Effects of Inspiratory Muscle Training in Elderly Women on Respiratory Muscle Strength, Diaphragm Thickness and Mobility

Helga Souza,[1] Taciano Rocha,[1] Maíra Pessoa,[1] Catarina Rattes,[1] Daniella Brandão,[1]
Guilherme Fregonezi,[2] Shirley Campos,[1] Andrea Aliverti,[3] and Armele Dornelas[1]

[1]Department of Physical Therapy, Universidade Federal de Pernambuco, Recife, Brazil.
[2]Department of Physical Therapy, Universidade Federal do Rio Grande do Norte, Natal, Brazil.
[3]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy.

Address correspondence to Armele Dornelas, PhD, Department of Physical Therapy, Universidade Federal de Pernambuco, Recife, Brazil.
Email: armeledornelas@hotmail.com

AGING results in a decline in lung function as in other systems. The principal changes in the respiratory system of the elderly include loss of chest wall compliance, decrease in strength of elastic recoil of lung parenchyma, decrease in respiratory muscle strength, and decreased responsiveness to hypoxemia and hypercapnia (1,2).

The loss of muscle mass or age-related sarcopenia potentially reduces the production of maximum strength (3). With the advance of age, the deficit in respiratory muscle strength affects physical performance leading to loss of exercise per-formance, deterioration of gait, and decrease of the quality of life (4,5). The reduction of respiratory muscle function in the elderly makes this population more vulnerable to disease and disability (6), therefore the prevention of a deficit in res-piratory muscle strength reduces functional decline in the elderly by reducing the risk of morbidity and mortality (7).

Peripheral muscle exercises promote an increase in respiratory muscle strength and endurance (8). However, these gains appear to be higher when combined with specific training of the respiratory muscles (9), making this an option to supplement the training of peripheral muscles and generating benefits in different current comorbidities such as hypertension (10), obesity (11), and diabetes (12) that affect a large portion of the elderly.

As in postmenopausal women the reduction in levels of estrogen appears as an additional factor for the emergence of sarcopenia (13), we hypothesized that inspiratory muscle training (IMT) could be particularly beneficial for this population. So, the primary objective of this study was to evaluate the efficacy of an IMT protocol on respiratory muscle strength and diaphragmatic thickness and mobility in the elderly women.

METHODS

Study Design

This was a controlled, randomized, double-blind trial and with allocation concealment. It was approved by the Research Ethics Committee of the Center for Health

Sciences at the Federal University of Pernambuco and complied with the Declaration of Helsinki. The study was registered in the clinical trials database of the United States with the number NCT 01791010.

The research was conducted in the Laboratory of Cardiopulmonary Physiotherapy, Physiotherapy Department, Federal University of Pernambuco (UFPE). All volunteers signed a free and informed consent form.

Participants

Elderly women aged between 60 and 80 years were included, who had normal spirometry ($FEV_1 \geq$ LLN and FVC ≥ LLN) were capable of walking without aid and with cognitive health assessed through the mini mental state examination. Exclusion criteria were the following: participation in any previous rehabilitation training protocol, contra-indication, or difficulty carrying out the evaluation procedures, respiratory muscle strength less than 70% of the predicted level (14) difficulty of adaptation or adhesion to the training protocol, smokers, presence of hemodynamic instability (heart rate >150 bpm, or systolic blood pressure >140 mmHg or diastolic blood pressure >90 mmHg), neuromuscular or degenerative diseases, pulmonary comorbidities, heart disease, and users of medications that interfere in bone metabolism or in muscle strength.

The sample size was determined by sampling calculation done from data collected during a pilot study with 10 volunteers, which established a sample of 9 individuals for each group. The statistical program G*Power 3 was used (15,16), which considered a power (1–β) of 95% and an α of 5% for the inspiratory muscle strength outcome based on the average and standard deviation of maximum inspiratory pressure (MIP) of the training and control groups after the intervention.

Procedures and Measures of Outcomes

Anthropometric, clinical, and demographic data were collected and the level of physical activity was evaluated through a self-reported instrument adapted to the Brazilian population, the profile of human activity [PHA (17)]. This instrument quantifies the level of physical activity through the adjusted activity score (AAS) sorting the individual into three categories: inactive (AAS < 53), moderately active (53 ≤ AAS ≤ 74) and active (AAS > 74). Subsequently, the participants were evaluated at two moments: before training and 1 week after completion of the training by an examiner who did not know the allocation group.

The primary outcomes were respiratory muscle strength, diaphragmatic thickness and mobility; secondary outcomes were adverse effects of IMT.

After the initial evaluation, the participants were randomly distributed into blocks of four individuals (18) using a table of random numbers by a third person who did not directly participate in the research, thus ensuring the allocation concealment. This informed the therapist, responsible for the training, where the participant would be allocated: control group (CG) or training group (TG).

Pulmonary Function Tests

The pulmonary function tests were accomplished through a portable spirometer (Micro Medical, Microloop, MK8, England), which recorded the best value of the forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), forced expiratory flow 25%–75% ($FEF_{25\%-75\%}$) and the ratio FEV_1/FVC after three acceptable maneuvers, being considered the reference spirometry values for the Brazilian adult population, in accordance with the following reference equations (19):

$$\text{FVC (liters)} = 0.0441 \times \text{height (cm)} - 0.0189\ \text{age (years)} - 2.848 \qquad (r^2 = 0.66)$$

$$\text{FEV}_1\ \text{(liters)} = 0.0314 \times \text{height (cm)} - 0.0203\ \text{age (years)} - 1.353 \qquad (r^2 = 0.66)$$

$$\text{FEV}_1/\text{FVC} = 0.140 \times \text{height (cm)} - 0.158\ \text{age (years)} + 111.5 \qquad (r^2 = 0.17)$$

$$\text{FEF}_{25\%-75\%}\ \text{(liters/s)} = 2.7183^{(0.998\,(\log n\ \text{height (cm)})-0.588\,(\log n\ \text{age (years)})-1.852)} \qquad (r^2 = 0.36)$$

Respiratory Muscle Strength

The measurement of the MIP and maximum expiratory pressure (MEP) was performed through a digital manometer (MVD300, Globalmed, Brazil) from residual volume and total lung capacity, respectively (20). At least five measurements were carried out, until three acceptable and reproducible measurements were obtained, that is, without air leakage and with less than 10% difference among them, with the highest value obtained being registered (14). The following reference equations were used (14):

$$\text{MIP (cm } H_2O) = -0.49 \times \text{age (years)} + 110.4 \qquad (r^2 = 0.465)$$

$$\text{MEP (cm } H_2O) = -0.61 \times \text{age (years)} + 115.6 \qquad (r^2 = 0.479)$$

Diaphragm Thickness and Mobility

To evaluate diaphragmatic thickness ultrasound (Sonoace R3, Samsung Medison, South Korea) in B-mode was used. The volunteer was positioned in left lateral decubitus (21) and a linear transducer with high resolution and low pen-etration (7.5 MHz) was placed at right angles to the ribcage between the eighth and ninth intercostal space on the right side between the anterior and medial axillary lines (22).

Diaphragm thickness was evaluated in three different conditions (Figure 1). Measurements of diaphragm thickness at FRC (with relaxed diaphragm, T_{rel}) were obtained by asking the subject to breath quietly and spontaneously. The measurements at TLC (with contracted diaphragm, T_{cont}) were obtained by asking the subject to take a maximal inspiration starting from the end of a spontaneous expira-tion. The measurements at MIP were obtained by asking the subject to perform a maximal inspiratory contraction at the end of a spontaneous expiration.

For each condition, each measurement was repeated on five occasions and the mean value of diaphragm thickness

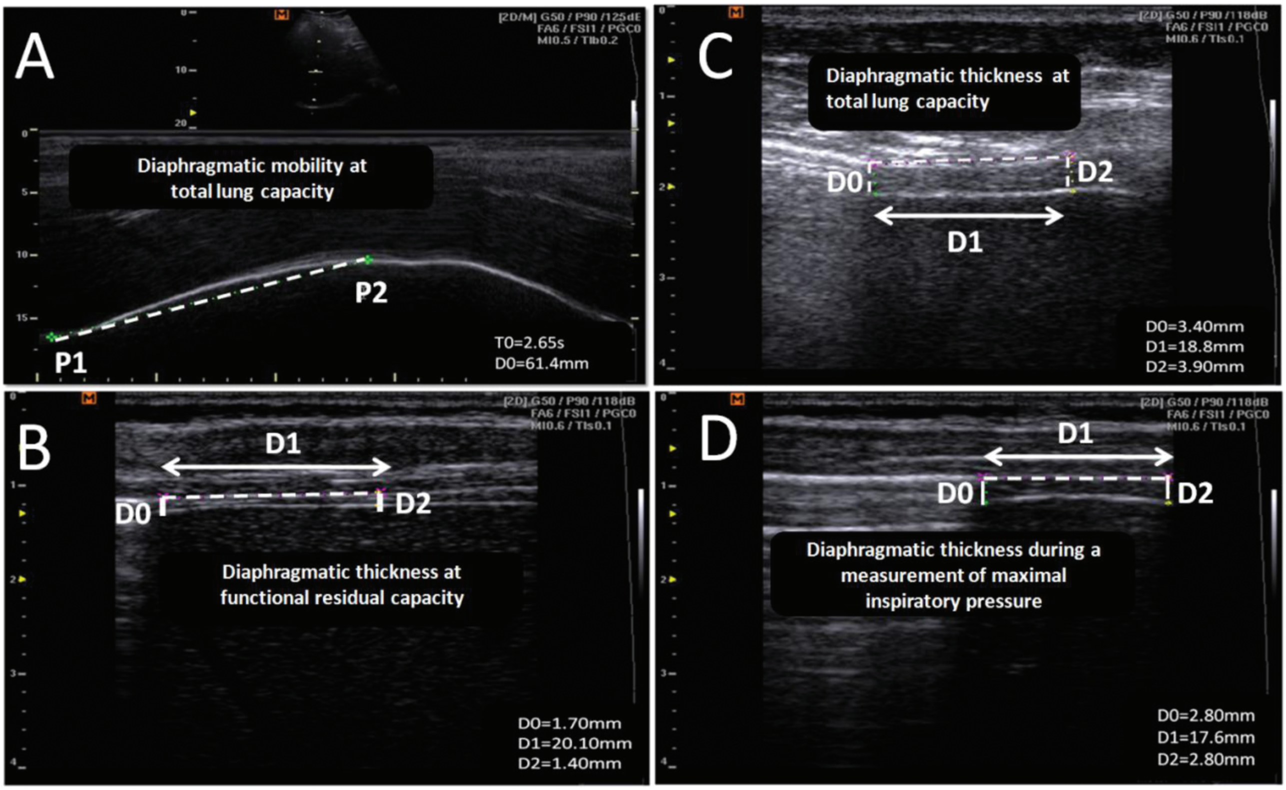

Figure 1. Evaluation of diaphragmatic thickness and mobility. **A**: example of M-mode ultrasound image to assess diaphragm mobility from functional residual capacity (Point P1) to total lung capacity (Point P2). Examples of B-mode ultrasound images to assess diaphragm thickness at functional residual capacity (FRC) (**B**), total lung capacity (TLC) (**C**) and during a measurement of maximal inspiratory pressure (MIP) (**D**). In each condition, two measurements of thickness (D0 and D2) are taken at a distance of 2 cm apart (D1).

(Figure 1B–D) was calculated on all measurements obtained with less than a 10% difference among them. Thickening ratio (TR) was determined as follows (22):

$$\text{TR} = \frac{\text{Thickness during MIP maneuver at FRC}}{\text{Mean thickness while relaxing at FRC } (T_{\text{rel}})}$$

The measurement of diaphragmatic mobility was taken as the displacement of diaphragm dome between FRC and TLC (Figure 1A) with the volunteers lying at a 45° angle. The meas-urements were performed using ultrasound in M mode with a convex transducer (3.5 MHz) positioned in the medial axillary line on the right side below the costal margin of the ribcage, with the steady hand directed cranially (23). For each M-mode recorded image, the vertical distance between the point cor-responding to the beginning of the full inspiration (Point P1 in Figure 1A) and point corresponding to the maximal diaphragm displacement (Point P2 in Figure 1A) was determined.

Experimental Protocol

The elderly women performed the intervention protocol over 8 weeks using the Threshold IMT (Respironics, NJ). The TG performed IMT with a frequency of two sessions per day, 7 days a week, with one weekly session in the presence of the therapist responsible for training and the remaining sessions conducted by the participant at home. The participants performed eight series of 2 minutes with a 1-minute rest between them and were directed to perform standard diaphragmatic breaths. The intensity of the training was adjusted to 40% of the MIP (12), measured during the initial evaluation. The load intensity adjustment was performed weekly by evaluating the MIP. During the entire period of the intervention protocol, the resistive load was kept at 40% of MIP or 41 cm H_2O when the MIP of the participant exceeded the value of 103 cm H_2O. The CG performed the same protocol except for the training load intensity of training. Load adjustment was simulated on a weekly basis to reproduce the same frequency of weekly return of the TG.

The training protocol of both groups was carried out by a single therapist in order to standardize the training. All the volunteers were given a training diary where the time of the completion of training, the pauses which occurred and the presence of adverse effects were reported. Telephone contact was held twice a week to ensure the completion of training and clarify any doubts. All the participants maintained their habitual physical activity without any increase to that referred to in the initial assessment period.

Statistical Analysis

The results of the initial characteristics of the sample and statistical analysis of the data were expressed as mean and standard deviation (SD). The Shapiro–Wilk and Levene tests were used to evaluate the normality and homogeneity of the data. The *t*-test for independent samples and the Mann–Whitney test were used to compare the basic characteristics of the groups. The analysis of variance (ANOVA) for repeated measurements (with Greenhouse-Geisser correction) was used to investigate the effects on time (within groups) and on the group (between groups) with the Power related to the following outcomes: respiratory muscle strength (MIP and MEP), diaphragm thickness (T_{cont} and TR) and diaphragm mobility. To compare other outcomes was used the Mann–Whitney test. To estimate the size of the effect of differences between the groups for the respective outcome, the Cohen *d* was calculated. The analysis was conducted by the program SPSS for Windows (version 20.0, Chicago, IL) being established a significance level of $p < .05$.

Results

In the period from March to September 2012, 43 elderly women were contacted by phone; of these 25 participants were randomly distributed in the CG or TG (Figure 2).

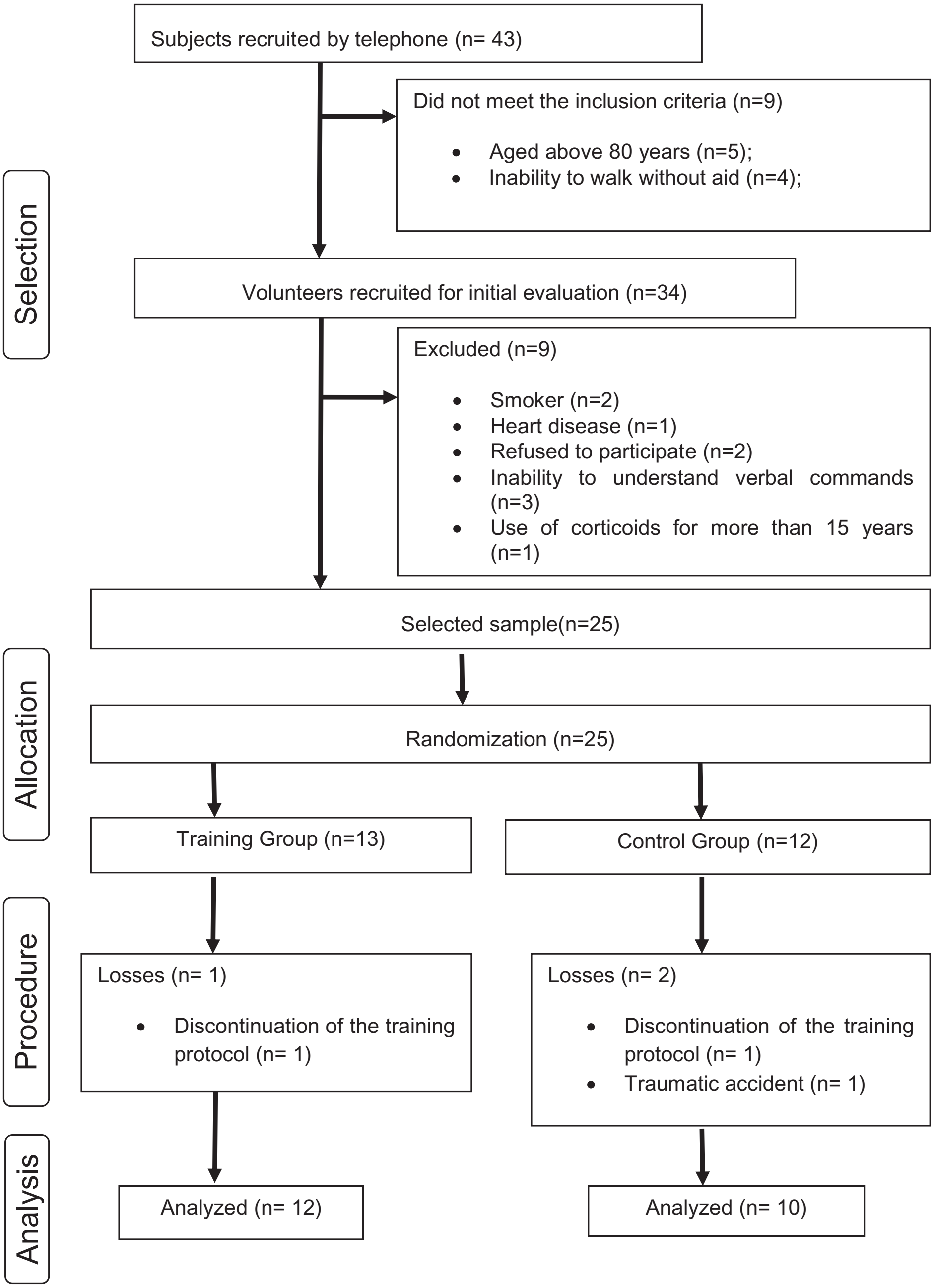

Figure 2. Flowchart of participants.

The baseline characteristics of the sample are shown in Table 1.

Respiratory Muscle Strength

Figure 3 shows MIP and MEP variations before and after IMT. Significant effects of IMT were observed on MIP between pre- and post- treatment ($p < .001$, Power = 1.0) and between groups ($p < .001$, Power = 1.0) in favor of the TG. Percentage changes of MIP were significantly different between the TG and CG ($p < .001$).

MEP changes were also significantly higher in the TG considering pre- versus post- ($p = .001$, Power = 0.967) and group ($p = .013$, Power = 0.732) differences. Percentage changes of MEP were significantly different between the TG and CG ($p = .017$).

Diaphragm Thickness and Mobility

As shown in Figure 3, T_{cont} significantly increased in the TG considering pre- versus post- ($p < .001$, Power = 1.0) and group ($p = .001$, Power = 0.941) differences. Percentage changes of T_{cont} were significantly different between TG and CG ($p = .002$). Diaphragm mobility was significantly differ-ent in favor of the TG considering pre- versus post- ($p = .001$, Power = 0.949) and group ($p = .013$, Power = 0.744) differences. Percentage changes of diaphragm mobility were significantly different ($p = .011$) between the TG and CG. TR values did not show significant differences between the groups, not affected by neither pre- versus post- ($p = .508$, Power = 0.098) nor group ($p = .216$, Power = 0.230). Percentage changes of TR and T_{rel} were not significantly different between the TG and CG ($p = .418$ and $p = .058$, respectively). Percentage changes of T_{rel} were significantly different ($p = .009$) between the TG and CG.

The values of all parameters and their differences, averaged in the different groups are shown in Table 2.

Correlation Between Inspiratory Muscle Strength and Diaphragm Thickening Ratio

A moderate positive correlation was observed between the MIP and the TR ($r = .427$ and $p = .048$).

Adverse Effects

Three volunteers (13.6%) in the intervention group reported respiratory distress during the sessions however this adverse effect ceased during the training protocol. The same subjects had normal spirometric measures without restric-tive or obstructive pattern, nevertheless they presented a lower inspiratory muscle strength (MIP = 60, 60, and 70 cm H_2O) compared to the average of the group they belonged (73.3 ± 12.1 cm H_2O). Two volunteers belonging to the intervention group and one belonging to CG (13.6% of the total sample) reported nausea after training sessions although this adverse effect ceased after the first month of training protocol.

Discussion

Our results revealed that a protocol of 8 weeks of IMT improves respiratory muscle strength, diaphragm thickness,

Table 1. Basic Characteristics of Participants in Both Groups (mean ± *SD*)

Parameters	Training Group ($n = 12$)	Control Group ($n = 10$)	p Value
Age (years)	68.3 ± 5.2	68.3 ± 5.3	.982
Weight (kg)	69.2 ± 7.4	70.9 ± 7.8	.636
Height (cm)	154 ± 4	156 ± 6	.599
BMI (kg/m^2)	28.1 ± 3.6	29.9 ± 4.5	.295
AAS	63.5 ± 8.1	57.7 ± 7.6	.079
FEV$_1$ (L)	1.9 ± 0.3	2.1 ± 0.5	.207
FEV$_1$ (% predicted)	90.3 ± 11.9	94.4 ± 19.6	.414
FVC (L)	2.3 ± 0.4	2.5 ± 0.5	.147
FVC (% predicted)	83.3 ± 13.1	88.1 ± 18	.488
FEV$_1$/FVC (ratio)	89.9 ± 6.5	87.5 ± 18.3	.462
FEV$_1$/FVC (% predicted)	112.7 ± 9.1	109.2 ± 22.8	.419
FEF$_{25\%–75\%}$ (L/s)	2.4 ± 0.7	2.4 ± 0.9	.988
FEF$_{25\%–75\%}$ (% predicted)	119.5 ± 33.5	114.3 ± 39.8	.755
MIP (% predicted)	95.3 ± 15.4	103.1 ± 23.2	.348
MEP (% predicted)	120.7 ± 12.5	127.9 ± 19.1	.166
MIP (cm H_2O)	73.3 ± 12.1	79.4 ± 18.4	.361
MEP (cm H_2O)	89.2 ± 9.3	94.4 ± 13.7	.307
T_{rel} (mm)	2.1 ± 0.1	2.0 ± 0.3	.221
T_{cont} (mm)	4.4 ± 0.5	4.5 ± 0.5	.663
TR	1.6 ± 0.6	1.6 ± 0.5	.795
Diaphragm mobility (mm)	63.3 ± 8.0	65.0 ± 4.3	.599

Note: AAS = adjusted activity score; BMI = body mass index; cm H_2O = centimeters of water; FEF$_{25\%–75\%}$ = forced expiratory flow between 25% and 75% of the expiratory cycle; FEV1 = forced expiratory volume in the first second; FVC = forced vital capacity; MEP = maximum expiratory pressure; MIP = maximum inspiratory pressure; T_{cont}: diaphragm thickness at total lung capacity; T_{rel}: diaphragm thickness at functional residual capacity; TR = thickening ratio.

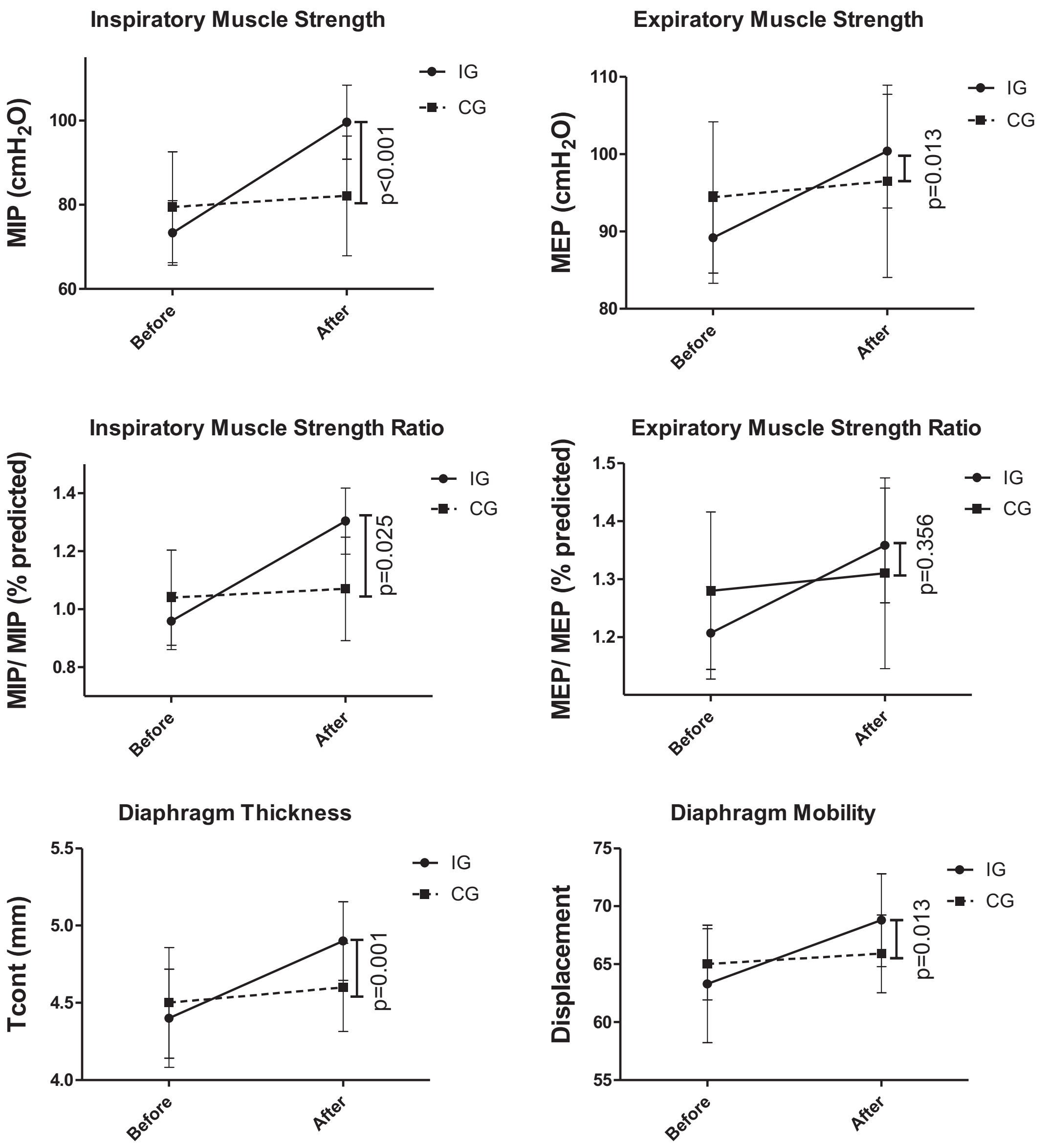

Figure 3. Mean values and 95% CI of maximal inspiratory pressure (MIP), maximum expiratory pressure (MEP), maximal inspiratory pressure ratio (MIP/MIP % predicted), maximal expiratory pressure ratio (MEP/MEP % predicted), diaphragm thickness in maximum contraction (T_{cont}) and diaphragmatic mobility before and after the inspiratory muscle training in Intervention Group (IG) and Control Group (CG).

and mobility in elderly women. The training protocol was described and the intensity of the load applied in the volun-teers was controlled and readjusted weekly, with adherence to the controlled training as suggested by Illi and colleagues (9), through diary and phone contacts.

Respiratory Muscle Strength

The TG showed an increase in inspiratory muscle strength similar to the results found in other studies conducted on elderly people (24–26), healthy subjects (9,27), hypertensive patients (10), and obese (11). In addition to MIP, there was an increase in MEP in the TG. The latter result can be explained by the neural conditioning resulting from repeated exposures to the same task (learning effect), a mechanism that generates an increase in respiratory muscle strength by improving neuromuscular recruitment pattern (28,29).

Some studies have noted that the IMT reduces sympathetic activity (30), providing benefits for the whole body. Other studies have reported that increases in MIP lead to improved cardiopulmonary fitness by better utilization of locomotor muscles (24), which is also associated with reduction of blood pressure in hypertensive patients (10) and increased sensitivity to insulin in patients with diabetes (12).

Regardless of the mechanism, it is suggested that the increase in respiratory muscle strength may contribute to improve exercise capacity and decrease the risk of respiratory

Table 2. Mean Values and Gains of Respiratory Muscle Strength, Diaphragm Thickness, and Mobility After Intervention

Outcomes	Training Group (n = 12) (mean ± SD)	Control Group (n = 10) (mean ± SD)	Differences of the means (95% CI)	Size of Effect (*d* of Cohen)
MIP (cm H_2O)	99.6 ± 13.8	82.1 ± 19.9	−17.5 (−32.5; −2.5)	1.0
ΔMIP (%)	26.3 ± 7.6	2.8 ± 7.4	−23.5 (−30.2; −16.8)	3.1
MEP(cm H_2O)	100.4 ± 11.6	96.5 ± 17.4	−3.8 (−16.8; 9.1)	0.3
ΔMEP (%)	10.7 ± 6.9	1.5 ± 7.7	−9.2 (−15.7; −2.7)	1.3
T_{rel} (mm)	2.2 ± 0.1	2.0 ± 0.3	−0.2 (−0.4; 0.0)	0.9
ΔT_{rel} (%)	5.0 ± 6.1	−1.7 ± 6.1	−6.7 (−12.2; −1.2)	1.1
T_{cont} (mm)	4.9 ± 0.4	4.6 ± 0.4	−0.3 (−0.6; 0.1)	0.7
ΔT_{cont} (%)	9.4 ± 4.8	2.2 ± 5.0	−7.2 (−12.2; −2.1)	1.5
TR	1.7 ± 0.5	1.6 ± 0.6	−0.1 (−0.5; 0.4)	0.1
ΔTR (%)	6.2 ± 18.7	−3.5 ± 11.0	−9.7 (−23.7; 4.3)	0.7
Diaphragm mobility (mm)	68.8 ± 6.3	65.9 ± 4.7	−2.9 (−8.5; 2.8)	0.5
ΔDiaphragm mobility (%)	8.5 ± 5.4	2.5 ± 4.3	−6.0 (−10.4; −1.6)	1.3

cm H_2O = centimeters of water; MEP = maximum expiratory pressure; MIP = maximum inspiratory pressure; ΔOutcome% = (outcome after intervention − outcome before intervention/outcome before intervention) 100; T_{cont} = diaphragm thickness at total lung capacity; T_{rel} = diaphragm thickness at functional residual capacity; TR = thickening ratio.

infections and hospitalizations due to expiratory force gain that generates greater effectiveness of coughing (31,32).

Diaphragm Thickness and Mobility

Ultrasound has been used as a noninvasive method to evaluate diaphragm thickness in the zone of apposition dur-ing the different volumetric changes of the lung (22,33,34). However, no previous studies were found that evaluated the effect of a program of IMT on diaphragmatic thickness and mobility in the elderly. Despite using the same methodology described in previous studies (22,34) diaphragmatic thickness values found in the volunteers of the pretraining study were greater than those assessed in healthy young people (33,34), making evident the gap in the literature about the standardization of diaphragmatic thickness values. This difference may be related to infiltration of muscle fat that may contribute in part to the decline in senile muscle function (3,35,36).

In the present study it was found that the IMT proto-col increased T_{cont} in trained volunteers suggesting that increased MIP in the TG could be associated with muscular hypertrophy. This findings are in accordance with those of Enright and colleagues (34), who observed an increase in T_{cont} in a trained group after 9 weeks of IMT with high intensity performed three times a week in healthy young people, and those of Downey and colleagues (33), who found an increase in T_{cont} in healthy young people after 4 weeks of IMT. Another study (37) reported that training of respiratory muscles through global physical training produces an increase of 26% in the thickness of the diaphragm after 16 weeks of intervention.

Also, we did not find any difference was found between the groups in T_{rel}. This measure is performed at rest (with equilibrium between retractable and expansive forces of the lung), and presumably it is not affected by training.

Although T_{rel} might be considered the best outcome measure to evaluate IMT effect over diaphragm thickness and considered more unbiased compared to T_{cont} because it is independent of patient's effort our findings, corroborated by those of Enright and colleagues (34), suggest that T_{rel} underestimate the initial effects of neuromuscular adaptations to training.

In the present study, it was also found that after 12 weeks of IMT, diaphragm mobility and the maximal respiratory pressures were improved in the trained volunteers. Thus, intervention may have caused neuromuscular adaptations that preceded the hypertrophy effects of training (38) as increasing of motor unit recruitment (39) and firing frequency, beside a reduction on muscle excitability threshold (38). Therefore, this idea strengthens the hypothesis that despite of being an effort dependent measure, T_{cont} can reflect a combination of both hypertrophy and changes in contractile specific force (through neuromuscular adapta-tions) of diaphragm muscle during effort.

Maintenance of TR with no difference between the groups was an unexpected finding in our study, diverging from the results found by other authors in young healthy subjects (33,34) and patients with cystic fibrosis (21). However, those studies considered a IMT protocol with intensity greater than that used in our research, thus it seems that IMT with moderate intensity does not produce effects on the TR. The TR showed moderate correlation with MIP, suggesting that increased inspiratory muscle strength is not the only contributing factor. It is also important to note that the TR is derived from the measured thickness during maneuver of MIP and two possible factors may have influenced this result: the thickness obtained is caused by an isometric contraction of the diaphragm, as it occurs with little change of volume (40) and the increase in maximum inspir-atory strength of the elderly women produced after the IMT protocol may not have been sufficient to generate detectable thickness increases during an isometric maneuver.

Finally, in our our study we found an increase in the diaphragm mobility in the volunteers who performed IMT.

This finding suggests that increased inspiratory muscle strength with muscle hypertrophy generates benefits that might improve respiratory mechanics.

Adverse effects reported by the volunteers ceased after the first month of training, therefore IMT seems to be a safe procedure that might induce only short term adverse effects over this population. We believe that the respiratory distress reported was caused by the effort to open the inspiratory valve of the training device, since all volunteers presented normal spirometric measures, but had a low initial MIP which may have worsened the performance of the procedure. Nausea during the training might be related to the use of the mouthpiece what induces a mouth breathing pattern associated to a hyperventilation pattern during IMT. Since both adverse effects ceased during the rest of the intervention protocol, probably those volunteers did a higher effort than necessary during beginning of IMT. This finding suggests that individuals with lower levels of MIP, perhaps, should be initially trained with lower intensities load which could decrease the adverse effects in the first period and might provide an increase in the rate of adherence to the training protocol, although this has to be verified in future studies. It should also be considered that during the study those volunteers might have learned the correct form to perform the IMT technique concurrent with the increase in MIP-generated by training.

Limitations

The lack of follow-up of the volunteers in the subsequent months after the training did not allow to evaluate the long-term efficacy of IMT. Another limitation was the fact that the TG showed a trend toward increased AAS and maybe this group appeared to improve more.

CONCLUSION

This study showed that an IMT protocol of moderate intensity produces an increase in respiratory muscle strength, generates morphological alterations in the diaphragm and optimizes diaphragmatic mobility in elderly in the short term. These findings suggest that IMT generates benefits in this population, making it a supplementary alternative for peripheral muscle strength training to minimize the muscular and respiratory changes associated with senescence.

FUNDING

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CONFLICT OF INTEREST

None declared.

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