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Original Research

Can diaphragmatic mobility be measured by chest wall volumes?

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Abstract

Background: The evaluation of the diaphragm muscle is important in clinical practice as a way to investigate its relationship with lung volumes. This allows the knowledge of pulmonary variations via different equipment, enabling the accessibility of the ventilatory evaluation. **Objective**: To investigate the relationship between chest wall volumes and diaphragmatic mobility in the sitting position and dorsal decubitus at 30° of trunk inclination. **Methods**: 40 participants of both sexes, aged between 20 and 50 years, were submitted to measurements of volume changes in three chest wall compartments by optoelectronic plethysmography. Diaphragmatic mobility (DM) was assessed by ultrasonography. Statistical analysis: univariate analysis was performed using Spearman´s rank correlation, followed by linear regression to determine the influence of lung volume changes in each compartment on DM. Significance was set at ≤5%. **Results**: DM was correlated with the volume of the abdominal rib cage (Vrca) at 30° (r=0.33, p=0.03) and with abdominal volume (Vab) in both sitting position and at 30° inclination, respectively (r=0.62, p<0.001; r=0.61, p<0.001). However, in multivariate analysis, Vab contributed to 68% and 50% of DM variance while sitting and at 30º, respectively. **Conclusion**: Abdominal volume (Vab) can be used as an indirect measure of DM in men and women in the sitting position and at 30º of trunk inclination in dorsal decubitus .

Keywords: Diaphragm; Chest Wall; Respiratory Mechanics.

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How can the results of this study be used in clinical practice?

Knowledge of diaphragmatic mobility, even if indirectly, can in practice help in the specificity of treatment

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Background

The movement of the diaphragm muscle within the thoracoabdominal structure contributes significantly to pulmonary ventilation; as such, this muscle plays an important role in clinical practice[1,2]. However, the diaphragm is relatively inaccessible for direct assessment. Lung volumes and inspiratory flows can be used as an indirect measurement of the tension, length and shortening velocity of this muscle, but not necessarily of its mobility, which is typically measured by imaging methods[3,4].

Optoelectronic plethysmography (OEP) is a valid[5,6], reliable[7] and non-invasive instrument, and stands out among the tools available to assess lung volumes[8]. OEP allows real-time three-dimensional measurement of lung volume changes based on the movement of the chest wall and its three compartments (pulmonary rib cage, abdominal rib cage and abdomen) for each respiratory cycle[8-10].

In contrast to imaging methods that assess diaphragmatic mobility (DM), ultrasonography (US) is fast, portable, devoid of ionizing radiation[11,12], valid[13] and reliable[12,14]. The relationship between DM assessed by US and chest wall motion measured by pulmonary volume changes via OEP has been previously investigated in two studies[15,16]. In 2003, Aliverti et al.[15] studied this relationship in four healthy men in the sitting position. The authors found that the variation in abdominal compartment volume contributed to 89% of DM variability during quiet breathing and 96% during physical exercise. Similarly, Aliverti et al.[15,16] assessed 12 healthy male subjects in the supine position and observed that abdominal volume changes contributed to 94% of DM variance during quiet and deep breathing.

The abovementioned studies[15,16] were limited by the small number of male adults assessed. Thus, comprehensive studies including a larger sample size and female subjects may contribute to determining the relationship between DM and chest wall motion, especially in the abdominal compartment.

Therefore, the present study aimed to assess a possible relationship between changes in chest wall compartment volumes (pulmonary rib cage, abdominal rib cage and abdomen) and DM in healthy adults (men and women), evaluated in the sitting position and dorsal decubitus at 30° of trunk inclination.

Methods

Population and sample

Convenience sampling was used and the inclusion criteria were as follows[1]: absence of self-reported pulmonary, cardiac or metabolic diseases[2]; normal pulmonary function test[3,17] age between 20 and 50 years[4]; body mass index (BMI) between 18.5 and 29.9 kg/m^2[18];[5] no history of chest wall injury or deformity[6]; non-smoker[7]; absence of infectious respiratory process four weeks prior and on the day of assessment ; and[8] no self-reported pregnancy. The exclusion criterion was being unable to adequately perform any of the proposed evaluation procedures due to lack of understanding and/or cooperation.

Research procedures

The study was approved by the UDESC Research Ethics Committee (CAAE: 64592016.4.0000.0118).Once participants had provided written informed consent, they were submitted to anthropometric assessment (height and weight), cardiopulmonary parameter measurement [heart rate (HR), respiratory rate (RR), blood pressure (BP) and peripheral oxygen saturation (SpO_2)], and the International Physical Activity Questionnaires (IPAQ). Pulmonary function was tested by spirometry, followed by a random draw to determine the position (sitting or 30° of trunk inclination in dorsal decubitus) and the first piece of equipment to be used (US or OEP). The draw was performed using the Lucky Wheel mobile app. In order to allow cardiopulmonary parameters to return to baseline values, an interval of at least 5 minutes was permitted after spirometry, US and OEP (Figure 1).

Physical examination

A calibrated digital scale (Actilife® Slimtop-180, Balmak, China) was used to measure weight, and a portable stadiometer (Sanny®, W200/5, Welmy) for height. BMI was calculated with the formula: weight/(height)^2 (kg/m^2), and participants

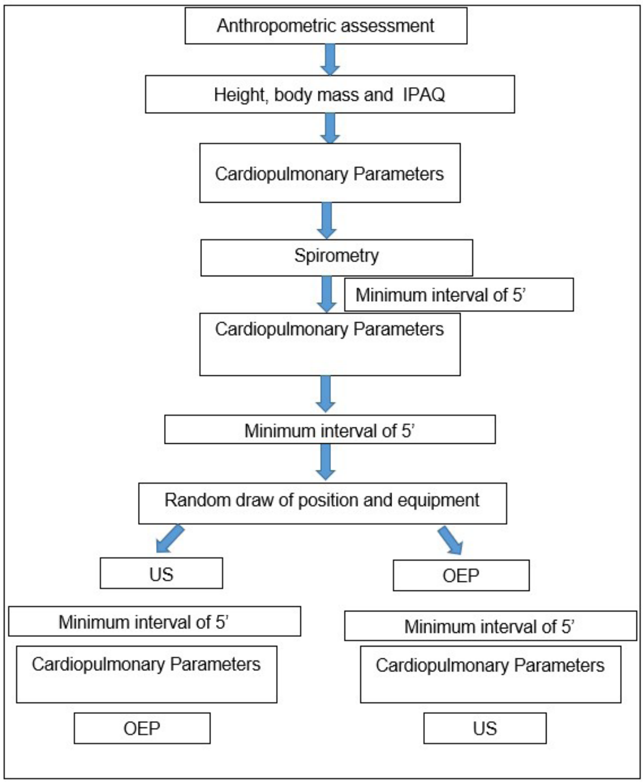

Figure 1. Flow chart of the methodological procedures of the study. Abbreviations- IPAQ: International Physical Activity Questionnaire; US: ultrasonography; OEP: Optoelectronic plethysmography; ': minutes.

classified as normal weight (BMI of 18.5 - 24.9 kg/m^2) or overweight (25 - 29.9 kg/m^2)[18].

Cardiorespiratory parameters (HR, RR, BP and SpO_2) were measured in the sitting position. A sphygmomanometer (Accumed® Premium, China) and a stethoscope (Accumed® Premium, China) were used to measure BP and a pulse oximeter (Fingertip® SB100, Taiwan) for SpO_2.

Pulmonary function test

Spirometry was performed according to the methods and criteria recommended by the American Thoracic Society and European Respiratory Society, using a previously calibrated portable digital spirometer (NDD® EasyOne, USA)[19]. The following parameters were obtained: forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1) and the FEV_1/FVC ratio. At least three acceptable and two reproducible maneuvers were performed. The parameters for a normal pulmonary function test were FVC and $FEV_1 \geq 80\%$ of the predicted value and $FEV_1/FVC \geq 0.7$, as established by Pereira et al.[17].

Chest wall volume measurement

Chest wall volume changes were evaluated by OEP (BTS® Bioengineering, Italy) while participants were sitting and in DD at 30° of trunk inclination. OEP indirectly evaluates lung volumes and the contribution of its different compartments (pulmonary rib cage, abdominal rib cage and abdomen) via cameras that capture infrared light reflected by markers (reflective plastic beads) attached to specific points on the chest wall[8,20,21]. In the present study, eight cameras were used.

For assessment in the sitting position, participants remained seated with their feet supported on a gurney, hips flexed and arms resting on their thighs. In DD at 30° inclination with trunk support, participants were positioned with their hips and knees flexed (for comfort), feet supported on the gurney and arms at their sides to avoid interfering on image acquisition (Figure 2).

The markers were positioned according to the protocol, with 89 used in the sitting position (42 hemispheres in the anterior region of the chest, 37 in the posterior region and 10 spherical markers positioned laterally, five on the left and five on the right side)[8,20,22,23] and 52 on the anterior chest wall at 30° inclination (Figure 3).

After placement of the markers, the system was statically calibrated using a metal structure with X (mid-lateral), Y (anteroposterior) and Z coordinates (upper-lower). The X, Y and Z coordinates were placed in the collection area, with the Y-coordinate positioned upwards so that the system recorded the area to be evaluated, correcting the optical distortions. Calibration lasted five seconds[5].

Next, to inform the system of the location of the individual's trunk and the camera's exact orientation, dynamic calibration was only performed with the stem representing the Y-coordinate. A 40-second scan was performed in the sagittal plane, 20 seconds in the frontal plane and 20 seconds in the transverse plane in the area where the subject's chest wall was positioned[24].

The three-dimensional image was formed by the reflection of the markers on the subject's chest, via a computerized system based on Gauss's theorem. This made it possible to analyze the total volume and compartmental volumes. The following anatomical limits were established: the border between Pulmonary rib cage and abdominal rib cage at the level of the xiphoid process; the border between abdominal rib cage and abdomen along the costal margin anteriorly and at the lowest point of the lower costal margin posteriorly[8].

Figure 2. Assessment position.

Figure 3. Markers positioned according to the protocol.

Each participant performed 5 minutes of quiet breathing in line with their normal breathing pattern, in both the sitting position and at 30° of trunk inclination. For data analysis, the first and final 60 seconds of data collection were disregarded.

Diaphragmatic mobility measurement

Diaphragmatic mobility was assessed using a portable US device (Nanomax®; Sonosite, Bothell, WA, USA). A 2-5 MHz convex transducer was used, positioned directly under the xiphoid process and angled towards the skull so that the ultrasound beam reached the posterior third of the right hemidiaphragm. Initially, B-mode ultrasonography was used to visualize the diaphragm window, followed by M-mode ultrasonography to measure the amplitude of diaphragmatic excursion during quiet breathing in the sitting position and at 30° of trunk inclination[12,25].

Diaphragmatic mobility was expressed in centimeters and calculated by the distance moved between inspiration and expiration. Five measurements were taken during quiet breathing. The arithmetic mean of the 3 highest values recorded was considered for the study, with a variation of no greater than 10% between measurements[12,25].

Statistical analysis

Sample size was calculated considering the linear regression model, with diaphragmatic mobility as a dependent variable and the volume variation of Pulmonary rib cage and abdomen as independent variables. Thus, an a priori calculation was performed using the formula (10 *[k+1])[26], where K is the number of explanatory variables of the predictive model (n=3). Consequently, the ideal sample size was 40 subjects. Variables related to sample characterization, lung volume changes and diaphragmatic mobility were reported as mean or median and standard deviation.

The Shapiro-Wilk test was applied to evaluate normal data distribution and Spearman's correlation test to analyze the correlation between lung volume changes and diaphragmatic mobility for non-normal data distribution. The magnitude of the correlations was described in accordance with Munro[26], with r between 0.26 and 0.49 considered low; 0.50 and 0.69 moderate; 0.70 and 0.89 high; and 0.90 and 1.00 very high.

Multiple regression analysis (backward procedure) was performed to determine the influence of each lung compartment volume on diaphragmatic mobility. Height, weight, sex and age were used to adjust the predictive model. All the necessary assumptions (absence of multicollinearity, presence of homogeneity and normal distribution of residuals) were considered in the analysis[27].

Based on normal data distribution, the Wilcoxon or paired t-tests were applied to compare the volumes of each chest wall compartment (pulmonary rib cage, abdominal rib cage and abdomen) and diaphragmatic mobility between the sitting and DD positions at 30º of trunk inclination. Analyses were performed using SPSS statistical software (Statistical Package for Social Sciences) version 20.0 and the data stored on Excel® 15. Significance was set at $\leq$ 5%.

Results

A total of 40 healthy subjects (20 women and 20 men) participated in the study. Data on sample characterization according to sex are shown in Table 1. Age was significantly higher among male participants. No statistically significant differences were observed for the other variables.

Results regarding the correlation between diaphragmatic mobility and chest wall volumes are summarized in Table 2. There was a statistically significant and moderate magnitude correlation between diaphragmatic mobility and abdominal volume (Vab), regardless of body position. In addition, the volume of abdominal rib cage (Vrca) exhibited a statistically significant and weak-magnitude correlation with diaphragmatic mobility in both positions.

As for the linear regression, 68% of diaphragmatic mobility variance in the sitting position and 50% at 30° of trunk inclination was explained by Vab. The equations obtained for the association between diaphragmatic mobility and Vab in the two positions are presented in Figure 4.

Table 3 shows the percentage contribution of each compartment in both positions, stratified by sex. There was a significant increase in Vab contribution (%) and a significant decrease in volume of the pulmonary rib cage (Vrcp) and Vrca (%) in the 30° of trunk inclination position for both sexes.

Comparisons of the contributions of each compartment in the same position (sitting or at 30º) indicated that Vab (%) had the highest contribution at 30º inclination in both sexes when compared to the other compartments (female:

Table 1. Characterization of the study sample.

	Men	Women	Total	*P*-value
Age (years)	32 ± 8	25 ± 5	29 ± 7	<0.001*
Height (cm)	175.35 ± 5.49	164.35 ± 6.08	169.85 ± 7.98	0.981
Weight (Kg)	72.72 ± 6.86	60.67 ± 7.24	66.69 ± 9.25	0.129
BMI (Kg/m^2)	23.65 ± 1.77	22.76 ± 5.80	23.2 ± 2.26	0.114
FEV_1/FVC (L)	0.84 ± 0.63	0.86 ± 0.607	0.85 ± 0.62	0.854
FEV_1 (% pred)	97.85 ± 9.61	99.80 ± 10.31	98.82 ± 9.88	0.553
FVC (% pred)	97.55 ± 8.10	96.95 ± 10.61	97.25 ± 9.31	0.358

Data presented as mean ± standard deviation. p: significance level; BMI: body mass index; Kg: kilogram; Kg/m^2: kilogram per square meter; FEV_1/FVC: ratio of forced expiratory volume in the first second and forced vital capacity; L: liters; FEV_1: forced expiratory volume in the first second; % predicted: percentage of predicted value; FVC: forced vital capacity; cm: centimeters; * significant difference between men vs women.

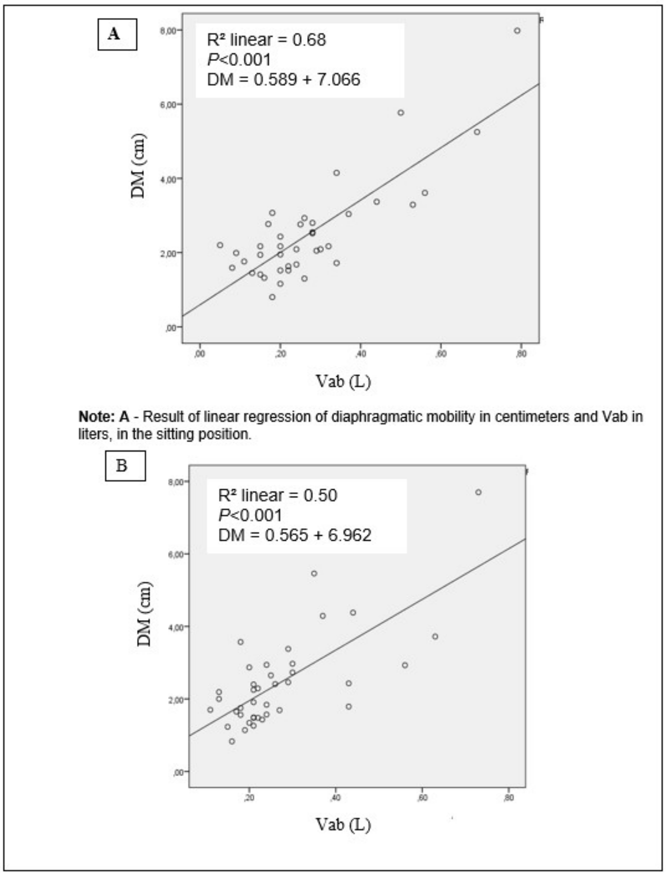

Figure 4. Results of linear regression of diaphragmatic mobility and Vab in the sitting position (A) and at 30° of trunk inclination (B). **Note: B** Result of linear regression of diaphragmatic mobility in centimeters and Vab in liters, at 30° of trunk inclination. Abbreviations: cm: centimeters; Vab: abdominal volume; L: liters.

p=0.05, male: p<0.001). The greatest contribution observed in the sitting position was for Vrcp (%) in women (p<0.001). However, in men, there was no differences between the contribution of Vrcp (%) and Vab (%) (p=0.84) in this position.

Table 2. Results of the correlation between diaphragmatic mobility and the volumes of the three chest wall compartments in the two positions assessed.

	OEP Volumes		
	Vrcp (L)	Vrca (L)	Vab (L)
DM sitting.	0.08	0.37	0.62
P-value	0.63	0.02	<0.001
DM at 30°	-0.58	0.33	0.61
P-value	0.72	0.03	<0.001

Data presented as correlation coefficients (r). Vrcp: volume of the pulmonary rib cage; OEP: Optoelectronic plethysmography; Vrca: volume of the abdominal rib cage; Vab: abdominal volume; 30°: 30° of trunk inclination in dorsal decubitus; L: liters; DM: diaphragmatic mobility.

In the total sample, no significant differences were observed between the sitting and 30° of trunk inclination positions (p=0.368). However, diaphragmatic mobility was higher in men than in women for both the sitting (p=0.02) and 30° of trunk inclination positions (p <0.001) (Table 4).

Discussion

The major finding of this study was that abdominal volume displacement was the only variable that remained in the explanatory model (Figure 2) for diaphragmatic mobility in both sitting and at 30° of trunk inclination positions, despite the statistically significant difference in abdominal compartment contribution observed between the two positions in both sexes in healthy persons. There were no statistically significant differences between the two positions. The only statistically significant difference observed was for greater diaphragmatic mobility in men.

The assessment of lung volumes and their variations in healthy individuals is important for understanding ventilatory mechanics under normal circumstances. This knowledge can be transferred to disease conditions later, for better

Table 3. Analysis of the contributions of chest wall compartments according to position in men and women.

	Men Women					
	Sitting	30°	*P*-value	Sitting	30°	*P*-value
Vrcp (%)	38.06±12.04	27.19±13.64*	<0.001	49.97±8.23	36.71±13.93*	<0.001
Vrca (%)	21.4 ± 4.44	13.5 ± 2.71*	<0.001	18.32±4.12	13.73±3.5*	<0.001
Vab (%)	40.51±13.65	59.18±14.82*	<0.001	31.71±11.08	49.71±15.11*	<0.001

Data presented as mean (standard deviation). Vrcp%: percentage contribution of the pulmonary rib cage to tidal volume; Vrca%: percentage contribution of the abdominal rib cage to tidal volume; Vab%: percentage contribution of the abdomen to tidal volume; 30°: trunk inclination at 30° in dorsal decubitus; p: significance level; *: significant difference between the positions of each compartment.

Table 4. Absolute values of diaphragmatic mobility in the sitting position and at 30° of trunk inclination.

	Men	Women Total		*P*-value
DM Sitting (cm)	3.09 ± 1.71	1.96 ± 0.57	2.48 ± 2.13	0.02*
DM 30° (cm)	3.11 ± 1.50	1.80 ± 0.67	2.42 ± 2.09	<0.001*
P-value	0.82	0.12	0.36	

Data presented as mean ± standard deviation. DM: diaphragmatic mobility; 30°: 30° of trunk inclination in dorsal decubitus; cm: centimeters; p: significance level; * significant difference between men vs women.

therapy management . It is known that lung volumes are directly related to height and gender, and the differences in resting pulmonary function are attributable to the smaller lung volumes in women relative to men, as demonstrated by Vogiatzis et al.[6]. The authors consider that during breathing, lung volume changes the configuration of the rib cage, so that in men the inspiratory capacity was significantly greater than in women.

In the present study, Vab contributed to 68% and 50% of diaphragmatic mobility variance in the sitting position and DD at 30º of trunk inclination, respectively. Wang et al.[16] reported a 94% influence of Vab on diaphragmatic mobility in the supine position and Aliverti et al.[15] found that Vab influenced 96% of diaphragmatic mobility in the sitting position. The influence of Vab on diaphragmatic mobility in our sample may have been lower because both sexes were evaluated in the present study, whereas the abovementioned investigations assessed only men and had considerably smaller sample sizes.

Statistically significant correlations were observed between Vab and diaphragmatic mobility in the sitting position ($r=0.62$, $p<0.001$), and between Vrca ($r=0.37$, $p<0.001$), Vab ($r=0.61$, $p= 0.03$) and diaphragmatic mobility in DD at 30° inclination. Wang et al.[16] and Aliverti et al.[15] reported significant high magnitude correlations between diaphragmatic mobility and the Pulmonary rib cage ($r=0.81$; $p<0.001$), Abdominal rib cage ($r=0.91$; $p<0.001$) and abdomen inclination ($r=0.94$; $p<0.001$), regardless of body position. However, only Vab remained in the regression model as an explanatory variable of diaphragmatic mobility in these two studies.

The correlation between Vrca, Vab and diaphragmatic mobility may be the result of diaphragm contraction, causing the abdominal wall to expand[28] along with the Abdominal rib cage. Rib cage muscles such as the intercostal, parasternal and scalene muscles generate pressures that make the upper rib cage to move, while the synergistic action of the diaphragm and abdominal muscles displace the lower ribcage and abdomen[29].

Chen et al.[30] demonstrated that abdominal displacement is influenced by diaphragm contraction. These results corroborate to our findings, whereby abdominal compartment motion can indirectly predict diaphragmatic mobility in healthy subjects, in both positions, using the equation for diaphragmatic mobility=0.589 + 7.066 Vab for the sitting position ($r^2=0.68$), and diaphragmatic mobility=0.565 + 6.962 Vab ($r^2=0.50$) for DD at 30º of trunk inclination.

The US has many advantages, including the lack of ionizing radiation and the possibility of use at the bedside of the patient. Over the last decades, this method is considered accurate to determine dysfunctions of diaphragm, while being a validated indirect method that proved to be reproducible[14]. The present study also showed that diaphragmatic mobility is greater in men, regardless of the body position. These results are consistent with those of Boussuges et al.[12], who evaluated 210 healthy individuals (150 men and 60 women) in the standing position during US. In our study, diaphragmatic mobility was also greater in men (1.8cm±0.3; $p<0.001$) than in women (1.6cm±0.3, $p<0.001$). Kantarci et al.[31] investigated diaphragmatic mobility using US in the supine position and also reported lower diaphragmatic mobility in women when compared to men (4.6cm±1.03 and 5.3cm±1.10, respectively).

On the other hand, in our study, there was no significant difference in diaphragmatic mobility between the sitting and at 30º of trunk inclination positions. A possible explanation for these results is that our sample was homogeneous in terms of weight. According to Kantarci et al.[31], weight influences diaphragmatic mobility, which is lower in underweight individuals (BMI <18.5 diaphragmatic mobility=4.09±8.89; BMI between 18.5 and 25 diaphragmatic mobility=5.03±10.27; BMI between 25 and 30 diaphragmatic mobility=5.16±11; $p<0.05$) than in their normal weight or overweight counterparts.

In the present study, chest wall motion was significantly influenced by body position. This corroborates to the findings of Kaneko and Horie[32], who reported that changes in body position influence the respiratory pattern. Using OEP, these authors observed a greater contribution of abdomen than the rib cage at 45° inclination in DD. The opposite was true in the sitting position, so that the rib cage exhibited greater participation than the abdomen. Likewise, Romei et al.[33] assessed 34 healthy subjects during quiet breathing in 5 different positions, beginning in the sitting position and progressively increasing trunk inclination to the supine position. The authors found that the contribution of volumes changed as trunk inclination increased, with a greater contribution of the abdomen in supine subjects and the rib cage in the sitting position. They also hypothesized that, in the sitting position without support, the abdominal muscles contract to maintain the trunk position and stabilize the spine, resulting in greater chest wall motion. On the other hand, the abdominal muscles relax in the supine position, allowing a greater contribution of the abdominal compartment. Another factor that may explain these differences is the effect of gravity. Moving from a sitting position to 45° inclination causes a decline in the effect of gravity on the abdomen, meaning that the abdominal contents offer less resistance to the descent of the diaphragm in the supine position[34].

Regarding the influence of sex on chest wall motion, our results confirm those of other authors, including Romei et al.[33] and Binazzi et al.[35], who observed a lower Vab contribution (%) in women than men during quiet breathing in DD inclined at 30°.

The most widely used instruments to measure lung volumes in clinical practice are full body plethysmography and spirometry, both used to assess lung function and to evaluate, monitor disease progression and plan treatments for the patients. However, they do not measure chest wall motion. We therefore suggest that OEP is an appropriate complementary assessment tool to support clinical diagnosis. The OEP guides us in the thoracic compartments, showing even where the slightest chest expandability occurs, making it easier for clinicians to choose the best individualized treatment option.

As identified in the present study, positioning does not seem to be a restriction during care, since there was no difference between volumes. However, knowing that the exercises that promote greater abdominal expansion are the ones that most interfere in diaphragmatic mobility is of great value for patients with diagnoses such as obesity, or those patients bedridden or undergoing ventilatory weaning processes in intensive care units.

While a number of imaging methods have been used to evaluate diaphragmatic mobility, US exhibits some advantages over other techniques. Additionally, studies have shown a high correlation between M-mode ultrasonography and fluoroscopy ($r = 0.89$-0.99)[36].

Diaphragmatic mobility was assessed only on the right side, which could be considered a limitation of this study. However, research has shown that there is no difference in diaphragmatic mobility between the right and left hemidiaphragm[37,38]. Furthermore, although lung volume could not be assessed concomitantly with diaphragmatic mobility, the measurements were performed on the same day and under the same conditions.

Conclusion

The abdominal compartment, specifically Vab, can be used as an indirect measure of diaphragmatic mobility in healthy men and women while sitting and at 30º of trunk inclination in dorsal decubitus. Studies on individuals with cardiorespiratory system dysfunction would contribute to determine whether the relationship between diaphragmatic mobility and chest wall volumes is similar in that population.

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Conflict of interest

The authors have no conflicts of interest to report.

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TDP: conceptualization of the study, data acquisition, writing, analysis and/or interpretation; JCG: revising and/or editing the manuscript; CLM: data acquisition; DSF and CCP: data acquisition, analysis and/or interpretation, writing; DM: analysis and/or interpretation, revising and/or editing the manuscript; DSRV: analysis and/or interpretation, revising and/or editing the manuscript; EP: conceptualization of the study, supervision, analysis and/or interpretation, revising and/or editing the manuscript.

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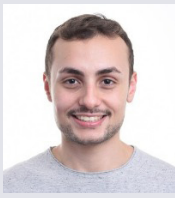

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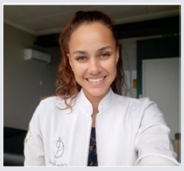

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