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ORIGINAL RESEARCH

Mobility of right and left hemidiaphragms in healthy individuals and in individuals with chronic obstructive pulmonary disease

Mobilidade diafragmática direita e esquerda em indivíduos saudáveis e na doença pulmonar obstrutiva crônica

Movilidad diafragmática derecha e izquierda en individuos saludables y en la enfermedad pulmonar obstructiva crónica

Ana Karla Vieira Brüggemann[1], Bruna Estima Leal[2], Márcia Aparecida Gonçalves[2], Liseane Lisboa[3], Michelle Gonçalves de Souza Tavares[4], Elaine Paulin[5]

ABSTRACT | To evaluate the diaphragm muscle is important for verifying its possible changes or malfunctions. There are several ways to evaluate the diaphragmatic mobility, but only a few compare the mobility of the right hemidiaphragm with the left one. The aim of this study was to evaluate whether there are differences between the mobility of right and left hemidiaphragms in healthy individuals and individuals with chronic obstructive pulmonary disease (COPD), as well as to evaluate the diaphragmatic mobility between men and women, and between healthy and COPD patients. We evaluated 40 healthy individuals and 40 individuals with clinical diagnosis of COPD. Anthropometric and cardiopulmonary parameters were used. The diaphragmatic mobility was evaluated by radiography. Data were statistically analyzed and processed with descriptive analysis (mean and standard deviation) and inferential analysis. To compare the mobilities of the right and left hemidiaphragms, the paired t-test was used. The significance level adopted for statistical treatment was 5% ($p<0.05$). There was no difference of the diaphragmatic mobility for both left and right sides in healthy individuals ($p=0.45$) and individuals with COPD ($p=0.77$). Also, no differences were found when groups were separated according to sex. An important difference was found comparing both diaphragmatic mobilities of the right and left sides between healthy and COPD individuals ($p<0.001$). We concluded that mobility of left and right hemidiaphragms in healthy and COPD individuals is the same. There is no difference for mobility between men and women. Diaphragmatic mobility is reduced in COPD patients.

Keywords | Diaphragm; Movement; Radiography.

RESUMO | Avaliar o músculo diafragma é importante para verificar suas possíveis alterações ou disfunções. Existem várias formas de avaliar a mobilidade diafragmática, mas poucos estudos que comparam a mobilidade do hemidiafragma direito com o esquerdo. O objetivo deste estudo é avaliar se existem diferenças entre a mobilidade diafragmática das hemicúpulas direita e esquerda em indivíduos saudáveis e em indivíduos com Doença Pulmonar Obstrutiva Crônica (DPOC), bem como comparar a mobilidade diafragmática entre homens e mulheres, e entre pacientes saudáveis e com DPOC. Foram avaliados 40 indivíduos saudáveis e 40 indivíduos com diagnóstico clínico de DPOC. Utilizaram-se os parâmetros antropométricos, cardiopulmonares e avaliação da mobilidade diafragmática pelo método

Study carried out in the Respiratory Physical Therapy Laboratory (Lafir) of the Center of Health and Sport Sciences of the Universidade do Estado de Santa Catarina (Cefid/Udesc) – Florianópolis (SC), Brazil.
[1]Master of Physical Therapy from the Universidade do Estado de Santa Catarina (Udesc) – Florianópolis (SC), Brazil.
[2]Master of Physical Therapy from the Universidade do Estado de Santa Catarina (Udesc) – Florianópolis (SC), Brazil.
[3]Undergraduate of Medicine from the Universidade da Região de Joinville (Univille) – Joinville (SC), Brazil.
[4]Doctorate of Medical Sciences from the Universidade Federal de Santa Catarina – Florianópolis (SC), Brazil. Professor of Physical Therapy in the Universidade do Sul de Santa Catarina (Unisul) – Palhoça (SC), Brazil.
[5]Doctorate of Sciences (Experimental Pathophysiology) from the Universidade de São Paulo (USP) – São Paulo (SP), Brazil. Professor of Physical Therapy of the Universidade do Estado de Santa Catarina (Udesc) – Florianópolis (SC), Brazil.

Corresponding address: Elaine Paulin – Center of Health and Sport Sciences (Cefid) – Rua Pascoal Simone, 358 – Coqueiros – Florianópolis (SC), Brazil – Zip Code: 88080-350 – Phone: (48) 3664-8602 – E-mail: elaine.paulin@udesc.br – Finance source: Nothing to declare – Conflict of interests: Nothing to declare – Presentation: Mar. 3rd, 2016 – Accepted for publication: Feb. 10th, 2018 – Approved by the Research Ethics Committee of Udesc, under protocol no. 668,409.

radiográfico. Os dados foram analisados estatisticamente e tratados com análise descritiva (média e desvio-padrão) e análise inferencial. Para comparar a mobilidade das hemicúpulas diafragmáticas direita e esquerda, utilizou-se o teste t pareado. O nível de significância adotado para o tratamento estatístico foi de 5% (p<0,05). Não houve diferença da mobilidade diafragmática tanto do lado direito quanto do lado esquerdo nos indivíduos saudáveis (p=0,45) e nos indivíduos com DPOC (p=0,77), assim como não houve diferenças quando os grupos foram separados por sexo. Foi encontrada uma diferença importante comparando tanto a mobilidade diafragmática do lado direito quanto do lado esquerdo entre indivíduos saudáveis e DPOC (p<0,001). Concluiu-se que a mobilidade diafragmática das hemicúpulas direita e esquerda em indivíduos saudáveis e em indivíduos com DPOC é a mesma. Não há diferença da mobilidade entre homens e mulheres. A mobilidade diafragmática é reduzida em paciente com DPOC.
Descritores | Diafragma; Movimento; Radiografia.

RESUMEN | Evaluar el músculo diafragma es importante para certificar sus posibles alteraciones o disfunciones. Hay varias maneras de evaluar la movilidad diafragmática, sin embargo, pocos estudios que comparan la movilidad del hemidiafragma derecho con el izquierdo. El objetivo de este estudio es evaluar si hay diferencias entre la movilidad diafragmática de las hemicúpulas derecha e izquierda en individuos saludables y en individuos con Enfermedad Pulmonar Obstructiva Crónica (EPOC), así como comparar la movilidad diafragmática entre hombres y mujeres, y entre pacientes saludables y con EPOC. Fueron evaluados 40 individuos saludables y 40 individuos con diagnóstico clínico de EPOC. Se utilizaron los parámetros antropométricos, los cardiopulmonares y la evaluación de la movilidad diafragmática por el método radiográfico. Los datos fueron analizados estadísticamente y tratados con el análisis descriptivo (promedio y desviación estándar) y el análisis inferencial. Para comparar la movilidad de las hemicúpulas diafragmáticas derecha e izquierda, se utilizó la prueba t pareada. El nivel de significancia adoptado para el tratamiento estadístico fue del 5% (p<0,05). No hubo diferencia de la movilidad diafragmática tanto del lado derecho cuanto del lado izquierdo en los individuos saludables (p=0,45) y en los individuos con EPOC (p=0,77), así como no hubo diferencias cuando los grupos fueron separados por sexo. Fue encontrada una diferencia importante comparando tanto la movilidad diafragmática del lado derecho cuanto del lado izquierdo entre individuos saludables y EPOC (p<0,001). Se concluyó que la movilidad diafragmática de las hemicúpulas derecha e izquierda en individuos saludables y en individuos con EPOC es la misma. No hay diferencia de la movilidad entre hombres y mujeres. La movilidad diafragmática es reducida en paciente con EPOC.
Palabras clave | Diafragma; Movimiento; Radiografía.

INTRODUCTION

The diaphragm is considered the primary muscle for ventilation. In its anatomy, the diaphragm separates the thorax from the abdominal cavity and shows differences between the hemidiaphragms, since the right one is higher than the left one[1,2]. The craniocaudal excursion of this muscle promotes the effective action of pulmonary mechanics, causing morphological and functional changes in thoracic and abdominal cavities, culminating with air entry into the lungs. For thus, the diaphragm must move in its fullness, with the ideal length-tension relationship, and an efficient interaction with abdominal muscles must occur[1,3].

There are several diagnostic methods by image to evaluate the diaphragmatic mobility, such as the fluoroscopy[4-6], the computed axial tomography[7], the nuclear magnetic resonance[8,9], the chest radiography[10-13] and the ultrasonography[7,14-18]. Each technique has its particularities for the observation of the diaphragm muscle, considering cost, radiation exposure and availability of the method in the evaluation environment[19,20]. To evaluate the mobility of the diaphragm muscle is important for understanding and diagnosing changes due to dysfunction of central and/or peripheral nervous system, muscle, thoracic and/or abdominal diseases, among others that may compromise the muscle functioning[20].

Among the major diaphragmatic dysfunctions that can compromise the mobility of the diaphragm, there are: paresis or paralysis, eventration, elevation and decrease of the hemidiaphragm[6,21-24]. These changes may occur due to surgeries, traumas, tumors, infections or diseases that affect innervation or muscle fibers[19,20]. For example, patients with chronic obstructive pulmonary disease (COPD) outstand because they show changes of the diaphragmatic cupula[3] and reduction of diaphragmatic mobility[5,8,25-27] mainly caused by the air entrapment due to the disease[25,26], obstruction of airways[5,25,26] and pulmonary hyperinflation[8], among other clinical and surgical conditions. Therefore, evaluation of diaphragmatic mobility will allow monitoring the position and movement of the hemidiaphragm after an intervention[28]. In addition, after identifying the reduction of diaphragmatic mobility in the patient, the physical therapist will be able to establish a more targeted and effective treatment.

Several studies have evaluated the diaphragmatic mobility in both healthy individuals and patients with any disease[7,10,11,14-16,25,27,29,30]. However, few studies compare the existence of differences between the left and the right diaphragmatic mobility[5,7,10,11,29] and some evaluate only the mobility of the right hemidiaphragm[14,16,25,27,30].

Given this, the aim of this study was to evaluate whether there are differences between diaphragmatic mobility of left and right hemidiaphragms in healthy individuals and in individuals with COPD, as well as compare the diaphragmatic mobility between men and women and between healthy and COPD patients.

METHODOLOGY

This research is characterized as an analytical observational, cross-sectional study with quantitative approach carried out in the Respiratory Physical Therapy Laboratory (LAFIR) of the Center of Health and Sport Sciences of the Universidade do Estado de Santa Catarina (CEFID/UDESC). It was approved by the Human Research Ethics Committee of UDESC (opinion no. 668,409). All participants signed the informed consent form.

Casuistry

A total of 40 healthy individuals and 40 individuals with COPD were selected by accessibility and voluntarism. For healthy individuals, inclusion criteria were: normal spirometry test (FVC and $FEV_1 \geq 80\%$ the predicted and $FEV_1/FVC \geq 0.7$), body mass index (BMI) <30 kg/m^2, nonsmokers, no clinical diagnosis of cardiorespiratory and/or neurological disorders, no pregnancy and/or suspicion of pregnancy, no cancer diagnosis and/or history of the disease or any other disorder that could interfere with conduction of tests. Exclusion criteria were: incapability of performing some of the procedures of the research (lack of understanding or collaboration), clinical intercurrence of respiratory tract (flu or cold) and request for exclusion from the research.

For individuals with COPD, inclusion criteria were: COPD diagnosis according to classification from the Global Initiative for Chronic Obstructive Lung Disease (GOLD, 2013), clinical stability in the last month and in the beginning of the evaluation protocol, peripheral oxygen saturation ($Sp0_2$) at rest >90%, independence from oxygen supplement, inexistence of other respiratory diseases, cardiovascular- or musculoskeletal-associated diseases, no involvement in training programs in the 6 months previous to the beginning of this study, no recent surgeries in the trunk or in lower limbs and/or no fractures in the previous 6 months. Exclusion criteria were: incapability of performing any evaluations of the study (lack of understanding or collaboration), exacerbation of the disease during the research, clinical intercurrences of cardiorespiratory and/or musculoskeletal nature during evaluations, and resignation of the patient during the evaluation period.

Data collection procedure

In the first evaluation day, individuals were subjected to evaluation of anthropometric and cardiopulmonary parameters by a single evaluator. After initial evaluation, individuals were guided, through appointment, for analysis of diaphragmatic mobility by radiography.

Anthropometric and cardiopulmonary evaluation

Body mass and height were evaluated by a balance, previously calibrated, and a stadiometer (Welmy W200/5). The body mass index (BMI) was calculated by the equation body mass/body height^2 (kg/m^2), and its classification was: underweight (≤18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2) and obese (≥30 kg/m^2)[31].

The cardiopulmonary parameters measured were: heart rate (HR), peripheral oxygen saturation (SpO_2) with pulse oximeter (MD300C11) and spirometry test.

Spirometry

The spirometry was conducted with a hand-held digital spirometer (EasyOne, ndd), previously calibrated, according to the methods and criteria recommended by the American Thoracic Society[32]. The forced vital capacity (FVC), the forced expiratory volume during the first second (FEV_1) and the ratio FEV_1/FVC before and 15 minutes after inhalation of the salbutamol (400 µg) bronchodilator (BD) were evaluated.

The spirometry variables were expressed in absolute values and in percentage value of predicted normality values, according the ones determined by Pereira et al.[33]. The criteria for normal pulmonary function test were FVC and FEV_1≥80% from the predicted and FEV_1/FCV≥0.7.

Diaphragmatic mobility

The diaphragmatic mobility was evaluated using the thoracic radiography in anteroposterior (AP) incidence, which is a valid[18], reliable and reproducible method for direct evaluation of diaphragmatic mobility[11]. First, a radiopaque graduated ruler was placed on the individuals' trunk, at a longitudinal direction and craniocaudal orientation, near the thoracic-abdominal transition, for later performance of the correction of ampliation determined by the divergence of rays. Subsequently, individuals were positioned in the radioscopy table in dorsal decubitus.

Before examination, the slow vital capacity (SVC) was measured with a ventilometer (Wright Respirometer Brit.) to ensure that individuals performed the maximum volume during evaluation of diaphragmatic mobility. The SVC was measured at the expiratory moment, based on the total lung capacity (TLC) until the next residual volume (RV) and, in sequence, at the inspiratory moment, a respiration starting from VR until close to the TLC.

Radiology experts performed the radiographic examination, guiding individuals in a standardized manner regarding respiration at expiratory and inspiratory moments, to record the maximum muscle movement, at both moments. The maximum muscle movement was confirmed when performing ventilometry during the examination and compared to values before examination. Radiographic images were recorded in the same film, in maximum inspiration and expiration.

Aiming to ensure the physical integrity of evaluators, the radiologists guided the individuals regarding the performance of respiratory maneuver behind a barium plaster wall to avoid exposure to radiation, together with the physical therapist, who followed every procedure and registered the value obtained in SVC in each respiratory moment.

To minimize possible methodological problems, the same physical therapist followed the performance of all radiographies. To ensure the maximum of diaphragmatic excursion during examination, a standardization process was conducted for radiographic technique, posture adopted during exposure, verbal stimulation and performance of ventilometry before and after acquisition of images.

The measure of diaphragmatic mobility was determined according to the method of diaphragmatic mobility by distance (DM_{dist})[11]. To measure DM_{dist}, the highest point of the right hemidiaphragm in maximum expiration was identified. Given this, a longitudinal line was outlined until finding the hemidiaphragm in maximum inspiration. The same procedure was conducted to obtain the mobility of the left hemidiaphragm. The mobility of right and left hemidiaphragms was determined according to the distance between the maximum expiration and inspiration points measured by a stainless-steel caliper (Somet 150 mm/6) (Figure 1).

For correction of image magnification caused by divergence of X-rays, a correction formula was used: corrected mobility (mm) = measured mobility (mm) × 10 / measure of graduated ruler (mm). Finally, the values in millimeters were converted into centimeters.

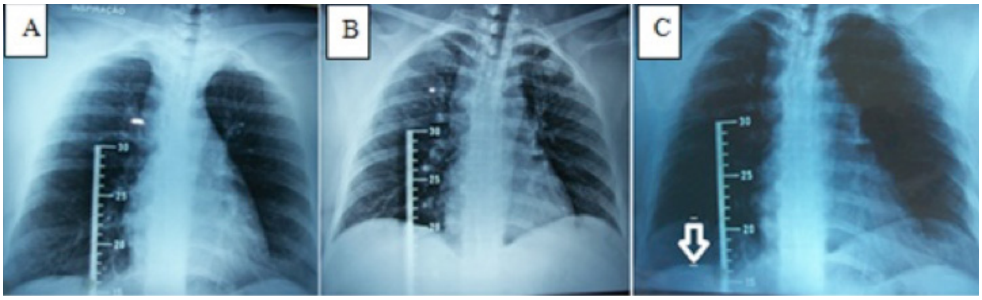

Figure 1. Thoracic radiographies, in AP incidence, in maximum expiration over maximum inspiration, using as reference the image of radiographic ruler. A: Radiography in maximum expiration. B: Radiography in maximum inspiration. C: Overlapping of maximum expiration and maximum inspiration radiographies, using as reference the image of radiographic ruler to evaluate diaphragmatic mobility

Statistical analysis

Data were analyzed using the SPSS for Windows 20.0 (IBM SPSS Statistics) program and processed with descriptive analysis (mean and standard deviation) and inferential analysis. The Shapiro-Wilk test was used to verify data normality.

The paired t-test was applied to compare the mobility of right and left hemidiaphragms for both groups of healthy individuals and individuals with COPD. To compare diaphragmatic mobility between men and women and between healthy and COPD groups, the Student's t-test was employed. The significance level adopted for statistical treatment was 5% (p<0.05).

RESULTS

Forty healthy individuals (23 women and 17 men), with mean age of 62.98±7.11 years, and 40 individuals with clinical diagnosis of COPD (20 women and 20 men), with mean age of 66.21±7.8 years were evaluated. Both healthy and COPD individuals were classified as overweight (BMI>24.9 kg/m²). Spirometry showed mean of values inside normality for healthy individuals and the mean for COPD individuals classified them as moderate to severe (Table 1).

Table 1. Anthropometric and cardiopulmonary characteristics of patients

Variables	Healthy (n=40)	COPD (n=40)
BMI (kg/m²)	27.18±3.6	26.96±5.7
HR (bpm)	77.40±10.7	80.82±13.9
SpO_2 (%)	97.98±0.5	96.59±1.9
FVC (L)	3.40±0.8	2.44±0.8*
FVC (% of the predicted)	95.73±9.75	67.82±16.5*
FEV_1 (%)	2.61±0.6	1.42±0.6*
FEV_1 (% of the predicted)	93.20±9.6	50.0±18.4*
FEV_1/FVC (L)	0.77±0.06	0.56±0.1*

The values were expressed as mean±standard deviation; n: number of individuals; kg: kilograms; m: meters; BMI: body mass index; HR: heart rate; bpm: beats per minute; SpO_2: peripheral oxygen saturation; FVC (L): value in liters of forced vital capacity; FVC (% of the predicted): estimated percentage of forced vital capacity; FEV_1 (L): value in liters of the forced expiratory volume at the first second; FEV_1 (% of the predicted): estimated percentage of forced expiratory volume at the first second; FEV_1/FVC (liters): relationship FEV_1 and FVC in liters. *p<0.001

There was no statistically significant difference between diaphragmatic mobility on both right and left sides in groups of healthy individuals and groups of individuals with COPD (Figure 2).

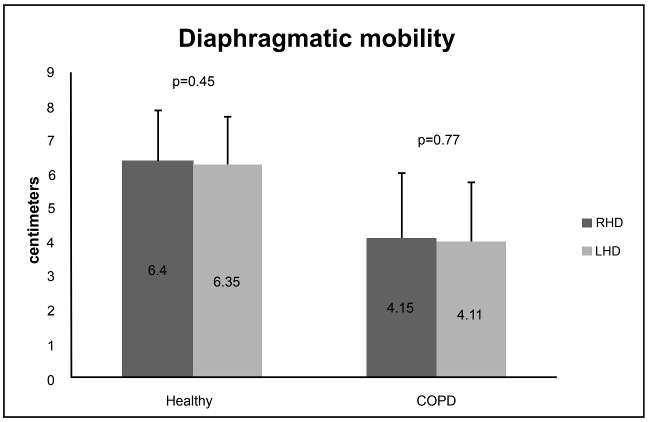

Figure 2. Comparison between mobilities of the right and left hemidiaphragms of healthy and COPD individuals

RHD: mobility of the right hemidiaphragm in centimeters; LHD: mobility of left hemidiaphragm in centimeters. *Statistically significant difference considered at p<0.05

There was no statistically significant difference between diaphragmatic mobility on both right and left sides in groups of healthy individuals and groups of individuals with COPD separated by sex (Table 2).

Table 2. Comparison of mobilities of right and left hemidiaphragms between sex in COPD and healthy groups

	Variables	Men	Women	P
COPD	RHD (cm)	4.49±1.98	3.79±1.80	0.25
	LHD (cm)	4.43±1.81	3.76±1.54	0.21
Healthy	RHD (cm)	6.43±1.57	6.44±1.42	0.99
	LHD (cm)	6.49±1.42	6.25±1.32	0.58

The values were expressed as mean±standard deviation; RHD: mobility of right hemidiaphragm; LHD: mobility of left hemidiaphragms; cm: centimeters; p: significance level. *Statistically significant difference considered at p<0.05

A statistically significant difference was found when comparing the values for mobility of right and left hemidiaphragms between COPD and healthy groups (Figure 3).

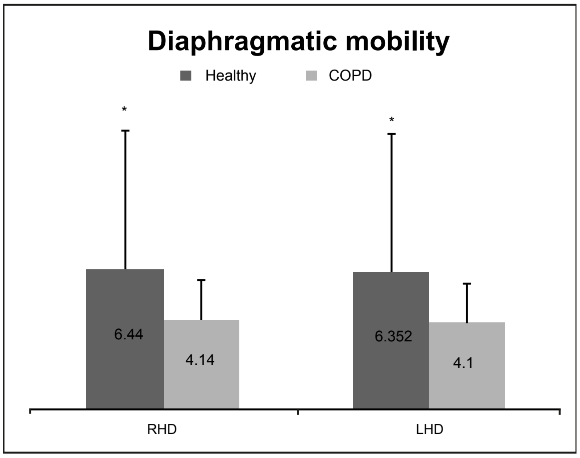

Figure 3. Comparison of mobilities of right and left hemidiaphragms between COPD and healthy groups

RHD: mobility of right hemidiaphragm in centimeters; LHD: mobility of left hemidiaphragms in centimeters. *p<0.001

The power of the sample consisting of 40 healthy patients and 40 COPD patients was calculated by *a posteriori* sample calculation, using the t-test in the GPower 3.1 program. An error of 5% was considered in all analyses. The power found in the sample to observe the difference of diaphragmatic mobility in healthy and COPD patients was 1.0.

DISCUSSION

This study observed no statistically significant differences between mobilities of right and left hemidiaphragms in both healthy and COPD individuals. In healthy individuals, Saltiel et al.[11], when analyzing the reliability of the radiographic method to evaluate the diaphragmatic mobility, also found no differences between right and left mobility in these individuals, as well as Gonçalves et al.[10], who evaluated the diaphragmatic mobility in healthy adolescents aged from 13 to 18 years by the same method. Considering the few studies with COPD patients, He et al.[7] also found no differences for left and right diaphragmatic mobility through evaluation by ultrasound, agreeing with results of Unal et al. [5], who used fluoroscopy for analysis.

When the comparison between sex for both groups was carried out, no significant differences were found, suggesting that healthy or COPD men and women have similar mobility of the hemidiaphragms. However, Kantarci et al.[34] found differences for mobility of right and left hemidiaphragms between healthy men and women, suggesting, by multiple regression analysis, that sex might be an important factor in the influence of diaphragmatic mobility. Mean values found by the authors also differ from our results, showing lower values for both men (5.27±1.10 cm RHD and 5.41±1.26 cm LHD) and women (4.69±1.03 cm RHD and 4.75±1.03 cm LHD). In addition, other differences that may have interfered in the divergence of results are the uneven amount of male (n=99) and female (n=65) participants in each group, and the absence of description and spirometry test to confirm that individuals showed no pulmonary changes that interfered on the diaphragmatic mobility, because it is known that changes in the mobility of the diaphragm are directly related with the parameter of pulmonary function that quantify the air entrapment and airway obstruction[5,26]. Parreira et al.[35] showed, through respiratory inductance plethysmography that, despite women showing a respiratory pattern, as tidal volume, minute ventilation and total respiratory cycle time, lower than men, the displacement of abdominal compartment seemed to be similar for both men and women in supine position, which can suggest that in this position, the diaphragmatic excursion does not alter, regardless of sex.

We highlight that COPD patients were expected to show less mobility for both right and left hemidiaphragms when compared to healthy individuals[5,7,25,26]. In individuals with COPD, the diaphragmatic mobility is lowered due to airway obstruction and lung hyperinflation caused by the disease, which affect the function of the diaphragm[5,26,36]. These pulmonary changes may compromise the diaphragmatic mobility and reduce its contribution in the thoracoabdominal movement, lowering the mechanical effect of diaphragmatic contraction[8,9,26]. Apparently, the mechanical disadvantage imposed by air entrapment is the primary determinant factor of diaphragmatic dysfunction of COPD individuals, because central neural activity remains preserved[25,26,37].

A study showed that individuals with COPD showed reduced diaphragmatic mobility when compared to healthy older individuals, being the air entrapment the main limiting factor of diaphragmatic mobility in COPD group[26]. In this same study, the lowest values of diaphragmatic mobility were detected for patients with moderate and severe obstruction (3.4±0.8 and 3.07±0.75 cm, respectively) in relation to those with light obstruction (4.42±1.23 cm) and there was significant difference for diaphragmatic mobility between groups.

We highlight that few studies investigated the relation between reduction of the diaphragmatic mobility and the functionality of the patient with COPD. However, it has been evidenced that individuals with COPD and reduced mobility (≤3.39 cm) showed lower tolerance to exercise and higher sensation of dyspnea after submaximal effort[25]. These findings indicated that dysfunction of diaphragmatic mobility can be associated with higher symptomatology and impairment of submaximal capacity of exercise. In addition, COPD individuals with diaphragmatic dysfunction showed higher score in the BODE (Body mass index, airflow Obstruction, Dyspnea and Exercise capacity) mortality index, indicating higher mortality risk in relation to individuals without diaphragmatic dysfunction[38].

The evaluation of diaphragmatic mobility has been shown to be important in other chronic pneumopathies aiming to understand and identify possible dysfunctions and early establish an adequate and efficient therapeutics[27], as in the interstitial lung disease, in which the diaphragmatic mobility showed to be related to the functional severity of the disease[39]; in the diaphragm paralysis, in which studies have evidenced improvement of diaphragmatic dysfunction after inspiratory muscle training in cardiac surgeries[28]; as well as during the weaning from mechanical ventilation, in which this evaluation showed to be an important tool for identifying patients with high risk of failure on weaning[40]. In addition, the evaluation of diaphragmatic mobility in other clinical situations has also been shown to be interesting, as in abdominal surgeries, in laparotomy or in videolaparoscopy for cholecystectomy[41] and in bariatric surgeries[42], as well as in patients with obesity[43].

There are several imaging methods for evaluation of diaphragmatic mobility. Among them, there outstand: the fluoroscopy, due to its ability of evaluating the mobility in real time; however, its manner to measure mobility is complex, requiring corrective calculations; the ultrasonography, which can directly evaluate the diaphragm, a little harder and not always possible manner, because it depends on the positioning of the transductor, and the indirect form based on the craniocaudal displacement in the left branch of the portal vein, with the disadvantage of evaluating only the right hemidiaphragm[16,18]; and, at last, the thoracic radiography[11,41], which is one of the most used methods in clinical practice, despite radiation, because it is an instrument of easy application, of low cost and that shows to have a intra and interobserver reliability and reproducible measure for direct evaluation of mobility of left and right hemidiaphragms.

Given this, we emphasize the importance of evaluating the diaphragmatic mobility and suggest that there are no differences between mobility of right and left hemidiaphragms between healthy individuals and individuals with COPD, and that COPD patients show lower diaphragmatic mobility when compared to healthy subjects.

CONCLUSION

There are no differences between mobility of right and left hemidiaphragms in healthy individuals and in individuals with COPD. Sex seems not to interfere on mobility in dorsal decubitus. Patients with COPD show less right and left diaphragmatic mobility when compared to healthy individuals.

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