

Diaphragmatic mobility in healthy subjects during incentive spirometry with a flow-oriented device and with a volume-oriented device*

Mobilidade diafragmática durante espirometria de incentivo orientada a fluxo e a volume em indivíduos sadios

Wellington Pereira dos Santos Yamaguti, Eliana Takahama Sakamoto, Danilo Panazzolo, Corina da Cunha Peixoto, Giovanni Guido Cerri, André Luis Pereira Albuquerque

Abstract

Objective: To compare the diaphragmatic mobility of healthy subjects during incentive spirometry with a volume-oriented device, during incentive spirometry with a flow-oriented device, and during diaphragmatic breathing. To compare men and women in terms of diaphragmatic mobility during these three types of breathing exercises. **Methods:** We evaluated the pulmonary function and diaphragmatic mobility of 17 adult healthy volunteers (9 women and 8 men). Diaphragmatic mobility was measured via ultrasound during diaphragmatic breathing and during the use of the two types of incentive spirometers. **Results:** Diaphragmatic mobility was significantly greater during the use of the volume-oriented incentive spirometer than during the use of the flow-oriented incentive spirometer (70.16 ± 12.83 mm vs. 63.66 ± 10.82 mm; $p = 0.02$). Diaphragmatic breathing led to a greater diaphragmatic mobility than did the use of the flow-oriented incentive spirometer (69.62 ± 11.83 mm vs. 63.66 ± 10.82 mm; $p = 0.02$). During all three types of breathing exercises, the women showed a higher mobility/FVC ratio than did the men. **Conclusions:** Incentive spirometry with a volume-oriented device and diaphragmatic breathing promoted greater diaphragmatic mobility than did incentive spirometry with a flow-oriented device. Women performed better on the three types of breathing exercises than did men.

Keywords: Diaphragm; Breathing exercises; Respiratory function tests; Ultrasonography; Respiratory muscles. (ClinicalTrials.gov identifier: NCT00997737 [<http://www.clinicaltrials.gov/>])

Resumo

Objetivo: Comparar a mobilidade diafragmática de indivíduos sadios durante a espirometria de incentivo orientada a volume, durante a espirometria de incentivo orientada a fluxo e durante exercícios diafragmáticos. Comparar a mobilidade diafragmática entre homens e mulheres durante esses três tipos de exercícios respiratórios. **Métodos:** Foram avaliadas a função pulmonar e a mobilidade diafragmática de 17 voluntários sadios adultos (9 mulheres e 8 homens). A avaliação da mobilidade do diafragma foi realizada durante a execução de exercícios diafragmáticos e durante o uso dos dois tipos de espirômetros de incentivo, por meio de um método ultrassonográfico. **Resultados:** A mobilidade diafragmática avaliada durante a utilização do espirômetro orientado a volume foi significativamente maior que aquela durante o uso do espirômetro orientado a fluxo ($70,16 \pm 12,83$ mm vs. $63,66 \pm 10,82$ mm; $p = 0,02$). Os exercícios diafragmáticos promoveram maior mobilidade diafragmática do que o uso do espirômetro orientado a fluxo ($69,62 \pm 11,83$ mm vs. $63,66 \pm 10,82$ mm; $p = 0,02$). Durante os três tipos de exercícios respiratórios, a relação mobilidade/CVF foi significativamente maior nas mulheres do que nos homens. **Conclusões:** A espirometria de incentivo orientada a volume e o exercício diafragmático promoveram maior mobilidade diafragmática do que a espirometria de incentivo orientada a fluxo. As mulheres apresentaram um melhor desempenho nos três tipos de exercícios respiratórios avaliados do que os homens.

Descritores: Diafragma; Exercícios respiratórios; Testes de função respiratória; Ultrassonografia; Músculos respiratórios.

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* Study carried out in the Department of Rehabilitation Medicine, Sírio-Libanês Hospital, São Paulo, Brazil. Correspondence to: Wellington Pereira dos Santos Yamaguti. Serviço de Reabilitação São Paulo, Rua Dona Adma Jafet, 91, CEP 01308-050, SP, Brasil. Tel 55 11 9226-4517. E-mail: wellpsy@usp.br
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Introduction

Patients submitted to upper abdominal surgery or thoracic surgery frequently have a high incidence of postoperative pulmonary complications, such as hypoxemia, pneumonia, and atelectasis.⁽¹⁾ Such complications can increase the risk of morbidity and mortality, prolong hospital stays, and raise health care costs in such patients.⁽²⁾ Respiratory therapy, which employs various techniques, such as deep breathing exercises, diaphragmatic breathing (DB), manual therapy techniques, positive pressure exercises, and incentive spirometry, has been used for the prevention and treatment of these complications.⁽³⁾

Incentive spirometry involves the use of a device designed to stimulate patients, by means of a visual stimulus, to inhale deeply and slowly, subsequently holding their breath. Incentive spirometers, which can be categorized as volume-oriented devices or flow-oriented devices, are portable and easy to handle.⁽⁴⁾ Despite the widespread use of incentive spirometry, some systematic reviews have found little evidence that the use of this technique is beneficial in terms of preventing postoperative complications.⁽⁵⁻⁷⁾ However, the articles reviewed typically employed inappropriate methodologies and produced results that were not comparable. In addition, few of those studies showed an interest in evaluating the biomechanical and physiological bases of the different types of device in order to improve the indication criteria, adjusting them to the desired therapeutic goals.

Some studies have shown that the use of incentive spirometry with a volume-oriented device (ISVOD) requires less respiratory effort than does that of incentive spirometry with a flow-oriented device (ISFOD).⁽⁸⁾ Other authors have observed that there is greater abdominal motion, lower accessory respiratory muscle recruitment, and higher tidal volume during the use of ISVOD than during the use of ISFOD.^(9,10) In addition to the evaluation parameters mentioned above, diaphragmatic mobility during the use of different types of incentive spirometers has not been quantified in previous studies, and such quantification could contribute to a better understanding of the mechanical effects of the devices and of their indications in clinical practice. Therefore, the primary objective of the present study was to compare diaphragmatic

mobility during ISVOD, ISFOD, and DB. In addition, as a secondary objective, we compared men and women in terms of diaphragmatic mobility during these three types of breathing exercises.

Methods

This was a randomized cross-over clinical trial involving 17 healthy volunteers (8 men and 9 women). All participants were required to meet the following inclusion criteria: being between 18 and 45 years of age; having normal pulmonary function test results; and having a body mass index (BMI) between 18.5 and 25 kg/m². Smokers were excluded, as were individuals with a history of cardiorespiratory diseases, those who had had previous experience with the devices tested, and those who were unable to perform the assessment tests or the breathing exercises proposed in this protocol. The study was approved by the Research Ethics Committee of the Sírío-Libanês Hospital, located in the city of São Paulo, Brazil, under registration number HSL2008/26, and all subjects gave written informed consent.

Initially, the volunteers underwent pulmonary function testing, which was performed at the Thoracic Center of Excellence of the institution, in accordance with the guidelines established in the First Brazilian Consensus on Spirometry.⁽¹¹⁾ In order to determine FVC and slow vital capacity (SVC), spirometry maneuvers were performed with a whole-body plethysmograph (Elite D MedGraphics; Medical Graphics Co., St. Paul, MN, USA). Expiratory maneuvers met the

Table 1 - Anthropometric and pulmonary function characteristics of the participating volunteers, by gender.^a

Variable	Men	Women
Age, years	23.88 ± 2.75	30.56 ± 6.17*
BMI, kg/m ²	23.81 ± 3.11	22.44 ± 2.63
FEV ₁ , % of predicted	95.41 ± 12.52	100.13 ± 8.07
FVC, % of predicted	93.83 ± 16.48	98.09 ± 6.40
FEV ₁ /FVC, %	85.88 ± 6.06	85.44 ± 3.88
SVC, L	5.36 ± 0.89	3.67 ± 0.24**
IC, L	3.51 ± 0.65	2.55 ± 0.16**

BMI: body mass index; SVC: slow vital capacity; and IC: inspiratory capacity. ^aValues expressed as mean ± SD. *p < 0.05. **p < 0.001.

acceptability criteria established by the American Thoracic Society and the European Respiratory Society,⁽¹²⁾ and we selected the best of three reproducible curves (variation < 5%). The variables analyzed were FVC and FEV₁, in liters and in percentage of predicted, according to the reference values established by Pereira et al.⁽¹³⁾ Inspiratory capacity and SVC are expressed only in liters, since reference values for the Brazilian population have yet to be established.

On a second day, the volunteers were referred to the rehabilitation center of the institution for the ultrasound assessment of diaphragmatic mobility, which was performed with a portable, B-mode ultrasound device (Logic 9; GE Healthcare, Milwaukee, WI, USA), combined with a 3.5 MHz convex transducer positioned in the right subcostal region, with the incidence angle perpendicular to the craniocaudal axis. After the left branch of the portal vein had been identified, its position was traced with the cursor during a maximal inspiratory maneuver and a maximal expiratory maneuver, while the examiner held the transducer at a fixed point on the skin. The distance (in mm) between these two points, that is, the craniocaudal displacement of the left branch of the portal vein, corresponded to the amount of diaphragmatic mobility. This method of assessment has been validated and used in previous studies.⁽¹⁴⁻¹⁷⁾ Diaphragmatic mobility was measured during DB, as well as during the use of ISVOD and during the use of ISFOD, with the volunteers in the supine position and the head of the bed elevated to 30°.⁽¹⁸⁾ The participants were randomized to undergo one of the six possible exercise sequences. The randomization of the sequences was stratified by a second researcher (who had no contact with the participants) in order to maintain the same proportion of possible sequences. Finally, the order in which the three types of breathing exercises were to be performed was determined by random drawing.

The exercises with ISVOD and ISFOD were performed in accordance with the guidelines of the American Association for Respiratory Care,⁽¹⁹⁾ which recommends that individuals inhale deeply and slowly, hold their breath at maximal inspiration for at least 3 s, and exhale normally. The participants followed these rules, and a diagram was used in order to instruct them in how to perform the exercises.

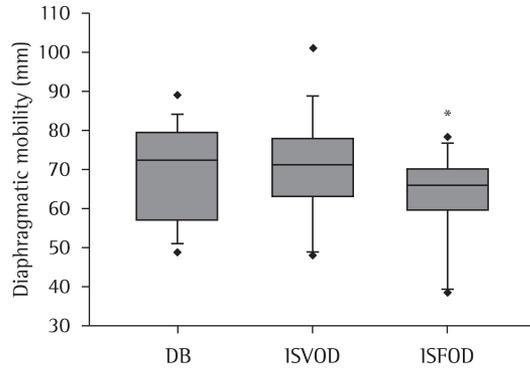


Figure 1 - Diaphragmatic mobility during the three types of breathing exercises: diaphragmatic breathing (DB); incentive spirometry with a volume-oriented device (ISVOD); and incentive spirometry with a flow-oriented device (ISFOD). *p < 0.05 vs. DB and ISVOD.

The volume-oriented device was a Voldyne spirometer (Hudson RCI, Temecula, CA, USA) and the flow-oriented device was a Respirom spirometer (Hudson RCI). In order to perform DB, the subjects were instructed to relax the upper chest, the shoulders, and the arms, while the lower chest and the abdomen were displaced during a deep inhalation.⁽²⁰⁾ All subjects received instructions and training on how to perform DB and how to use the incentive spirometers one day before the assessment. Each type of breathing exercise was performed until three reproducible values of diaphragmatic mobility were obtained (variation < 5%).

The sample size of 17 subjects was calculated with a two-tailed test for mean

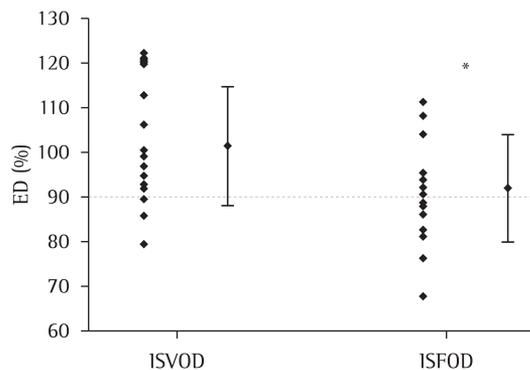


Figure 2 - Comparison between diaphragmatic mobility during the use of incentive spirometry with a volume-oriented device (ISVOD) and during the use of incentive spirometry with a volume-oriented device (ISFOD), in relation to that observed during diaphragmatic breathing (DB), which was considered the reference. Values expressed as % of DB. *p < 0.05.

Table 2 – Comparison between men and women in terms of diaphragmatic mobility during the three types of breathing exercises.^a

Diaphragmatic mobility	Men	Women	p
During DB, mm	73.26 ± 12.00	66.39 ± 12.10	0.20
During the use of ISVOD, mm	73.28 ± 15.67	67.40 ± 10.79	0.37
During the use of ISFOD, mm	65.26 ± 12.27	62.23 ± 10.58	0.59

DB: diaphragmatic breathing; ISVOD: incentive spirometry with a volume-oriented device; and ISFOD: incentive spirometry with a flow-oriented device.^aValues expressed as mean ± SD.

differences, in accordance with the following assumptions, which were based on the results for the first 5 volunteers: a standard deviation of 9.10 mm; an expected intergroup difference of 9.70 mm; a statistical power of 80%; and a level of significance of 5%, which suggested a sample size of 15 individuals. All data are expressed as mean and standard deviation, and data distribution was analyzed with the Shapiro-Wilk test. Repeated measures ANOVA and the Holm-Sidak post hoc test were used in order to compare diaphragmatic mobility during the three types of breathing exercises. The analyses were performed with the SigmaStat statistical package, version 3.5 (Systat Software Inc., San Jose, CA, USA), and the level of statistical significance was set at $p < 0.05$ for all tests.

Results

The anthropometric characteristics and the pulmonary function test results of the volunteers are described in Table 1. As can be seen, the pulmonary function values are within the range considered normal.

The assessment of diaphragmatic mobility revealed statistically significant differences between mobility during ISVOD and mobility during ISFOD (70.16 ± 12.83 mm vs. 63.66 ± 10.82 mm; $p = 0.02$), as well as between mobility during DB and mobility during ISFOD (69.62 ± 11.83 mm vs. 63.66 ± 10.82 mm; $p = 0.02$). There were no significant differences between DB and ISVOD in terms of diaphragmatic mobility

(70.16 ± 12.83 mm vs. 69.62 ± 11.83 ; $p = 0.05$). Figure 1 shows diaphragmatic mobility during the three types of breathing exercises.

Diaphragmatic mobility during DB was used as a reference to compare the different incentive spirometers. To that end, diaphragmatic mobility during the use of the spirometers was expressed as percentage of that observed during DB (% of DB). Diaphragmatic mobility during incentive spirometry was considered satisfactory when the subjects achieved at least 90% of DB. We found that 82.35% of the subjects achieved at least 90% of DB when they used ISVOD. In contrast, only 58.82% of the subjects achieved 90% of DB when they used ISFOD. In Figure 2, we can see that, with the use of ISVOD, the subjects achieved $101.46\% \pm 12.83\%$ of DB, whereas, with the use of ISFOD, they achieved $91.99\% \pm 10.82\%$ of DB, this difference being significant ($p = 0.04$).

Table 2 shows the comparison of the values of diaphragmatic mobility obtained for men and women during the different breathing exercises. Although the women were older and had lower FVC in liters (Table 1), there were no significant gender-related differences in terms of diaphragmatic mobility during the different breathing exercises. However, when diaphragmatic mobility was normalized to FVC in liters, we observed that, during all three types of breathing exercises assessed, the mobility/FVC (mm/L) ratio was higher for the women than for the men (Table 3).

Table 3 – Comparison between men and women in terms of the diaphragmatic mobility/FVC ratio during the three types of breathing exercises.^a

Diaphragmatic mobility/FVC	Men	Women	p
During DB, mm/L	14.20 ± 2.95	18.05 ± 3.36	0.02
During the use of ISVOD, mm/L	14.21 ± 3.49	18.27 ± 2.50	0.01
During the use of ISFOD, mm/L	12.76 ± 3.34	16.98 ± 3.38	0.02

DB: diaphragmatic breathing; ISVOD: incentive spirometry with a volume-oriented device; and ISFOD: incentive spirometry with a flow-oriented device.^aValues expressed as mean ± SD.

Discussion

It is known that, among patients undergoing upper abdominal or thoracic surgery, the major postoperative complications include atelectasis, hypoxemia, pneumonia, and pleural effusion, and that the most common causes of such complications are anesthesia, intraoperative manipulation, pain, and a change in breathing pattern.⁽²¹⁾ Any of these factors can lead to an inefficient pattern of thoracoabdominal motion, affecting the regional distribution of ventilation.⁽¹⁹⁾ Respiratory therapy aims to reduce the risk of postoperative pulmonary complications and to accelerate the functional recovery of patients. Patients at risk for pulmonary complications seem to benefit more from breathing exercises that maximize the inspiratory efforts than from those that do not.⁽²²⁾

An incentive spirometer is a portable device whose main purpose is to promote deep, slow inhalation, up to maximal inspiratory capacity, by providing patients with a visual stimulus signaling that the desired flow or volume has been reached. One group of authors⁽²³⁾ monitored patients submitted to upper abdominal surgery. Those patients were divided into two groups of postoperative intervention: one performing inhalation and assisted cough maneuvers (control group); and one using those techniques in combination with incentive spirometry (intervention group). The authors observed a reduction in length of hospital stay and a lower incidence of respiratory complications in the group using incentive spirometry. Another group of authors⁽²⁴⁾ assessed the effects of incentive spirometry combined with expiratory positive air pressure (EPAP) in patients submitted to myocardial revascularization. The patients were randomly assigned to the intervention group (incentive spirometry + EPAP) or to the control group (only instructed regarding the cough technique, early mobilization, and inhalation maneuvers). Those authors reported quicker recovery of respiratory muscle strength, pulmonary function, and functional capacity in the group using incentive spirometry combined with EPAP. In addition, the group using the combination therapy showed a lower incidence of postoperative complications and shorter hospital stays. In contrast with these findings, systematic reviews performed by two groups of authors,^(6,25) who assessed the effects of incentive spirometry

on the prevention of postoperative pulmonary complications in patients submitted to thoracic or upper abdominal surgery, found no evidence that the use of this technique is beneficial in such patients. However, those authors warned that their results should be analyzed with caution, since the number of patients included in the studies reviewed was small, the methodological quality was questionable, given that a variety of techniques were used in combination and were compared with one another (without assessing the effects of incentive spirometry in isolation), and the material specifications did not define the type of incentive spirometer used. In view of the unfavorable results reported in the systematic reviews of incentive spirometry, two lines of reasoning are applicable. The first is that the reviews reported results that reflect reality and that the use of incentive spirometry should therefore be discontinued. The second is that the methodological failures mentioned above significantly compromise the analysis of the results and, consequently, this issue has yet to be fully investigated.

One of the factors that can influence the success of the use of incentive spirometry for reducing postoperative pulmonary complications is the correct indication of the equipment to candidates who are more likely to benefit from the properties and mechanical effects produced by the device. When indicating incentive spirometry, we are faced with the choice between two types of spirometers: volume-oriented devices and flow-oriented devices. The effects of these devices on respiratory mechanics have yet to be fully defined. Some studies have shown differences between the different types of incentive spirometers in terms of respiratory pattern, thoracoabdominal motion, respiratory effort, and accessory muscle recruitment.⁽⁸⁻¹⁰⁾ In the present study, diaphragmatic mobility was measured via ultrasound during the use of incentive spirometers. Our results showed that diaphragmatic mobility was significantly greater during ISVOD and during DB than during ISFOD.

To our knowledge, there have been no studies assessing diaphragmatic mobility during the use of different types of incentive spirometers, which makes the comparative analysis of our results difficult. However, abdominal motion has been shown to correlate well with diaphragmatic

excursion during deep breathing in healthy subjects, and, therefore, the assessment of abdominal wall displacement can be used as an indirect measure of diaphragmatic function.⁽²⁶⁾ In one study,⁽⁹⁾ involving respiratory inductance plethysmography, it was demonstrated that abdominal motion is greater during ISVOD than during ISFOD. Another study showed that the electromyographic activity of the accessory respiratory muscles is significantly greater during ISFOD than during ISVOD.⁽¹⁰⁾ Our results corroborate the finding that diaphragmatic mobility is greater during ISVOD than during ISFOD.

When we compared the use of ISVOD with the use of ISFOD, employing DB as the reference, we obtained satisfactory results (diaphragmatic mobility > 90% of DB) with both spirometers. However, a greater number of individuals achieved satisfactory diaphragmatic mobility during the use of ISVOD than during the use of ISFOD (82.35% vs. 58.82%). In addition, in terms of the percentage of DB, diaphragmatic mobility was significantly greater during the use of ISVOD than during the use of ISFOD.

In the present study, diaphragmatic mobility during the various breathing exercises was lower in the women than in the men, although this difference was not statistically significant. One group of authors,⁽²⁷⁾ investigating the respiratory movements and breathing patterns of men and women during normal deep breathing, found that there was less abdominal motion in the women, suggesting decreased diaphragmatic mobility in women under these conditions. Some authors have reported that women show 11-20% less diaphragmatic excursion during deep breathing, in comparison with men.^(28,29) In the present study, the women showed 5% and 8% less diaphragmatic mobility during ISFOD and ISVOD, respectively, than did the men. Considering that during incentive spirometry, there are maximal amplitude inspiratory patterns, our results are in agreement with those of the studies mentioned above, although the difference was of lesser magnitude in our study. The lack of statistical significance in the present study can be explained by the small number of individuals evaluated in each category.

In an attempt to understand more clearly the difference between men and women in terms of diaphragmatic mobility during the different

types of breathing exercises assessed in this study, diaphragmatic mobility was normalized to FVC. This analysis was performed based on a previous study, which reported a significant correlation between diaphragmatic mobility and pulmonary function parameters, including FVC.⁽³⁰⁾ Our results showed that the mobility/FVC (mm/L) ratio was significantly greater in women than in men, indicating that women performed better than did men on all three types of breathing exercises. One group of authors⁽²⁸⁾ reported that BMI can be considered another factor affecting diaphragmatic mobility in healthy subjects. In the present study, this variable seems to have had no influence on the results of the comparison between men and women, since the two were similar in terms of BMI.

One of the limitations of the present study is the fact that we assessed healthy adults. Therefore, the relationship between our findings and clinical practice remains to be established. However, we were careful to select individuals who had no previous experience with the devices tested, in order to simulate a clinical context in which, frequently, the patient has no prior knowledge of how the devices work.⁽⁹⁾ We suggest that further studies be conducted to assess diaphragmatic mobility during incentive spirometry in patients at risk for pulmonary complications. In addition, the cumulative effects of the use of the three different approaches (DB, ISVOD, and ISFOD) had no influence on the results, since the order in which the approaches were assessed was randomized. Another limitation of the present study was the fact that we did not assess diaphragmatic mobility at rest, and, consequently, it was not possible to determine the proportion of variation obtained with the different types of breathing exercises in relation to basal conditions.

Our results suggest that ISVOD and DB promote greater diaphragmatic mobility than does ISFOD. Therefore, when the therapeutic goal is to increase diaphragmatic mobility, ISVOD and DB seem to be equally effective in the treatment of respiratory alterations. This criterion should be considered for the correct indication of the type of incentive spirometer to be used in clinical practice. Finally, we also found that women performed better than did men on all three types of breathing exercises.

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About the authors

Wellington Pereira dos Santos Yamaguti

Physical Therapist. Department of Rehabilitation Medicine, Sírio-Libanês Hospital, São Paulo, Brazil.

Eliana Takahama Sakamoto

Physical Therapist. Department of Rehabilitation Medicine, Sírio-Libanês Hospital, São Paulo, Brazil.

Daniilo Panazzolo

Physical Therapist. Heart Hospital of Londrina and Regional University Hospital of Northern Paraná, Londrina, Brazil.

Corina da Cunha Peixoto

Physician. Department of Ultrasound, Diagnostic Center, Sírio-Libanês Hospital, São Paulo, Brazil.

Giovanni Guido Cerri

Full Professor. University of São Paulo School of Medicine; Director. Diagnostic Center, Sírio-Libanês Hospital, São Paulo, Brazil.

André Luis Pereira Albuquerque

Physician in Charge of the Department of Pulmonary Function. Sírio-Libanês Hospital, São Paulo, Brazil.