Original Article

Inspiratory muscle training improves thoracic expansion and six-minute walking distance in female subjects with inspiratory muscle weakness

Orachorn Boonla†, Piyapong Prasertsri*†, Arunrat Srithawong***

Abstract

During physical activity, ventilation is elevated due to an increase in both the depth and frequency of breathing. The increase in breathing depth during training is attained by greater contraction of the diaphragm, external intercostal muscle, and accessory muscles. Fatigue of the respiratory muscles is an exercise-limiting factor by reducing exercise performance in healthy subjects. Maximum inspiratory pressure (MIP) serves as an indicator of inspiratory muscle strength. It seems that inspiratory muscle training (IMT) increases the strength of the inspiratory muscles, chest expansion, functional capacity and exercise performance. However, effects of IMT on chest expansion and functional capacity in subjects with inspiratory muscle weakness are not well defined. Therefore, the objective of this study was to evaluate whether IMT could improve chest expansion, diaphragmatic movement, and functional capacity in subjects with inspiratory muscle weakness. Eight female subjects displaying respiratory muscle weakness with less than 80% predicted MIP were recruited in this experiment. All subjects were assessed for their MIP, thoracic expansion (upper and lower thoracic expansion), diaphragmatic movement, and a six-minute walking distance procedure (6MWD) at pre and post-training intervals. The respiratory IMT program was performed using a Threshold Inspiratory Muscle Trainer at 80% MIP over 10 repetitions/set, 3 sets/day, 5 days/week, throughout 8 weeks. Results suggested that IMT at 80% of MIP for 8 weeks improved the strength of the inspiratory muscles in subjects with respiratory weakness, as shown by significantly raising MIPs compared with pre-training results. It also appeared that subjects with IMT exhibited increased lower thoracic expansion and diaphragmatic movement when compared with pre-training results. 6MWD outcomes also improved in subjects with inspiratory muscle weakness. Therefore inspiratory muscle training improves the strength of the inspiratory muscles, thoracic expansion, diaphragmatic movement, and 6MWD in trained subjects with inspiratory muscle weakness.

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Introduction

The degree of chest expansion during inspiration is associated with the elasticity of the soft tissue structures surrounding the thorax, chest shape, and strength of the inspiratory muscles. Elevated inspiratory muscle strength could be, in part, responsible for generating more negative pressure in the pleural cavity and increased lung volume.[1] The degree of chest expansion is not only due to movement of the rib cage and the external intercostal muscle expanding the transverse dimensions, but also associated with contraction of the diaphragm while expanding the vertical diameter of the thoracic cavity.

Maximum inspiratory pressure (MIP) serves as an indicator of inspiratory muscle strength. Diminished inspiratory muscle strength has been reported amid chronic diseases such as neuromuscular disorders,[2] chronic kidney disease,[3] chronic heart failure,[4,5] and chronic obstructive pulmonary disease (COPD).[6] Previous studies have shown that MIP as has a positive correlation with chest expansion,[7] total lung capacity,[8] and an association with functional capacity in hemodialysis patients.[9] In addition, inspiratory muscle weakness has also been observed in young as well as aging subjects.[7,10,11] Furthermore, fatigue of the respiratory muscles is an exercise-limiting factor which reduces exercise performance in healthy subjects.[12,13] It is possible that increased respiratory muscle strength and a reduction in the perception of respiratory fatigue may improve exercise performance or physical activity in subjects exhibiting respiratory weakness.

Inspiratory muscle training (IMT) is defined as a series of resistive breathing exercises that aim to improve the strength of the respiratory muscles. Several studies have demonstrated beneficial effects of IMT programs, for instance, increasing inspiratory muscle strength, improving functional capacity and

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expanding the chest wall in patients suffering with multiple sclerosis, COPD, chronic heart failure, and hemodialysis.[8,14-17] Additionally, previous studies showed IMT results in terms of increased performance in trained athletes.[18,19] Moreover, it would appear that IMT increases the strength of the inspiratory muscles, chest expansion, functional capacity, and exercise performance in healthy subjects. Nevertheless, the effects of IMT on chest expansion and functional capacity in subjects with inspiratory muscle weakness are, to date, not well defined. The objective of this study was therefore to evaluate whether IMT could improve chest expansion, diaphragmatic movement, and functional capacity in subjects exhibiting inspiratory muscle weakness.

Materials and Methods

Subjects

Sample size was calculated from the paired *t*-test equation. According to a previous study on IMT in the elderly by Kim and colleagues in 2015, the variables were set as follows: difference in mean of MIP was 18.2, standard deviation was 7.6, Zα 0.05, and power of test was 0.95, respectively.[11]

Subjects were recruited via advertisment with interested volunteers enrolling in the project contacted by researchers. Prior to participating in the study, an information document which incorporated an inclusion/ exclusion criteria checklist was given to participants. Accordingly, participants were included if they: 1) had respiratory muscle weakness, less than 80% predicted MIP;[11,20] 2) had normal pulmonary function test; 3) had a BMI of 17.5 - 22.9 kg/m^2; and 4) were non-smokers. Participants were excluded if they had: 1) a history of cardiovascular disease (e.g. heart attack, chest pain, or high blood pressure); 2) any musculoskeletal disorders (abnormal chest shape, lower back pain, or abnormal gait pattern); 3) abnormal chest shape; or 4) refused to participate. Among these participants, 12 were excluded due to high predicted MIP (> 80%). Consequently, 8 female subjects meeting inclusion criteria were enrolled in the study. Information pertaining to the study protocol was given to all subjects prior to signing a participation consent form.. All procedures in this research were approved by the Institutional Ethics Committee of Burapha University (114/2559).

General characteristics

At the study outset, all subjects' general characteristic data, i.e., age, height, body weight and body mass index (BMI), and pulmonary function test were measured. Outcome measurements consisted of MIP, thoracic expansion, diaphragmatic movement, and 6-minute walking distance test.

Reliability Test

All measurements were made by one observer. Prior to the study period, observations of intra-observer repeatability of MIP, pulmonary function test, thoracic expansion and diaphragmatic movement were obtained, showing an Intraclass Correlation Coefficient of more than 0.95 for all parameters.

Thoracic expansion and diaphragmatic movement

Thoracic expansion was measured at the thoracic circumference using a rigid tape. Thoracic expansion and diaphragmatic movement were recorded as per three different values between maximal expiration and maximal inspiration. Upper thoracic expansion was measured at the axillary level. For lower thoracic expansion, a measuring tape was placed at the xiphoid tip, and for diaphragmatic movement, the tape was placed at the lateral lower edge of the 10th rib.[7,21]

Maximum inspiratory pressure

MIP was evaluated by employing a respiratory pressure meter (*MicroRPM*™, Vyaire Medical, Mettawa, Illinois, USA) with a disposable mouthpiece as previously described.[22] The device was calibrated to within 3% of a pressure manometer reading.

MIP was determined for each participant. The researcher first demonstrated the correct maneuver to obtain MIP. In the sitting position, the subject was instructed to exhale slowly and completely, seal their lips firmly around the mouthpiece, and then perform a strong inhalation to draw as much additional air into the lungs as possible. Each maneuver was sustained for at least one second; participants were allowed to rest for one minute and then repeat the maneuver. The highest three MIP values were averaged and recorded.

The predicted equation for normal MIP in the Thai population was calculated from individual age and body weight, as per a previous study by Jalayondeja *et al*.[23]

Female MIP = 77.57 - 0.59 Age (yrs) + 0.62 Body weight (kg)

Inspiratory muscle weakness was determined when absolute MIP was less than 80% of predicted MIP in each subject.

Pulmonary function test

A pulmonary function test was performed in all subjects by using MicroLab spirometer (Vyaire Medical), following a spirometry standardization method.[24] A calibration check of expiration and inspiration report of less than 3% was considered passable.

The test was performed in the sitting position with a nose-clip attached. First, the observer demonstrated the correct maneuver. Second, the researcher asked the subject to inhale completely and rapidly. Then, a mouthpiece was inserted into the subject's mouth prior to beginning the forced exhalation. Finally, subjects exhaled maximally until no more air could be expelled and they were instructed to repeat three times with a "shot blow." The maneuver was repeated if the subject could not perform correctly; usually no more than eight are required.

Table 1 General characteristic of all subjects.

Parameters	Mean ± SD (n=8)
Age (yr)	21.00 ± 0.76
Height (m)	1.59 ± 0.05
Weight (kg)	52.10 ± 4.38
BMI (kg/m^2)	20.59 ± 1.59
Blood pressure (mmHg)	
SP	112.25 ± 5.50
DP	76.25 ± 4.33
Pulmonary function test (%predicted)	
FVC	89.31 ± 11.49
FEV1	92.92 ± 9.79
FEV_1/FVC	104.04 ± 3.85
6MWD (m)	546.17 ± 32.11

BMI, body mass index; SP, systolic blood pressure; DP, diastolic blood pressure; FVC, forced vital capacity; FEV_1, forced expiratory flow in 1 second; 6MWD, 6-min walking distance.

6-min walk test
6-min walk test (6MWT) provided information concerning functional capacity. Briefly, subjects were requested to walk as far as possible, but not run, for 6 minutes with the distance covered recorded.[25,26]

Inspiratory muscle training program
After baseline measurement, participants were assigned to the inspiratory muscle training program. This was performed in the sitting position, employing a Threshold Inspiratory Muscle Trainer (Powerbreathe K1 series, Warwickshire, England, UK) at a loading of 80% of actual MIP in each subject. The training program consisted of inhaling against loading for 10 repetitions/set, sustained for 3 s/repetition, and a rest for 10 s/repetition. This was performed for 3 sets/day, with a 5-min rest between sets, 5 days/week, over the course of 8 weeks. Subjects were supervised by a researcher throughout all training sessions. MIP was measured to monitor changes in inspiratory muscle strength, and adjusted to 80% of actual MIP in each participant to progress training intensity each week during the study period.

Statistical analysis
Data were expressed as mean ± standard deviation (SD) and analyzed using SPSS software version 17. Normality of MIP, chest expansion, and 6MWD were checked via Kolmogorov-Smirnov test. Comparisons between baseline and post-training were performed by employing a paired *t*-test. $P < 0.05$ was considered significantly different.

Results

Eight females were included in this study. General characteristics, age, height, weight, body mass index (BMI), and blood pressure are shown in Table 1. Baseline 6MWD and normal pulmonary function test results of all subjects were also presented in the table.

Subjects' baseline or pre-training MIP and % predicted are presented in Table 2. The percentage of predicted MIP at pre-training was 61.35 ± 12.00 %, demonstrating that participants exhibited inspiratory

Table 2 Maximum inspiratory pressure at pre-training and post-training of all subjects.

Parameters	Pre-training	Post-training
Subject MIP (cmH_2O)	-61.71 ± -15.71	-90.04 ± -13.52*
Predicted MIP (%)	61.35 ± 12.00	92.53 ± 13.17*

Data are Mean ± SD; n =8. MIP, maximum inspiratory pressure; *$P < 0.05$ compared with baseline.

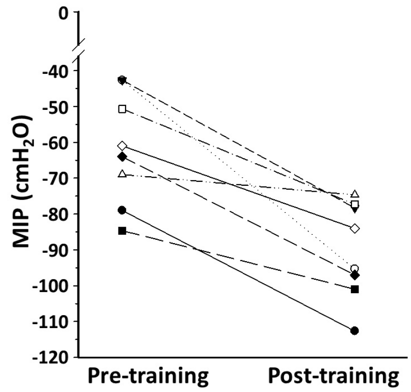

Figure 1 Absolute maximum inspiratory pressure at pre- and post-training in each subject (n = 8).

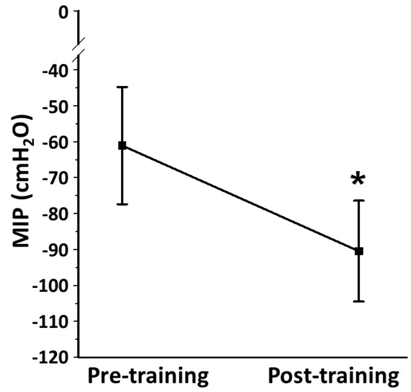

Figure 2 The effect of inspiratory muscle training on maximum inspiratory pressure (MIP). Data are mean ± SD. *$P < 0.05$ compared with pre-training (n =8).

muscle weakness (absolute MIP less than 80% of predicted value). Interestingly, a percentage of the predicted value was significantly increased and appeared as a normal predicted value post IMT training program compared with pre-training (61.35 ± 12.00 % *vs* 92.53 ± 13.17%, $P < 0.05$).

The absolute MIP changes in each subject were measured at the pre-training and post-training stages (Table 2 and Figure 1). The data showed MIP increase (increased negative pressure) in all subjects compared with the pre-training period. Moreover, post-training average MIP of all study participants was also significantly raised compared to that of pre-training stage (-61.71 ± -15.73 cmH_2O *vs* -90.04 ± -13.52 cmH_2O, $P < 0.001$; Figure 2).

The representation of weekly MIP changes during an 8-week program is presented in Figure 3. MIP progressively increased for 5 weeks post training and continued to increase throughout the study period when compared with the baseline.

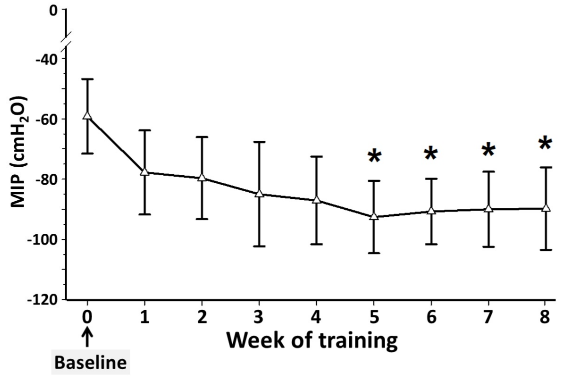

Figure 3 Average absolute MIP values in subjects undergoing inspiratory muscle training, showing changes with time during the study period. Data are mean ± SD. *$P < 0.05$ compared with baseline (n =8).

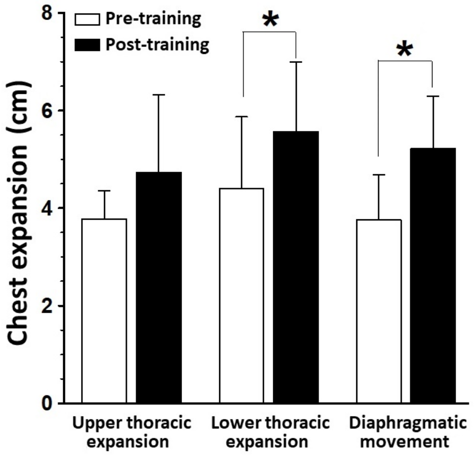

Figure 4 The effect of inspiratory muscle training on chest expansion and diaphragmatic movement. Data are mean ± SD. *$P < 0.05$ compared with pre-training (n =8).

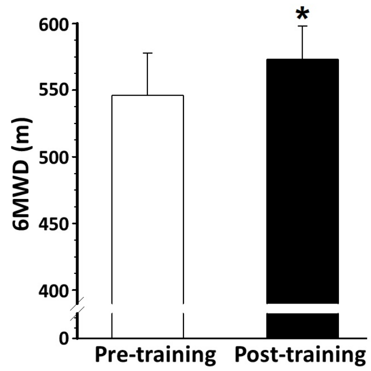

Figure 5 The effect of inspiratory muscle training on 6-minute walking distance (6MWD). Data are mean ± SD. *$P < 0.05$ compared with pre-training (n =8).

Figure 4 shows the effect of the IMT program on chest expansion and diaphragmatic movement in all subjects. Interestingly, after IMT program participation, the lower thoracic expansion (4.40 ±1.47 cm *vs* 5.57 ± 1.42 cm, $P = 0.017$) and diaphragmatic movement (3.76 ± 0.92 cm *vs* 5.22 ± 1.07 cm, $P = 0.04$) had increased compared with pre-training (Figure 4). These results suggest that IMT incorporating 80% of MIP for 8 weeks improved chest expansion in subjects exhibiting respiratory weakness.

6MWD was evaluated at the pre-training and post-training periods of the study. The data shown in Figure 5 reveals a significant increase in 6MWD post-IMT (546.17 ± 32.11 m *vs* 573.88 ± 25.17 m, $P = 0.008$).

Discussion

This study aimed to assess the effect of respiratory muscle training program at 80% of MIP on inspiratory muscle strength, chest expansion, diaphragmatic movement and 6MWD in subjects with inspiratory muscle weakness.

MIP is an indicator of inspiratory muscle strength. It is a principally determined by diaphragmatic and external intercostal contraction which is responsible for generating negative intrapleural and airway pressure. In addition, contraction of the scalene and sternocleidomastoid muscles plays a minor role in this process. Our data evidenced that an IMT program increased MIP after training for 8 weeks compared to pre-training outcomes. Hence, this program improved respiratory muscle strength in subjects. Similarly, a previous work showed that 10 weeks of IMT at 40-60% of MIP was responsible for significantly increased respiratory muscle strength in patients with multiple sclerosis.[27] Moreover, IMT at 80% of maximal effort improved vital capacity, total lung capacity, inspiratory muscle strength, and diaphragmatic thickness in healthy subjects.[28] Thus, a significant increase in MIP may be explained by the higher inspiratory muscle strength as a result of providing maximal contraction and muscle thickness.[28]

Chest wall expansion is influenced by several factors, for example, breathing training incorporating chest expansion exercises,[29] lung tissue elasticity, structure and elasticity of chest wall, and in particular inspiratory muscle strength. Inspiratory muscle strength, as a consequence, might be an important determinant for chest wall expansion. In accordance with this reasoning, previous results revealed a positive correlation between respiratory muscle strength and chest wall expansion in healthy subjects.[7] Likewise, the same result was observed in patients with cystic fibrosis.[30]

In the present study, our data showed the beneficial effect of IMT on the improvement of inspiratory muscle strength and increment of lower thoracic expansion and diaphragmatic movement. Further support of these results arise from the previous data with regards to high-intensity inspiratory muscle training increasing diaphragmatic thickness, whereby promoting maximal force contraction in healthy subjects.[28]

During physical activity ventilation is elevated due to an increase in both the depth and frequency of breathing. The increase in breathing depth during training is enabled by higher contractions of the diaphragm, external intercostal muscles, and accessory muscles. Respiratory muscle fatigue inducing increased metaboreflex activation has been reported to decrease exercise performance in healthy subjects.[12,13] In addition, inspiratory muscle weakness is associated with low functional capacity in patients with COPD, heart failure, and end-stage renal disease.[9,31,32] The 6MWT is the most popular of the field walking tests; its principal advantages being its operational simplicity and low cost. This test is useful in terms of measuring functional capacity by evaluating the distance that a subject can walk quickly on a flat surface over a period of 6 minutes. Hence, it investigates the global and integrated responses of all the systems involved during exercise, including the pulmonary and cardiovascular systems, systemic circulation, peripheral circulation, muscular metabolism, and neuromuscular units.[33] In this study, we demonstrated that an 8-week IMT intervention increased walking distance as measured by 6MWT in subjects with inspiratory muscle weakness. Consistent with our results, previous data showed a positive correlation between inspiratory muscle weakness and functional capacity as measured by distance walked during the incremental shuttle-walk test in hemodialysis patients.[9] Moreover, it has been reported that an IMT program increased the distance walked in 6 minutes among patients with stable chronic heart failure and COPD.[14,16] Furthermore, reduced respiratory muscle fatigue and perception of exertion, as well as increased blood flow to the working muscles via attenuation of respiratory muscle metaboreflex were reported post-IMT training, thus enabling subjects to perform a greater walking distance.[12,13] However, a previous study of inspiratory muscle training in endurance athletes discovered that increased respiratory muscle performance was not associated with improvement in aerobic capacity, as determined by VO_2max, or in arterial oxygen desaturation during maximal graded aerobic exercise test.[34]

The present study exhibits certain limitations. First, participants were only female. Second, the number of participants was relatively small. Third, the results of this research were limited to adults aged 21 ± 0.76 years. Accordingly, this does not correspond to the typical age range associated with clinical problems such as aging and chronic diseases. However, most participants seemed to exhibit a predominantly sedentary lifestyle. Fourth, subjects' physical activity levels during the 8-week study period were not controlled. Those, presenting higher physical activity levels may have caused an effect on respiratory muscle strength and 6MWT.

Finally, we evaluated functional capacity by applying a 6MWT. Although, a 6MWT is a submaximal exercise test, it does not provide specific information on the function of each organ or system involved in exercise, nor the mechanism of exercise limitations. Consequently, further studies conducted to yield functional capacity with maximal effort in normal subjects by utilizing the incremental shuttle walking test may be considered.

Conclusion

The findings of this study suggest that IMT at 80% of MIP for 8 weeks improved inspiratory muscle strength, chest expansion, and 6MWD in subjects with respiratory muscle weakness. In closing, this IMT program may be applied as a physical therapy rehabilitation program to improve chest expansion as well as functional limitations in subjects exhibiting inspiratory muscle weakness.

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Conflict of Interest

None to declare.

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