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TANAFFOS

Postural Balance Evaluation in Patients with Chronic Obstructive Pulmonary Disease

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Background: The risk of falling in patients with chronic obstructive pulmonary disease (COPD) is higher than healthy people, imposing a great financial burden on patients due to clinical diagnosis and treatment. This study aimed to compare static balance between two groups of healthy people and COPD patients, based on cognitive tasks and vision tests, using linear and non-linear analyses.

Materials and Methods: A total of 15 patients with COPD and 14 age- and gender-matched healthy individuals were recruited in this study. Variations in the center of pressure were recorded in both medial-lateral (ML) and anterior-posterior (AP) directions by implementing visual feedback and cognitive tasks, with the subject standing on a force plate. Data related to the center of pressure were analyzed in the AP and ML directions by linear methods (i.e., standard deviation of displacement, standard deviation of maximum velocity, average velocity, and phase plane). Also, the nonlinear method (Lyapunov exponents) was used in both directions.

Results: The cognitive tasks improved the center of pressure variables in both groups. In association with the vision tests, only lack of vision had a significant effect on the patients. The results of the linear analysis in the ML direction were significantly higher in the COPD group as compared to the healthy group; however, the results were not significant in the AP direction. Also, the non-linear analysis showed significant differences between the groups.

Conclusion: Use of both linear and non-linear analyses is necessary for evaluating the balance of patients with breathing difficulties. Balance disorders in COPD patients were mostly in the ML direction; therefore, postural deformities might be one of the reasons for balance problems in the AP direction.

Key words: COPD, Linear analysis, Center of pressure, Postural balance

INTRODUCTION

The increased prevalence of respiratory disorders due to factors, such as aging, increased prevalence of smoking, and increased levels of pollutants, microorganisms, and toxins in the environment, can result in chronic obstructive pulmonary disease (COPD), which is one of the main causes of mortality. COPD is expected to be the third most common cause of mortality and the fifth leading cause of disability around the world (1). According to the World Health Organization (WHO) reports, approximately 330 million people are suffering from COPD worldwide, and it is estimated that about 65 million people present with a severe form of COPD (2). In Iran, studies have reported the high prevalence of this disease, ranging from 9.3% to 14.13% (3).

COPD is characterized by its progressive pathophysiology in various body systems, including the respiratory, musculoskeletal, neurosensory, cardiovascular, and vascular systems; it is also known to have psychological manifestations (4, 5). Consequently, this disease may be associated with physical activity limitations. Due to anatomical variations in the lungs and diaphragm of COPD patients, the respiratory capacity is reduced, and fatigue results in decreased physical activity (6). On the other hand, inactivity commonly leads to muscular atrophy and weakness, reduced strength, and increased fatigue in skeletal muscles, resulting in functional impairments (7). Respiratory dysfunction sometimes affects the upper torso and pelvis in form of hyperkyphosis and increased posterior pelvic tilt, which may explain the imbalance in the patients' daily activities (8).

Beauchamp et al. by comparing COPD patients with healthy individuals using an isokinetic dynamometer, found that an increase in balance disorders and musculoskeletal weakness resulted from an increase in the severity of respiratory disease (9). Also, in a study by Smith et al., balance assessments, based on the center of pressure displacement and force plate data, showed that the medial-lateral (ML) displacement of the center of pressure and the hip-joint angle were higher in COPD patients than healthy individuals, which might result in a balance disorder in these patients (10).

Moreover, Janssens et al. studied balance in COPD patients to introduce suitable balance control strategies. In their study, a pressure transducer was used at different levels after removing visual feedback and using wrist and back muscle vibrations for the relative evaluation of different proprioceptive signals. Their results indicated that patients with respiratory muscle weakness were more likely to rely on the ankle sensory feedback, while their reliance on the feedback of back muscles decreased, as compared to the healthy control group. They concluded that these changes may be due to impaired respiratory muscle mobility rather than trunk instability (11).

Considering the importance of balance disorders in COPD patients, further research is needed in this area. The nonlinear analysis, which is a more advanced form of linear analysis, presents the degree of adaptability to the environment as a measure of the individual's equilibrium by examining the repeated behavior of a recorded signal, such as the center of pressure (12). Unlike the linear analysis, which is performed in two dimensions, in the nonlinear analysis, each segment of the signal is compared with all of its similar segments along the signal. Therefore, the nonlinear analysis should be performed in the n-dimensional space (13).

In this regard, Asgari et al. showed that the Lyapunov exponent, as a nonlinear index, can represent balance differences between healthy and injured individuals (14). Therefore, the present study aimed to compare static balance between two groups of healthy individuals and COPD patients, with and without cognitive and visual impairments, through linear and nonlinear analyses of the center of pressure data in the ML and anterior-posterior (AP) directions. To the best of our knowledge, there is no research comparing these two types of analysis in patients with COPD.

MATERIALS AND METHODS

Participants

The study population consisted of 29 men, including 15 men in the COPD group with a history of fall over the last two years and 14 men in the healthy control group. All participants were in the age range of 50-65 years with a body mass index (BMI) of 20-28 kg/m^2. The COPD patients were selected by a physician and were introduced to the research team after measuring the forced expiratory volume in one second (FEV1) (15). These patients had experienced respiratory disorders in the past two years and received medical treatments; however, they were not receiving rehabilitation care during the study period.

The inclusion criteria were as follows: being a non-smoker; lack of need for oxygen capsules during the test or simple daily activities; no history of surgery in the spine, chest, pelvis, or lower limb joints; no history of pelvic floor muscle dysfunction (e.g., urinary incontinence); and no pelvic fractures or dislocations. On the other hand, the exclusion criteria were the subject's unwillingness to continue the study at any point and the presence of factors that could affect the test outcomes. All participants signed an informed consent form before participation in the study. This study was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Table 1. Specifications of participants in the research

	Age(Year)	BMI(kg/m2)
Healthy group	57.2 ± 7.1	25.1± 1.2
COPD group	59.3 ± 3.7	26.6± 0.5
p-value	0.819	0.62

COPD: chronic obstructive pulmonary disease

Data collection method

First, the patients' demographic information (i.e., age, sex, height, weight, marital status, occupation, dominant hand and foot, duration of disease, and history of balance difficulties and falls) was collected. The subjects were instructed to immediately discontinue the test in case of a problem and notify the examiner. The presence of a breathing capsule and an experienced expert for therapeutic care was essential in this study. A Bertec Force Plate (series 9090, Columbus, Ohio, USA) was used to collect the center of pressure data; the data frequency was set at 100 Hz.

In the first step, to evaluate the patient's balance, he was asked to stand on the force plate for 35 seconds with eyes open and look ahead so that the center of pressure data could be recorded as the equilibrium indices; this process was also repeated with eyes closed. Also, as the cognitive task, the subjects were asked to count from 0 to 100 and vice versa with eyes both open and closed; the tests took about 35 seconds. Since some subjects started counting from an unusual number due to their old age, they were faced with a difficult, if not an impossible challenge to continue the test. Therefore, the subjects were asked to count in steps of five (5, 10, 15, etc.) to create a normal situation for all patients. During the test, the subject was only engaged in a single cognitive task, and there was no auditory or visual feedback by the examiner. Any manual or verbal reactions (involving talking or deep breathing) by the subjects led to the loss of balance, and as a result, the test was repeated.

Data analysis

The force plate data were analyzed linearly in both AP and ML directions. The outcome measures of the center of pressure in the AP and ML directions included the standard deviation (SD) of displacement, SD of maximum velocity, average velocity, and phase plane (space) portrait. The mathematical terms related to linear parameters are presented in Table 2. Due to the presence of noise in the center of pressure data, the relevant data had to be filtered. This filtering is considered a challenge in linear analyses, because if the cut-off frequency, which is one of the important factors in filtration, is not properly selected, more frequencies may be filtered out. Therefore, we may lose part of the time series behavior. Also, filtration may not be properly performed, and there may be noise-related frequencies in the system, making the analyses inaccurate. For this purpose, the exact frequency of interruptions needed to be determined first.

A spectral analysis method, which determines the signal energy in terms of frequency, was used to indicate whether the maximum signal energy is within the frequency range so that data outside this range (considered as noise due to very low energy) could be filtered. According to the spectral analysis, the fast Fourier transform (FFT) function was used to convert the signals to the frequency domain. Next, the signal strength was measured, and the Butterworth filter was applied twice on the signal. The test duration was 34 seconds. However, the first three seconds were not reliable, because the transition period to reach a stable status was deleted; the last one second was also omitted due to the effect of the sampler stop command. All data were collected using NEXUS software (Vicon Co., USA) and analyzed in MATLAB software by entering the formulae shown in Table 2 (16).

Table 2. Linear dependent variables and mathematical relations related to their calculation (16).

Standard deviation of anterior posterior COP displacement (mm)	$\sigma_x = \sqrt{\frac{\sum \sigma_y \equiv \sqrt{\frac{\sum(y_i-\bar{y})^2}{1 \setminus 1-1}}(x_{i-\bar{x}})^2}{N-1}}$
Standard deviation of medial lateral COP displacement (mm)	$\sigma_y = \sqrt{\frac{\sum(y_i-\bar{y})^2}{N-1}}$
Standard deviation of anterior posterior velocity (mm/s)	$\sigma_{v_x} = \sqrt{\frac{\sum\left(v_{x_i}-\bar{v}\right)^2}{N-1}}$
where in	$v_{x_i} = \frac{x_{(i+1)}-x_i}{t_{(i+1)}-t_i}$
Standard deviation of medial lateral velocity (mm/s)	$\sigma_{v_y} = \sqrt{\frac{\sum\left(v_{y_i}-\bar{V}\right)^2}{\mathrm{N}-1}}$
Where in	$v_{y_i} = \frac{y_{(i+1)}-y_i}{t_{(i+1)}-t_i}$
Mean velocity(mm/s)	$\bar{v} = \frac{1}{T}\sum_{i=1}^{T}\sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)2}$
Anterior posterior phase plane portrait	$\sigma_{rx} = \sqrt{\sigma_x^2+\sigma_{Vy}^2}$
Medial lateral phase plane portrait	$\sigma_{ry} = \sqrt{\sigma_y^2+\sigma_{Vy}^2}$
Total phase plane portrait	$\sigma_r = \sqrt{\sigma_{rx}^2+\sigma_{ry}^2}$

Lyapunov exponents

The center of pressure data were determined by the Lyapunov components, including the short and long Lyapunov components, so that the movement paths drawn in the phase space were closer together. The number of Lyapunov components was more negative and consequently more stable; therefore, the paths drawn in the phase space reached closer to their cycle or boundary point, and vice versa. Overall, the phase plane is the space in which all possible states are represented for a dynamic system. For plotting the paths of a dynamic system in a phase space, two parameters of dimension (m) and time delay (τ) are required to estimate these parameters in two conventional methods, namely, embedding dimension and average mutual information (17, 18). After the phase space was reconstructed according to the force plate time series using the nearest neighbors algorithm, the point $X_{\bar{\iota}}$ was obtained by searching through all points to minimize the distance by the reference point $X_{\bar{\iota}}$. This process is shown in Formula 1:

$$d_i(0) = \min_{x_{\bar{\iota}}}\|x_{\bar{\iota}} - X_{\bar{\iota}}\|$$

After measuring Formula 1, Formula 2 of the Lyapunov function was measured for each sample:

$$y_{(i)} = \frac{1}{\Delta t}\cdot\left(I_n, d_i(i)\right) = (\lambda)i + C$$

After the Lyapunov function was plotted for the sample (i), the function slope was obtained at the peak, that is, the short exponentλ_S. After the peak period was over, the slope of the area (where the Lyapunov function variations are almost constant) was called the long Lyapunov exponent λ_L (19). In this regard, Asgari at al. showed that the short Lyapunov exponent had a greater accuracy for measuring postural stability (14). Therefore, only this criterion was reported in the present study.

Statistical analysis

SPSS version 25 was used for all statistical analyses. First, the normal distribution of data was examined by Kolmogorov-Smirnov (K-S) test. To evaluate the effects of group (healthy and COPD), cognitive load (with and without cognitive load), and vision (open and closed eyes) on eight dependent variables (shown in Table 2), three-factors repeated measures analysis of variance (mixed model ANOVA) was used. P-value <0.05 was considered significant.

RESULTS

The results of K-S test indicated that the data distribution was normal. No significant difference (P>0.05) was found in BMI or age between the two groups (Table 1). Table 3 and Table 4 show the results of statistical analysis for the comparison of postural performance between the healthy and COPD groups. As shown in Table 3, the values of linear variables in the ML direction were higher in COPD patients as compared to healthy individuals.

According to Table 4, the effects of the independent variable on the SD of center of pressure displacement and SD of velocity were significant in the ML direction in COPD patients, as compared to the healthy group, although no significant difference was found in the AP direction (P=0.212 and P=0.784, respectively). The effect of vision on the phase plane in the ML direction was in contrast to the AP direction (P=0.14). The effects of cognitive load on the mean velocity and phase velocity were also significant in both ML and AP directions (P<0.05). However, none of the two- or three-factor conditions, resulting from the interactions of independent variables, were statistically significant (P>0.05).

The results presented in Table 5 and Table 6 are related to the nonlinear analysis. The only significant effect of group was found on the Lyapunov exponent[5] in both AP and ML directions (P<0.05). However, the cognitive and visual tasks, as well as their two- and three-factor interactions, showed no significant differences (P>0.05).

Table 3. Mean values and standard deviation, "Mean (SD)" for dependent variables in 4 tests for linear parameters

Independent variable		Dependent variable	σ_{ML} (SD)	σ_{AP} (SD)	σ_{VML}(SD)	σ_{VAP}(SD)	V_{mean} (SD)	$Phase_{ML}$ (SD)	$Phase_{AP}$ (SD)	$Phase_{total}$ (SD)
Without a cognitive task	Open eye	Healthy	2.16(0.92)	4.58(1.02)	10.6(6.3)	19.4(6.2)	19.5(1.3)	11.88(6.4)	19.6(9.4)	22.1(8.4)
		COPD	2.51(0.56)	4.07(0.95)	15.9(2.9)	16.9(4.3)	17.8(5.4)	12.1(2.9)	17.8(6.3)	23.3(6.6)
	Closed eye	Healthy	1.79(0.97)	3.13(0.78)	9.33(0.92)	13.7(2.9)	14.5(2.2)	9.54(1)	13.7(2.9)	17.1(2.7)
		COPD	2.85(0.92)	5.09(0.7)	14.4(2.5)	23.43(5.4)	25.5(5.4)	14.7(2.5)	25.9(6.4)	30.3(6.5)
With a cognitive task	Open eye	Healthy	2.96(0.53)	4.44(1.12)	21.53(9.6)	25.9(6.4)	26.7(2.58)	14.6(3.3)	22.3(9.6)	28.1(5.7)
		COPD	3.08(0.91)	4.87(0.91)	13.4(4.9)	24.12(3.3)	23.9(4.1)	14.1(5.7)	23.9(5)	33.4(13.1)
	Closed eye	Healthy	2.32(0.88)	6.34(1.61)	16.98(2.42)	16.7(5.1)	16.9(3.7)	11.2(2.4)	18.02(5.7)	21.3(6.02)
		COPD	3.35(0.75)	4.64(0.49)	15.72(5)	26.53(12.1)	26.6(10.6)	16.1(5)	26.9(12)	31.5(12.8)

Table 4. Results of statistical analysis for dependent variables in 4 tests for linear

Independent variable	σ_{ML}		σ_{AP}		σ_{VML}		σ_{VAP}		V_{mean}		$Phase_{ML}$ (SD)		$Phase_{AP}$ (SD)		$Phase_{total}$ (SD)	
	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P
Main effect																
cognitive	3.32	0.11	8.98	0.015	6.66	0.14	7.38	0.45	6.91	p<0.05*	6.64	p<0.05*	10.8	p<0.05*	9.92	0.81
vision	0.951	0.42	1.07	0.32	0.627	0.44	0.012	0.912	0.118	0.73	0.653	p<0.05*	0.953	0.41	0.728	0.35
group	0.97	P<0.05*	0.11	0.748	0.025	p<0.05*	0.154	0.212	0.83	0.87	0.026	0.87	2.21	0.171	0.496	0.48
Interaction																
Group×cognitive	0.65	0.44	0.611	0.45	1.37	0.02	0.388	0.549	6.37	0.08	1.35	0.33	0.766	0.404	1.507	0.251
vision×group	1.96	0.19	0.134	0.72	1.51	0.24	1.38	0.26	1.53	0.24	1.56	0.27	1.26	0.289	1.485	0.257
vision×cognitive	0.69	0.42	0.351	0.56	1.41	0.45	0.532	0.484	1.14	0.31	1.4	0.26	0.243	0.634	0.886	0.371
vision×group×cognitive	0.48	0.51	3.71	0.41	0.703	0.42	0.801	0.36	0.88	0.515	0.73	0.41	0.129	0.728	0.866	0.152

*p<0.05

Table 5. Mean values and standard deviation for dependent variables in 4 tests for Lyapunov exponent

Independent variable			Ly_{ML} (SD)	Ly_{AP} (SD)
Without a cognitive task	Open eye	Healthy	0.16(0.1)	0.09(0.04)
		COPD	0.24(0.3)	0.14(0.1)
	Closed eye	Healthy	0.15(0.3)	0.09(0.03)
		COPD	0.25(0.6)	0.16(0.1)
With a cognitive task	Open eye	Healthy	0.21(0.2)	0.17(0.08)
		COPD	0.27(0.2)	0.17(0.08)
	Closed eye	Healthy	0.2(0.1)	0.11(0.1)
		COPD	0.29(0.7)	0.19(0.2)

Table 6. Results of statistical analysis for dependent variables in 4 tests Lyapunov exponent

Independent variable	Ly_{ML}		Ly_{AP}	
	F	P	F	P
Main effect				
Cognitive	1.12	0.41	1.98	0.15
Vision	3.15	0.82	2.11	0.33
Group	0.51	p<0.05*	0.22	p<0.05*
Interaction				
Group×Cognitive	2.63	0.08	3.21	0.31
Vision×Group	2.45	0.34	1.42	0.38
Vision×Cognitive	1.28	0.88	1.93	0.66
Vision×Group× Cognitive	0.92	0.27	1.1	0.42

*p<0.05

DISCUSSION

This study aimed to determine and compare static stability, with and without cognitive tasks, in COPD patients and healthy people through linear and nonlinear analyses. The results of linear analysis showed that people with COPD were weaker than healthy individuals in maintaining their equilibrium in the ML direction. In this regard, Maki et al. showed that weakness, which is common in postural control in the ML direction, is considered as one of the major contributors to the increased risk of falls in the elderly (20). Based on the findings of the present study, in healthy individuals, closing the eyes, with and without cognitive tasks, significantly decreased the phase plane in the ML direction. The results of nonlinear analysis were also similar regarding the visual and mental effects, although the effect of group was significant in both AP and ML directions.

The results of the present study are consistent with a study by Smith et al. which showed that displacement of the center of pressure and hip joint angle in the ML direction were higher in COPD patients as compared to the healthy group (10). Generally, the presence of balance problems in the ML direction is considered as the main cause of falls (21). In patients with COPD, the center of pressure displacement seems to increase in the ML direction as a compensatory strategy due to muscular activity disorders (22). Although the ankle joint is effective due to its symmetrical structure and degree of freedom in the posterior position of the AP direction (ankle strategy), the ML control is more likely to occur by generating a torque required in the hip and trunk (hip strategy) (23, 24).

Patients with pulmonary diseases, due to their increased effort for respiration, need to activate their abdominal, lumbar, and diaphragm muscles more than normal individuals to improve respiratory failure (25, 26); this increases the stiffness of the trunk and prevents it from creating a proper balance. Moreover, it simultaneously increases the center of pressure displacement in the ML direction, thereby increasing the risk of falling (10). The results related to the Lyapunov exponent, which is a more advanced computational method than linear analysis, showed a significant difference between the two groups in the AP direction. Overall, the increase in the respiratory rate of healthy individuals causes disorders in the AP direction (27). Since COPD patients also develop hyperkyphosis and posterior pelvic tilt deformities (28), keeping balance in the AP direction may be challenging for them.

The present results also showed that lack of environmental information, such as vision, led to postural instability, resulting in mental stress and possibility an increased respiratory rate. Previous studies suggest that more difficult cognitive tasks can increase balance responses and consequently shift the center of pressure in both patient and healthy groups; this finding is in line with the results of the present study (9, 10, 29). A previous study on COPD patients showed that these patients are less capable of adapting and balancing in challenging situations. Moreover, Grant et al. showed that patients showed less balance as the difficulty of mental tasks increased (29).

According to a study by Beauchamp et al., patients showed poorer performance after the timed up and go test, which is a tool for balance evaluation (9). It seems that postural sway and muscle weakness increase when the entrance of air into the lungs during activities (e.g., walking, placement on a foam surface, or complex mental tasks) becomes harder. Also, the results showed the significance of changes in the phase plane under a cognitive load in both AP and ML directions (30). Moreover, Jacobi et al. found that patients with cerebellar disorders were more likely to be at risk of developing mental retardation while performing cognitive tasks (31).

In the present study, the effect of vision on the phase plane was significant in the ML direction. In other words, closing the eyes in the absence of a cognitive task increased postural sway in patients, which is in line with the results of a study by Chang et al. (32), indicating the negative effect of vision loss and balance disorder in the ML direction on COPD patients. However, in the presence of a cognitive load, visual impairment in the AP direction had no definite effects, whereas in the ML direction, the balance indices remained higher than the open-eye mode (33).

Fear of falls, which is common among the elderly (20), seems to be a serious problem in COPD patients; however, it can be improved by using long-term cognitive exercises (34). The present study indicated that mental load or immediate eye closure caused more anxiety in these patients due to the fear of postural balance loss. Therefore, long-term exercises for the balance improvement of these patients are recommended.

In the current study, besides investigating the simultaneous effects of vision and cognitive tasks on COPD patients, a new criterion was considered, which has not been previously examined in these patients. The measurement of the phase plane portrait helped us understand the significant effects of visual and cognitive tasks on the balance of patients. The cumulative metric of the mathematical phase represented the effect of displacement and the velocity of center of pressure (Table 2), suggesting the simultaneous effects of these variables. The mean velocity was also helpful in demonstrating the effects of cognitive tasks.

Although a mathematical criterion was used for analyzing the time series obtained from empirical tests, such as the center of pressure, linear indicators cannot simply illustrate the nature of a complex system, such as the human body's control system. Therefore, the use of nonlinear criteria, such as the Lyapunov exponent, can help us better understand the individual's balance status. In this study, the Lyapunov exponent could indicate the status of balance disorders in COPD patients as compared to healthy individuals, which was not possible in the linear analysis. However, the effects of vision and cognitive tasks were only determined by the linear analysis. Therefore, we suggest using both linear and nonlinear analyses in future studies on COPD patients.

The most significant limitation of this study was its small sample size. Further studies are needed to evaluate the effect of subgrouping based on different stages of COPD on postural stability. Also, the effects of smoking, drug abuse, percentage of expired oxygen, status of the heart's lower right chamber, and pulmonary artery pressure on postural control can be assessed in future studies.

CONCLUSION

In conclusion, by using linear measures of the center of pressure, such as phase plane, SD of displacement, SD of maximum velocity, and mean velocity, we can evaluate the static balance of COPD patients and determine the existence of postural balance disorders in the ML direction as compared to healthy individuals. Although cognitive tasks did not improve the patients' postural status, long-term mental exercises may help these patients overcome their fear of falling. Also, by using the nonlinear Lyapunov exponent criterion, we could detect the center of pressure disorders in the AP direction in these patients. Lack of vision could also increase the risk of falls in patients with COPD. Therefore, both linear and nonlinear computational methods are essential for a better understanding of postural balance in COPD patients.

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