FFT: Fast Fourier transform; FOG: Freezing of gait; LoS: Limits of stability; MEG: Magnetoencephalography; ML: Medio-lateral; MRI: Magnetic resonance imaging; PD: Parkinson's disease; SOT: Sensory organization test; SPS: Synapsys Posturography System; VE: Vision erroneous

Acknowledgements

Not applicable

Authors' contributions

ME and NMIMN have participated in data acquisition and interpretations and drafting of the manuscript. MAMT, AE and ME diagnosed the cases and made the concept and design of the work and made major contributor in writing the manuscript. NMIMN and ME participated in the analysis of data and interpretation of the results. ME was a major contributor in writing the manuscript and made intelligible revision of the text. The authors read and approved the final manuscript.

Funding

None.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The current research was approved by the Institutional Ethical Committee of the Faculty of Medicine, Alexandria University (EC Ref No: 0105400). Also, written informed consents were obtained from all patients to participate in the research.

Consent for publication

Written informed consents for publication were obtained from all patients.

Competing interests

The authors declare that they have no competing interests.

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Received: 13 November 2020 Accepted: 10 June 2021
Published online: 21 August 2021

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