Analysis of Dynamic Balance during Walking in Patients with Parkinson's Disease & Able-Bodied Elderly People

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ABSTRACT

Purpose: Walking pattern in patients with Parkinson's disease (PD) is abnormal, and dynamic balance of these patients is not clear yet. The objective of this study was to analyze the dynamic balance of patients with PD during walking and comparing it with normal elderly individuals.

Methods: This is an Ex-post - facto research study design. Twelve male patients with PD (mean age: 64.0±7.8 y; mean height: 165.0±7.0 cm; mean mass: 65.3±10.3 kg; and mean BMI: 24.1±3.6 kg/m^2) and 12 healthy male subjects as the peer group with matched age, height, weight, and BMI participated in this study. All subjects were chosen using convenience sampling method. Vicon motion analysis system was used to analyze temporal variables and center of mass (COM) displacement of the subjects during walking. Data were analyzed in SPSS-19 using independent t test with $P<0.05$.

Results: Stride length and walking speed was significantly smaller in patients with PD than that in peer group ($P<0.05$). Mediolateral displacement of COM was not different between the two groups ($P>0.05$). However, posterioanterior and vertical displacements of COM were significantly smaller in patients with PD.

Conclusion: Stride length, walking speed, as well as the posterioanterior and vertical displacement of COM in patients with PD were lower than those variables in normal subjects. These changes might be considered as a compensatory response of neuromuscular system to the affected dynamic postural control in these patients.

1. Introduction

Parkinson's disease (PD) results from degeneration of the brain cells and reduction in dopamine enzyme [1]. Almost 1% of the population over 60 years is affected [2]. Loss of dopamine in PD causes neuromuscular system disorders such as tremor, slow movement [2], poor static and dynamic stability, weak postural control [3], low fine motor function, and gait disorders. Walking is the most important daily activity, so its impairment affects the patient's life. Therefore, identifying abnormalities of the gait in PD is clinically important. Previous studies have shown that patients with PD compare to normal individuals walk slowly [4, 5] and have shorter steps [5], smaller cadence [4], freezing [6], smaller range of motion of lower limb joints [4], swing drag [7], instability during walking [8], greater stance phase [13], and more falling rate [5].

However, most of these studies have only examined the kinematics of gait such as gait initiation [9], gait termination [10], crossing the obstacles [7], change direction [11], and walking with cognitive dual task [12]. In patients with PD, the abnormal walking pattern, comprising the reduced step length, lower speed, unusual foot

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clearance, and increased stance phase [13] is associated with walking instability and higher falling risk [14]. Each year, more than 68% of patients with Parkinson fall [14] and more than half of them fall twice a year. Falling in these patients is associated with the risk of bone fracture. The related health care costs are very high. Therefore, understanding the mechanism of the gait abnormality in patients with PD has clinical importance and may help plan a more effective rehabilitation and falling prevention program.

Walking stability is defined as the ability to keep the body center of mass (COM) as close as possible to the midline of the walking [15]. Evaluating the stability during walking can be used to determine the risk of falling [18, 19]. Some researchers postulated that with aging, decrease in muscle strength and endurance will result in postural instability and increased falling risk [20]. It is shown that there is a positive correlation between the strength of knee extensors and dynamic stability performance. In progressed Parkinson's disease the knee extensor muscles are severely weakened [14]. It has been shown that COM-COP (Center of Mass-Center of Pressure) difference is the dynamic stability control index. This index in young people is higher than that in patients with PD and those with vestibular disorder [21, 22].

Failure to maintain the stability in patients with PD have been studied not only in static stability but also during transition of static to dynamic stability such as gait initiation, termination, and change direction [23, 24]. Martin and colleagues reported that patients with PD have smaller COM-COP difference compared to healthy peers during gait initiation [25]. Hahn and Chou mentioned that a little difference between COM-COP was attributed to decrease in muscle strength [26]. Davis et al. found a significant positive correlation between leg strength and anterioposterior stability. They mentioned that strength of muscle determines that at what distance COM can be placed in front of the Base of Support (BOS) [27].

Parkinson's disease also affects gait termination. During gait termination, patients with PD show lower dynamic stability in anterioposterior plane. They extend their step width in gait termination in order to increase their stability in mediolateral plane [28].

Little is known about posture and stability problems of patients with PD during standing [29-32], gait initiation [21], and termination as well as in turning [28]. Although previous research has confirmed that poor stability, walking impairments, and increased falling rate exist in patients with PD, the mechanism of these abnormalities is unknown. It is unclear whether a short step and reduced walking speed in these patients are kind of neuromuscular adaptation to compensate the poor stability.

The purpose of this study was to evaluate the spatiotemporal variables and COM path of the patients with PD compared to healthy subjects. The hypotheses were as follows: a) the kinematics gait pattern (spatiotemporal variables) in patients with PD is different from healthy subjects and b) translocation of COM in patients with PD is more than that in peer subjects.

2. Materials & Methods

A group of 12 healthy individuals with the mean age, height, and mass of 61.7±8.0 year, 166±7.0 cm, and 70.3±10.3 kg, respectively were selected as peer group. Also, a group of 12 patients with PD with matched age, height, and mass were selected as the Parkinson group.

Patients with PD were diagnosed based on the mentioned criteria and referred to the researchers by a neurologist from Hamedan Neurological Disease Center.

The main inclusion criteria for the subjects were having PD of level II and III based on Hoehen and Yahr scale [16] and being able to walk independently. Subjects would be excluded if they had musculoskeletal disorders, history of major surgery, or auditory problems.

Ethical approval was received from Ethics Committee of Hamedan University of Medical Sciences, Hamedan. Written informed consent was obtained from each subject before data collection.

Instruments

Vicon Motion Analysis system with 4 cameras (100 Hz) and 2 Kistler force plates were used to record the motions of the segments and reaction forces during gait assessment. A low pass filter (Butterworth) was used to filter the kinematic data with a cut off frequency of 10 Hz. Measurement error of the kinematic evaluations was about 0.2 mm.

Using Vicon motion analysis system, the interclass correlation coefficient for 10 gait repetitions was 0.9. Cameras were placed on both sides of a walkway at a distance of 5 m from the center of the calibrated space.

The walkway path along the laboratory was 18 m. Calibration space dimensions were 300*150*200mm (length, width, and height, respectively). Participants

walk 7 m before entering the calibrated space. The calibration frame length allowed full left and right strides to be placed in the calibrated frame.

Sixteen 14-mm diameter markers were placed on left and right superior anterior iliac spine, superior posterior iliac spine, thigh, lateral condyle of the knee, shank, lateral malleoli, heel, and second distal metatarsal. The markers reflected the infrared light toward the cameras. All markers were placed according to Plug-in-Gait protocol [34].

After calibrating the cameras, the anthropometric data, including weight, height, leg length, knee and ankle width, and the distance of left and right anterior superior iliac spine were recorded in the Nexus software. These data are necessary for kinetics and kinematics analyses.

The subjects were asked to walk with a comfortable speed to accomplish 5 successful trials. The mean values of 5 trials were used for each parameter. Image markers during walking with force plate data were recorded.

Dynamic stability was recorded by tracking the movement of the COM during walking. COM position was calculated from the force components of the force plate [37]. In order to normalize data, the movements of COM in mediolateral and vertical planes were divided by the Base of Support (BOS) width and leg length, respectively. Internal distance between left and right lateral malleoli was defined as the width of the BOS. The vertical distance between hip joint and ground was defined as the leg length (Figure 1).

The main parameters for dynamic stability in this study were as follows:

Figure 1. Step width and leg length during gait.

1) Vertical displacement of COM that was normalized to leg length,

2) Mediolateral displacement of COM that was normalized to width of BOS,

Table 1. The mean values of anthropometric data of the Parkinson and peer groups.

	Peer group	Parkinson group	P value
Variable	Mean±SD	Mean±SD	
Age (y)	61.7±8.0	64.0±7.8	0.37
Height (m)	166±7.0	165±7.0	0.72
Weight (kg)	70.3±10.3	65.3±10.3	0.19
BMI (kg/m^2)	25.6±3.1	24.08±3.55	0.22
Leg length (cm)	88.7±5.9	87.5±4.9	0.16
Step width (cm)	22.0±2.0	22.0±3.0	0.94
Pelvis width (cm)	29.8±2.2	29.9±1.5	0.83
foot length (cm)	25.5±1.5	25.1±2.4	0.63

Table 2. The mean values of spatiotemporal variables in peer group and patients with PD.

	Spatiotemporal variables	Peer group	Parkinson group	Sig.
Right	Cadence (step per min)	104.1±13.3	99.4±21.5	0.46
	Stride length (m)	1.3±0.1	0.3±0.1	0.00*
	Walking speed (m/s)	1.1±0.2	0.8±0.3	0.01*
Left	Cadence (step per min)	104.1±14.2	99.8±22.1	0.52
	Stride length (m)	1.27±0.1	0.3±0.1	0.00*
	Walking speed (m/s)	1.1±0.2	0.32±0.8	0.00*

* Shows significant difference.

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3) Spatiotemporal gait parameters including walking speed, stride length, and cadence.

Using Nexus 3.2.1 software, the data were extracted. Shapiro-Wilk test was used to test the normality distribution of data. The difference between the mean values of each parameter of normal group and the patients was evaluated by independent T-test for 2 groups with significant value of<0.05.

3. Results

Table 1 shows the anthropometric characteristics of the subjects participated in this study. Independent T-test for 2 group shows that there were no significant differences between the Parkinson and peer groups with regard to anthropometric variables (Table 1).

The mean values of spatiotemporal gait parameters of normal and the patients with PD are shown in Table 2. As it can be seen, there was no difference between the left and right cadence of normal subjects and those with PD (P>0.05). Walking speed was significantly lower in patients with PD than that in the normal group for both the right (P<0.001) and left (P=0.01) legs. The length of left (0.26 m) and right (0.3 m) strides in patients with PD were lower than those strides in peer group (P<0.05).

Table 3 shows the mean values of dynamic stability of normal people versus the patients with PD during walking. The displacement of COM in mediolateral plan in patients with PD was 0.6 cm, which was significantly larger than that in the peer group (P<0.05). The mean values of the displacement of COM in anterioposterior plane in normal group was 100.9±3.0 cm, which is 24.1 cm greater than that in the patients with PD (P=0.02). There was not any significant difference between the Parkinson and peer groups with regard to the mediolateral plane displacement of COM (P>0.05). The mean value of vertical displacement of COM (normalized to leg length) in peer group was 0.04±0.01 cm, while this value was 0.03±0.01 cm in Parkinson group (P<0.05).

4. Discussion

Stability is the ability of a subject to keep the body in a stable position and to return it from an unstable position to a stable one [15, 40, 41]. Despite many studies performed on posture analysis in patients with PD, the dynamic stability of these patients during walking has not been well addressed. The authors of present study did not find any similar study in the available literature. There are various parameters used to assess dynamic stability, the most widely-used parameters are displacement of the COM about the BOS, vertical displacement of the COM, and walking speed [38, 39].

Table 3. The displacement of the COM in the Parkinson and peer groups.

Variables	Peer group	Parkinson group	Sig.
M/L (cm)	5.5±1.3	6.1±1.4	0.31
A/P (cm)	100.9±30.0	76.8±20.0	0.02*
Z (cm)	3.8±0.6	2.7±1.0	0.02*
M/L (cm)	0.25±0.1	0.28±0.1	0.23
Z (cm)	0.04±0.01	0.03±0.01	0.00*

M/L: Mediolateral, A/P: Anterioposterior, Z; vertical.
*Shows significant differences.

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The results showed that walking speed and stride length are significantly smaller in patients with PD than those in peer group. Most of the patients with neuromuscular disorders reduce their walking speed in order to improve stability. During walking, patients with PD decrease their speed and rise double support [42] to increase the time needed for stabilization and consequently to improve their walking stability. The result of this study is consistent with the results obtained by Morris and associates [3].

In the peer group, vertical displacement of COM, both in terms of not normalized and normalized to leg length, was significantly higher in patients with PD ($P<0.05$). Vertical displacement of COM is considered an advantage for walking stability [43]. During walking, COM of the body acts as an inverted pendulum. In the first half of the stance phase, it moves upward, and in the second half it moves downward [43]. With increasing the height of the COM, potential energy is made, and by dropping the COM, this potential energy is converted into kinetic energy. Quadriceps and gluteus maximus muscles decelerate the COM in the first half of the stance phase, while gastrocnemius and soleus muscles accelerate it in the second half of the stance phase of walking and pushing the COM forward and upward [44]. Perhaps one of the reasons for reducing the vertical displacement of COM is walking with short step and flexed posture.

In patients with PD, using flatfoot pattern instead of heel contact pattern during initial contact results in an incomplete push off in the terminal stance phase of walking. The muscle weakness and the low activity of hip and knee extensors and ankle plantar flexors in patients with PD are associated with smaller propulsion force in walking. This might explain the smaller amount of upward displacement of COM. There were no significant differences between two groups regarding both normalized and not normalized displacement of the COM (Table 3) ($P>0.05$). Step width was similar in both groups [48], as the width of the BOS might be wide enough to stabilize patients with PD in frontal plane.

Some researchers have shown that patients with PD have a poor stability in mediolateral plane. And the cause has been attributed to the decrease in the BOS in mediolateral plane. Other researchers have shown that in gait initiation, the differences between COM-COP in patients with PD are less than that of healthy peers [29-32]. In patients with PD, lowering the difference between COM-COP reduces the movement arm of body weight force; therefore, less muscle activity is required for the postural control. As a result, patients with PD use this strategy during gait to compensate the muscle weakness. In this study, the stability of patients in mediolateral plane was normal.

Walking speed is an important variable to measure dynamic stability, so faster walking needs higher dynamic stability [38, 39]. If walking speed is constant, reducing the displacement of COM increases the dynamic stability during walking. Anterioposterior and vertical displacements of the COM have decreased in patients with PD. Reduction in displacement of the COM in various directions is associated with the decrease in walking speed showing the decrease in the dynamic stability during walking.

Disorders of the CNS and the lack of accurate sensory inputs in patients with PD [50, 51] may lead to the destruction of motor unit action and increased stiffness in the ankle [52], knee [48], thigh, and trunk joints [53]. In addition, stiffness in patients with PD [53] and decreased joints' range of motion and the smaller fluctuation of the body's COM reduces the ability to adopt with the environment during walking.

The limitations of this study are the small sample size, uncertainty of the information about the drug consumption, and the general health situation of the patients. Therefore, we recommend that this study is conducted with higher number of subjects under various postures and balance tests.

Dynamic stability of patients with PD is impaired. Vertical and anterioposterior displacements of COM and walking speed in them are significantly smaller than those parameters in the peer group ($P<0.05$). Reduced vertical and anterioposterior displacements of COM as well as walking speed decrease the dynamic stability of walking in patients with PD.

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