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Diaphragmatic mobility: relationship with lung function, respiratory muscle strength, dyspnea, and physical activity in daily life in patients with COPD

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ABSTRACT

Objective: To evaluate diaphragmatic mobility in relation to lung function, respiratory muscle strength, dyspnea, and physical activity in daily life (PADL) in patients with COPD. **Methods:** We included 25 patients with COPD, classified according to the Global Initiative for Chronic Obstructive Lung Disease criteria, and 25 healthy individuals. For all of the participants, the following were **evaluated:** anthropometric variables, spirometric parameters, respiratory muscle strength, diaphragmatic mobility (by X-ray), PADL, and the perception of dyspnea. **Results:** In the COPD group, diaphragmatic mobility was found to correlate with lung function variables, inspiratory muscle strength, and the perception of dyspnea, whereas it did not correlate with expiratory muscle strength or PADL. **Conclusions:** In patients with COPD, diaphragmatic mobility seems to be associated with airway obstruction and lung hyperinflation, as well as with ventilatory capacity and the perception of dyspnea, although not with PADL.

Keywords: Pulmonary disease, chronic obstructive; Diaphragm; Spirometry; Dyspnea; Maximal respiratory pressures.

INTRODUCTION

Several studies have shown a decrease in diaphragmatic mobility (DM) in patients with COPD.[1-4] However, COPD also has significant extrapulmonary effects,[5] which result in systemic inflammation, loss of muscle mass,[6,7] malnutrition, depression,[8] physical deconditioning,[9] and, consequently, reduced health status.[10]

Despite significant systemic involvement in patients with COPD, few studies have investigated the relationship between DM and the systemic changes caused by COPD. However, the relationship of DM with the six-minute walk distance,[2,11] dyspnea,[2] and mortality[12] has previously been described.

Several studies have shown a relationship between DM and lung function changes.[3,11,13] Recently, Davachi et al.[11] found that DM was greater in patients classified as having mild COPD than in those classified as having very severe COPD. They also found that DM was related to FVC and slow VC (SVC). It has previously been shown that DM is associated with air trapping,[3,14,15] maximal voluntary ventilation (MVV),[3] and lung hyperinflation.[1] These results support the hypothesis that decreased DM is related to lung disease severity.

To date, no studies have investigated the relationship between DM and physical activity in daily life (PADL), and few have related DM to dyspnea and lung function.[2,3] Therefore, the primary objective of the present study was to evaluate DM in relation to lung function, dyspnea, and PADL in patients with COPD. A secondary objective was to compare COPD patients and healthy individuals in terms of lung function, respiratory muscle strength, and DM.

METHODS

This was a quantitative descriptive cross-sectional study. It was approved by the local human research ethics committee (Protocol no. CAEE 08871312.7.0000.0118). All participants gave written informed consent. The study sample consisted of 25 patients with COPD (14 males and 11 females) and 25 healthy individuals (5 males and 20 females). We included patients diagnosed with COPD in accordance with the 2015 Global Initiative for Chronic Obstructive Lung Disease criteria[9] and meeting the following criteria: 1) having no associated pulmonary, cardiovascular, or musculoskeletal diseases; 2) having participated in no training programs in the 6 months prior to the study; 3) requiring no oxygen therapy supplementation; and 4) being a nonsmoker. The criteria for inclusion of healthy individuals in the present study were as follows: 1) having normal pulmonary function test results (FEV_1/FVC ≥ 0.7; FEV_1 ≥ 80% of predicted; and FVC ≥ 80% of predicted); 2) being a nonsmoker; and 3) having no cardiorespiratory, hepatic, neurological, or oncologic diseases. The exclusion criteria were as follows: 1) being unable to perform any of the required tests (being unable to understand the instructions or being uncooperative);

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2) experiencing COPD exacerbation during the study period; 3) having cardiorespiratory or musculoskeletal complications during the tests; and 4) having a body mass index (BMI) > 30 kg/m^2 (i.e., being obese).

Spirometry and respiratory muscle strength

Spirometry was performed with a previously calibrated portable digital spirometer (EasyOne®; ndd Medical Technologies, Andover, MA, USA), in accordance with the methods and criteria recommended by the American Thoracic Society and the European Respiratory Society.[16] The following parameters were measured: FVC; FEV_1; FEV_1/FVC before and 15 min after inhalation of a bronchodilator (albuterol, 400 µg); and inspiratory capacity (IC). A minimum of three acceptable maneuvers and two reproducible maneuvers were performed; for IC, however, the average of three maneuvers was used, as reported by Miller et al.[16] All spirometric variables are expressed as absolute values and as a percentage of reference values, in accordance with Pereira et al.[17]

A digital manometer (MVD500®; Globalmed, Porto Alegre, Brazil) attached to a mouthpiece with an air outlet of 1 mm in diameter was used in order to measure inspiratory and expiratory muscle strength. MIP and MEP were measured as indicators of inspiratory and expiratory muscle strength, respectively, in accordance with the Brazilian Thoracic Association guidelines.[18] MIP was measured after a maximal expiratory maneuver (near RV), whereas MEP was measured after a maximal inspiratory maneuver (near TLC). A minimum of three acceptable maneuvers and two reproducible maneuvers were performed. The values of MIP and MEP are expressed as absolute values and as a percentage of reference values, in accordance with Neder et al.[19] The average of the reproducible maneuvers was used in the present study.

DM

Patients initially underwent familiarization with diaphragmatic breathing for diaphragmatic proprioception and maximal evaluation of diaphragm amplitude during radiographic examination. Patients were asked to perform two series of ten repetitions of diaphragmatic breathing, proprioceptive stimulation being provided by placing their hands on their chest and abdomen and verbal encouragement being provided in order to enable patients to direct the air toward the lung bases, in accordance with Leal.[20]

After having become familiar with diaphragmatic breathing, patients performed three SVC maneuvers using a Wright spirometer (Ferraris Medical Ltd., Hertford, England). SVC maneuvers were performed from TLC to RV and from RV to TLC. The highest value was recorded for comparison with the value obtained during the evaluation of DM, in order to determine whether patient respiratory effort was the same before and during DM evaluation.

After having become familiar with the diaphragm and having performed all SVC maneuvers, patients underwent DM evaluation by anteroposterior chest X-rays, which were taken with patients lying supine on a fluoroscopy table. A radiopaque ruler was placed longitudinally under the trunk in the craniocaudal direction, near the thoracoabdominal junction, for subsequent correction of the magnification caused by the divergence of the X-rays. The same film was used for all examinations, which were performed during a maximal inspiratory maneuver and a maximal expiratory maneuver.

DM was measured by the method of Saltiel et al.[21]: a straight line was drawn from the highest point of the hemidiaphragm during exhalation to the hemidiaphragm during inhalation with the use of a 150-mm digital caliper (Messen; Sensor Technology Co., Guangdong, China; Figure 1).

Dyspnea

Dyspnea was measured with the modified Medical Research Council dyspnea scale,[22] the degree of dyspnea ranging from 0 (no dyspnea) to 4 (very severe dyspnea). Patients were instructed to select the number that best represented their perception of dyspnea.

PADL

PADL was evaluated with a triaxial accelerometer (DynaPort activity monitor; McRoberts, The Hague, the Netherlands), which is a small, lightweight device worn on a belt around the waist. It can distinguish among activities such as sitting, reclining, and walking, and it measures the time spent in each activity.[23] Patients were monitored 12 h per day for two consecutive days, patient monitoring beginning immediately after waking. Patients were subsequently classified as active (on the basis of the time spent walking) or sedentary (on the basis of the time spent sitting or lying down), the average of the two days being used for analysis. Patients were instructed on how to position the device and received a manual with clear instructions and explanatory illustrations. In addition, they were asked not to change their daily activities while wearing the device.

Sample size calculation

The power of the sample, which consisted of 25 patients, was calculated post hoc with the free statistical software program G*Power, version 3.1.9.2.

Statistics

All statistical analyses were performed with the IBM SPSS Statistics software package, version 20.0 (IBM Corporation, Armonk, NY, USA), descriptive (mean and standard deviation) and inferential statistics being used. Data normality was verified with the Shapiro-Wilk test. Either a parametric test or a nonparametric test was used depending on the data distribution. The independent sample t-test and the Mann-Whitney U test were used in order to determine the difference between the two groups. In order to evaluate the correlation of DM with BMI, FEV_1/FVC, FEV_1, FVC, IC, MVV, MIP, MEP, perception

of dyspnea, and PADL, Pearson's and Spearman's correlation coefficients were used for parametric and nonparametric variables, respectively. The magnitude of the correlations was described in accordance with Dancey and Reidy,[24] values of r = 0.10-0.39 indicating a weak correlation, value of r = 0.40-0.69 indicating a moderate correlation, and values of r = 0.70-1.00 indicating a strong correlation. The level of significance was set at 5% ($p < 0.05$) for all tests.

RESULTS

A total of 25 COPD patients and 25 healthy individuals who did not differ in terms of age, weight, or respiratory muscle strength participated in the present study. Although the individuals in the control group were classified as being overweight and those in the COPD group were classified as being normal weight,[25] there was no statistically significant difference between the two groups regarding the BMI. There were differences between the two groups regarding height, FEV_1/FVC, FEV_1, FVC, and DM. The results for the two groups are presented in Table 1.

The coefficients of determination for DM and the study variables in the COPD group are presented in Table 2. For a significance level of 5%, the following powers were found: 0.96 for FEV_1/FVC; 0.95 for FEV_1; 0.84 for FVC; 0.99 for IC; 0.99 for MVV; 0.95 for MIP; and 0.73 for the perception of dyspnea. Given that neither MEP nor PADL correlated with DM, neither variable was used.

In the COPD group, DM correlated moderately with lung function, inspiratory muscle strength, and the perception of dyspnea. In addition, it correlated strongly with MVV and IC. In the control group, DM did not correlate with any of the lung function or respiratory muscle strength variables (Table 2).

DISCUSSION

In the present study, DM was found to correlate moderately with FEV_1 and strongly with IC in COPD

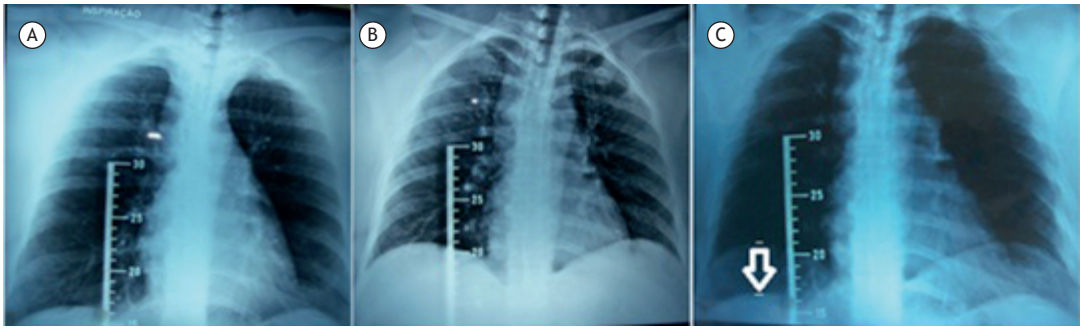

Figure 1. Anteroposterior chest X-rays. In A, chest X-ray taken during a maximal expiratory maneuver; in B, chest X-ray taken during a maximal inspiratory maneuver; and in C, superimposition of the two aforementioned images, the image of the radiographic ruler being used as reference to assess diaphragmatic mobility.

Table 1. Anthropometric, spirometric, and functional characteristics of the groups studied.

Variable	Control	COPD	p
Age, years	64.68 ± 6.63	67.56 ± 9.21	0.21
Height, m	1.59 ± 0.11	1.66 ± 0.08	0.01
Weight, kg	64.86 ± 9.85	68.38 ± 11.58	0.25
BMI, kg/m^2	25.13 ± 2.81	24.64 ± 3.08	0.52
FEV_1/FVC	0.79 ± 0.06	0.54 ± 0.12	0.001
FVC, % predicted	99.96 ± 13.95	71.84 ± 17.08	0.001
FEV_1, % predicted	98.20 ± 12.39	53.88 ± 21.62	0.001
IC, L	-	2.16 ± 0.76	-
IC, % predicted	-	91.32 ± 64.15	-
MVV, L/min	-	52.84 ± 26.40	-
MIP, cmH_2O	73.25 ± 18.66	62.88 ± 19.05	0.058
MEP, cmH_2O	96.48 ± 37.55	99.40 ± 24.60	0.74
mMRC scale score		1.24 ± 0.77	-
DM, mm	62.82 ± 14.86	41.73 ± 19.39	0.001
Active time, min	-	228.12 ± 105.80	-
Number of steps	-	6388.12 ± 3671.66	-
Movement intensity, m/s^2	-	0.18 ± 0.03	-
Sedentary time, min	-	500.12 ± 128.76	-

BMI: body mass index; IC: inspiratory capacity; MVV: maximal voluntary ventilation; mMRC: modified Medical Research Council; and DM: diaphragmatic mobility.

patients, which is possibly due to the fact that increased airflow obstruction, as assessed by FEV_1, and static lung hyperinflation, as assessed by IC, increase the workloads that affect the chest wall, placing the diaphragm at a geometric and mechanical disadvantage.[26,27] In addition, lung hyperinflation reduces the ability of the diaphragm to generate flow and pressure,[28] resulting in decreased diaphragmatic excursion.[29]

Lung hyperinflation is one of the primary changes in patients with COPD; however, air trapping is the principal factor limiting DM in such patients.[3] Structural changes result in diaphragm remodeling, which results in flattening of the diaphragm and, consequently, decreased diaphragmatic excursion.[30] The aforementioned changes explain the differences in DM and lung function between COPD patients and healthy individuals; they were expected and have previously been reported.[1-3,29]

In the present study, a strong correlation was found between DM and MVV in patients with COPD, showing that a greater DM translates to a better ventilatory capacity. This finding is in agreement with those of Kang et al.,[31] who found a significant correlation between DM and MVV and posited that there might be a relationship between decreased DM and hypercapnia in patients with COPD.

In patients with COPD, airflow limitation during exercise is due to reduced ventilatory capacity associated with increased pulmonary obstruction and, consequently, lung hyperinflation, as evidenced by reduced IC and ventilatory reserve.[32] In the present study, in which patients with moderate to severe obstruction participated, DM correlated moderately with IC, which also accounted for 65% of the variation in DM, reinforcing the influence of lung hyperinflation on diaphragmatic mechanics. However, it is known that the influence of air trapping on DM can be greater than that of lung hyperinflation itself.[3]

Although DM has been shown to correlate with parameters such as pulmonary obstruction, lung hyperinflation,[33] and air trapping,[3] Davachi et al.[11] found no relationship between DM and lung hyperinflation, which is possibly due to the fact that they selected patients with less severe COPD and, consequently, reduced airflow obstruction, resulting in less damage to the diaphragm.

In the present study, a moderate negative correlation was found between DM and the perception of dyspnea in patients with COPD, indicating that changes in the position of the diaphragm make ventilation difficult, reducing respiratory capacity and increasing the sensation of dyspnea.[34] These findings corroborate those of Paulin et al.,[2] who found that patients with decreased DM had a greater sensation of dyspnea after submaximal exercise.

Although no correlation was found between PADL and DM in the COPD patients in the present study, it is known that exercise capacity decreases with the progression of the disease.[35] This creates a vicious cycle of increasing dyspnea during physical activity, leading to physical inactivity, decreased physical conditioning, and an increased number of comorbidities and hospitalizations.[36] It has been shown that, in comparison with healthy, sedentary elderly individuals, most COPD patients spend more time sitting or lying down than walking or standing[23,37]; however, to date, no studies have established a relationship between DM and PADL in COPD patients.

It is of note that assessment of PADL by means of a triaxial accelerometer reveals how much individuals are physically active or inactive in their daily life.[38] However, assessment of PADL with a triaxial accelerometer probably depends on several factors other than DM evaluation, and this might explain the lack of correlation between these variables. In addition, it is possible that the number of patients in the study sample and the evaluation period were insufficient to observe this relationship.

In the present study, no relationship was found between DM and the BMI. Kantarci et al.[39] performed a multiple regression analysis and found that waist circumference apparently plays a more significant role

Table 2. Relationship between diaphragmatic mobility and the study variables in the COPD group.

Variable	p	r	r^2, %
BMI, kg/m^2	0.20	0.58	20
FVC, % predicted	0.01	0.48	23
FEV_1, % predicted	0.003	0.56	32
FEV_1/FVC	0.002	0.58	34
IC, L	0.001	0.80	65
MVV, L/min	0.001	0.73	54
MIP, cmH_2O	0.003	0.56	32
MEP, cmH_2O	0.10	0.33	11
mMRC scale score	0.01	−0.48	18
Active time, min	0.82	−0.04	0.2
Number of steps	0.85	−0.04	0.2
Movement intensity, m/s^2	0.26	0.23	5
Sedentary time, min	0.62	0.10	1

BMI: body mass index; IC: inspiratory capacity; MVV: maximal voluntary ventilation; and mMRC: modified Medical Research Council.

in the evaluation of DM than does the BMI, a finding that suggests that, although the BMI is a good indicator of nutritional status, it does not reflect individual differences in body composition, such as abdominal fat distribution.

We found a relationship between MIP and DM that can be explained by the mechanical disadvantage in which the diaphragm is as a result of air trapping, which leads the inspiratory muscles to work in a shortened position, thus affecting their potential for contraction.[30] Kodric et al.[40] showed that inspiratory muscle training improved DM in patients with diaphragmatic dysfunction following cardiac surgery, a finding that suggests a relationship between improved MIP and DM.

Our results suggest that DM is a parameter that can provide information on respiratory mechanics in patients with COPD and that is related to certain pulmonary parameters (FEV_1, FEV_1/FVC, FVC, IC, and MVV) and functional parameters. However, studies involving a higher number of patients are needed in order to examine the relationship between DM and PADL.

One potential limitation of the present study is that no stage I COPD patients were evaluated. However, this is a common problem in the literature, given that stage I COPD patients are usually asymptomatic and, consequently, do not seek medical attention. Nevertheless, the results obtained in the present study cannot be extrapolated to all stages of COPD severity. In addition, the posture adopted during DM evaluation might influence the result obtained; therefore, we suggest that DM be evaluated in the orthostatic and supine positions in future studies.

In summary, in patients with COPD, DM is related to airway obstruction, lung hyperinflation, ventilatory capacity, and the perception of dyspnea. However, it appears to have no relationship with PADL.

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