The Effect of Expiratory Muscle Training on Pulmonary Function in Normal Subjects

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Abstract. The objective of the present study was to investigate the effects of expiratory muscle training (EMT) on pulmonary function, including peak cough flow (PCF), by administering EMT at a natural or fast flow rate to healthy volunteers. Subjects comprised 33 healthy volunteers randomly divided into 3 groups: EMT at a natural expiratory flow rate (NFR group); EMT at a fast expiratory flow rate (FFR group); and no EMT (Control group). For the NFR and FFR groups, subjects trained using a device for expiratory muscle training at 30% maximal expiratory muscle pressure (PE_{max}) for 15 min twice daily, 7 days a week for 4 weeks. Before and after training, PE_{max} and pulmonary function were measured. For the NFR and FFR groups, PE_{max} significantly increased but pulmonary function, including PCF, was unchanged. Moreover, no significant correlation was seen between changes in PE_{max} and changes in pulmonary function parameters in the NFR and FFR groups. In conclusion, natural or fast flow rate EMT increases PE_{max} , but neither technique improves pulmonary function, including PCF. Thus, velocity-specific muscle strengthening by EMT does not contribute to changes in pulmonary function related to expiratory flow.

Key words: Expiratory muscle training, Pulmonary function, Airway clearance

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INTRODUCTION

Ventilatory muscle training (VMT) is one form of pulmonary rehabilitation^{1, 2)}. The evidence-based guidelines¹⁾ of the American College of Chest Physicians (ACCP) and the American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) refer to a meta-analysis³⁾ of VMT by Smith et al. which states that, since VMT improves respiratory distress and/or exercise tolerance, inspiratory muscle training (IMT) could be administered to patients with chronic obstructive pulmonary disease (COPD) who did not respond to therapy and displayed residual symptoms. Lötters et al. then conducted a meta-analysis⁴⁾ revealing that IMT significantly increases inspiratory muscle pressure (PI_{max}) and endurance, significantly improves rest and exercise respiratory distress, and

tends to strengthen exercise tolerance. However, a meta-analysis by Salman et al.⁵⁾ showed that IMT does not improve gait distance or respiratory distress. Subsequent studies have since documented the efficacy of IMT^{6–11)}, and the American Thoracic Society and European Respiratory Society²⁾ issued a statement that, “IMT could be considered as adjunctive therapy in pulmonary rehabilitation, primarily with suspected or proven respiratory muscle weakness.” Studies have shown that expiratory muscle training (EMT) increases maximal expiratory muscle pressure (PE_{max}), improves pulmonary function, ventilation function and exercise capability and alleviates respiratory distress caused by inspiratory load, activities of daily living or exercise in patients with COPD^{12, 13)}, healthy individuals^{10, 14–19)}, multiple sclerosis (MS) patients^{20–22)}, myasthenia gravis

(MG) patients²³), neuromuscular disease (NMD) patients^{24, 25}), patients with tetraplegia caused by spinal cord injury^{26, 27}) and Parkinson's disease patients^{28, 29}). However, some studies have found that: EMT does not increase PE_{max} ³⁰); EMT only improves PE_{max} , with no effect on other parameters^{31, 32}); and EMT increases PE_{max} , but has no marked impact on other parameters or sufficient evidence is lacking^{33–36}).

Acute exacerbation and complications markedly affect morbidity and mortality, not only in patients with respiratory diseases, but also in patients with diseases caused by central nervous system damage or degeneration and NMD patients. Impaired airway clearance increases the risk of pulmonary infection due to the accumulation of airway secretions^{37–41}). Coughing^{39, 40}) or forced expiration techniques (called huffing)⁴³) represent a key mechanism for airway protection. The effectiveness of mucus clearance depends largely on peak cough flow (PCF) and/or peak expiratory flow. Weak expiratory muscles result in decreased PCF and peak flow rate (PFR). Decreased respiratory muscle strength in COPD patients affects not only the inspiratory muscles, but also the expiratory muscles¹²). In patients with NMD, advanced stages of disease are associated with decreased strength of the expiratory muscles, in addition to a decrease in vital capacity^{44, 45}). In MS patients, PE_{max} decreases before PI_{max} ³⁰). In patients with such diseases, preventing decreases in expiratory muscle strength is crucial.

While some studies have reported that EMT improves pulmonary function related to expiratory flow in healthy individuals, COPD patients, MS patients and MG patients^{19, 23}), the overwhelming majority have documented no changes^{10, 12, 13, 15, 16, 18, 22, 31, 32}). Although some studies have described that EMT may be expected to increase the ability to cough^{18, 21, 29, 46}), no general consensus has been reached, as some studies have documented significant improvements in the cough efficacy of MS patients³⁰), while others have found no changes in maximal voluntary cough of MS patients²²). In recent reviews^{35, 36}), the effects of EMT on cough effectiveness have been described as minimal, and further investigations are warranted. The effects of EMT on pulmonary function, including PCF, have not been sufficiently investigated, but the insufficient effects of EMT on pulmonary function may be due to the contraction velocity of expiratory muscles during EMT.

Velocity-specific resistance training has demonstrated that the greatest gains in strength occur at or near training velocity⁴⁷).

The present study administered EMT to healthy volunteers at either natural or fast expiratory flow rates for a certain period of time and then assessed the effects of EMT on pulmonary function, including PCF.

METHODS

Subjects

Subjects comprised 33 healthy students who were given a thorough explanation of the study, both orally and in writing, and who then signed a consent form. Subjects were randomly divided into the following 3 groups (n=11 each): EMT at natural expiratory flow rate without setting a specific flow rate (NFR group); EMT at fast expiratory flow rate (FFR group); and no EMT (Control group). Background characteristics for each group are shown in Table 1. No significant differences were seen among groups with respect to age, sex or physical characteristics.

Measurements

Expiratory muscle strength and pulmonary function were measured before and after EMT. Expiratory muscle strength was determined using a Vitalopower KH-101 respiratory muscle dynamometer (Chest, Tokyo, Japan). Measurements were performed as previously described by Black and Hyatt⁴⁸). Specifically, while sitting and wearing a nose clip, the subject was fitted with a mouthpiece and, at total lung capacity, sustained a maximal expiratory effort for ≥ 1 s. This method was used to measure mouth pressure 3 times, and the maximum value was used to determine PE_{max} . Spirometry for pulmonary function testing was performed using a ChestGraph HI-701 spirometer (Chest, Tokyo, Japan). While sitting and wearing a nose clip, the subject was fitted with a mouthpiece and asked to exhale as rapidly as possible from maximum inspiration to maximum expiration. Measurements were performed 3 times. PCF was determined using the same spirometer used for spirometry. A facemask (size, medium adult; King Systems, Indiana, USA) was connected so that the mouthpiece of the spirometer did not leak. With the subject sitting, the mouth and nose were covered with a facemask so that no leaks were present, and

Table 1. Background characteristics of each group

	NFR group (n=11)	FFR group (n=11)	Control group (n=11)	p
Age (years)	23.9 ± 5.1	25.7 ± 6.6	20.5 ± 1.8	NS
Sex (male, female)	8, 3	8, 3	7, 4	NS
Height (cm)	171.1 ± 9.3	168.2 ± 6.9	167.6 ± 8.2	NS
Weight (kg)	61.5 ± 9.4	62.1 ± 8.2	66.5 ± 17.4	NS
Body mass index (kg/m ²)	20.9 ± 2.2	21.9 ± 1.9	23.4 ± 4.3	NS

One-way ANOVA, χ^2 test.

NS: not significant.

NFR: natural flow rate; FFR: fast flow rate.

the subject forcibly coughed strongly from maximum inspiration. Measured parameters comprised forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_{1.0}), PFR and PCF. The values used were the best values obtained from 3 measurements.

Training protocol

Subjects in the two training groups (NFR and FFR groups) used the Threshold-PEP (HealthScan, New Jersey, USA) for EMT. This device consists of a plastic tube with a spring-loaded valve, one end connecting to a mouthpiece and the other end forming an expiratory orifice. When breathing through the mouthpiece, the subject must generate sufficient positive expiratory pressure to open the spring-loaded valve and initiate airflow, whereas inhalation is unloaded. The amount of resistance can be adjusted by varying the compression of the spring-loaded valve. Since the device was used in healthy volunteers, a spring with which 3 times the normal load (12–60 cmH₂O) could be applied was used. Subjects in the NFR and FFR groups trained using the Threshold-PEP at 30% of PE_{max} for 15 min twice daily, 7 days a week for 4 weeks. Subjects in the control group did not perform EMT. Subjects in the NFR group performed EMT at a natural expiratory flow rate without setting any specific expiratory flow rate, while subjects in the FFR group performed EMT at a fast expiratory flow rate with exhalation during each respiratory cycle at as quick a speed as possible. A physical therapist demonstrated the use of the Threshold-PEP and explained EMT to train the subjects. After the training period, a record of performance was made to indicate the state of training.

Statistical analysis

Changes before and after EMT were compared between groups using 2-way repeated-measures analysis of variance (ANOVA). The relationship between changes in PE_{max} and changes in pulmonary function parameters in the training groups were examined using Pearson's product-moment correlation test. Values of $p < 0.05$ were considered statistically significant.

RESULTS

Based on the training records, while there were 56 training times in the training period, the subjects performed training 38.1 times on average in the NFR group, and 42.9 times on average in the FFR group.

Changes in PE_{max} after training compared to before EMT are shown in Table 2. No differences were seen among the 3 groups before EMT. In regard to PE_{max}, repeated-measures ANOVA showed interactions among the 3 groups ($p = 0.011$). While no significant changes were seen for the Control group, PE_{max} increased from 140.0 ± 44.9 cmH₂O to 167.8 ± 55.5 cmH₂O after training for the NFR group and from 158.9 ± 58.7 cmH₂O to 174.2 ± 61.3 cmH₂O after training for the FFR group. Table 3 shows changes in pulmonary function before and after training. In regard to pulmonary function, repeated-measures ANOVA showed no interactions among the 3 groups for all parameters. Moreover, no significant correlations were seen between changes in PE_{max} and changes in pulmonary function parameters in either a combination of the 2 training groups or in each training group.

Table 2. Changes in expiratory muscle strength with expiratory muscle training

		NFR group (n=11)	FFR group (n=11)	Control group (n=11)	ANOVA (interaction)
PE _{max} (cmH ₂ O)	Pre	140.0 ± 44.9	158.9 ± 58.7	146.7 ± 60.1	p=0.011
	Post	167.8 ± 55.5	174.2 ± 61.3	142.9 ± 44.2	

Repeated two-way ANOVA.

PE_{max}: maximal expiratory mouth pressure.

NFR: natural flow rate; FFR: fast flow rate.

Table 3. Changes in pulmonary function with expiratory muscle training

		NFR group (n=11)	FFR group (n=11)	Control group (n=11)	ANOVA (interaction)
FVC (L)	Pre	4.9 ± 1.0	4.6 ± 0.7	4.3 ± 1.0	NS
	Post	4.6 ± 0.8	4.3 ± 0.6	4.3 ± 1.1	
FEV _{1.0} (L)	Pre	4.3 ± 0.8	4.2 ± 0.6	3.9 ± 1.1	NS
	Post	4.1 ± 0.6	3.9 ± 0.6	3.8 ± 1.0	
PFR (L/s)	Pre	7.8 ± 2.3	8.6 ± 2.0	8.1 ± 1.6	NS
	Post	8.6 ± 2.0	8.8 ± 0.9	8.4 ± 1.7	
PCF (L/s)	Pre	8.4 ± 2.3	8.7 ± 0.9	7.6 ± 2.3	NS
	Post	8.9 ± 1.3	8.5 ± 0.8	7.9 ± 2.0	

Repeated two-way ANOVA.

NS: not significant.

FVC: forced vital capacity; FEV_{1.0}: forced expiratory volume in 1 s; PFR: peak flow rate; PCF: peak cough flow rate.

NFR: natural flow rate; FFR: fast flow rate.

DISCUSSION

The effects of EMT on pulmonary function, including PCF, have not been clearly confirmed, and this may be due to the contraction velocity of expiratory muscles during EMT. The present study therefore investigated the effects of EMT on pulmonary function by administering EMT at 2 speeds: NFR and FFR. PE_{max} increased for both the NFR and FFR groups, but no change was seen in pulmonary function. Furthermore, changes in PE_{max} did not correlate with changes in pulmonary function, suggesting that increases in PE_{max} do not affect pulmonary function.

According to evidence-based guidelines¹⁾, IMT is effective at a training intensity of ≥30% PI_{max}. However, no guidelines exist regarding the training intensity of EMT. One study administered EMT to healthy subjects and reported that training at 30% PE_{max} for 4 weeks increased PE_{max}¹⁴⁾. Studies have also documented that EMT increases PE_{max} with training at 30% PE_{max} for 2 weeks^{10, 15)} or at 20%

PE_{max} for 2 weeks¹⁶⁾. In the present study, healthy subjects trained at 30% PE_{max} for 4 weeks. As a result, intensity and duration of training were sufficient to increase PE_{max} in healthy individuals. Studies on COPD patients have shown that EMT increases PE_{max} within 3 months by elevating training intensity gradually from 15% to 60% PE_{max}^{12, 32)} or in 5 weeks by training at 50% PE_{max}¹³⁾. In MS patients, PE_{max} increased in 8 weeks by elevating training intensity gradually from 40% to 80% PE_{max}²²⁾. In MG patients, PE_{max} increased in 3 months by elevating training intensity gradually from 15% to 60% PE_{max}²³⁾. In NMD patients, PE_{max} increased in 6 months using 60% PE_{max}²⁵⁾. In Parkinson's disease patients, PE_{max} increased in 20 weeks with 75% PE_{max}²⁸⁾. In one study on MS patients, 3 months of EMT at 60% PE_{max} did not increase PE_{max}³⁰⁾. Thus, the intensity and duration of training need to be longer for patients with various diseases than for healthy individuals.

Normal cough consists of the inspiratory,

compressive and expiratory phases^{39, 49–51}). The inspiratory phase is associated with glottic opening and the inhalation of variable amounts of air. The compressive phase consists of glottis closure and contraction of the expiratory muscles, resulting in raised intrathoracic pressure. In the expiratory phase, the glottis opens suddenly and air is forcibly released leading to transient supramaximal flow. The high air flow velocities transfer kinetic energy from air to secretions or foreign bodies, shearing these off the bronchial wall and transporting them to the pharynx or mouth⁵¹). Based on the mechanism for normal cough, since expiratory muscles need to contract markedly during the compressive phase, muscles contract in a relatively static manner (more isometric) until the glottis opens. Conversely, a huffing maneuver consists of 1–2 forced expirations without glottal closure^{38, 43}), and contraction is relatively dynamic (more isotonic). From the perspective of velocity-specific muscle strength training⁴⁷), NFR appears useful for improving PCF, while FFR may improve PFR or FEV_{1.0} without glottal closure, as in huffing. However, in the present study, neither NFR nor FFR improved pulmonary function, including PCF, and the degree of increase in PE_{max} following EMT did not correlate with changes in pulmonary function. In other words, EMT-induced increases in PE_{max} do not appear to improve pulmonary function.

Smeltzer et al.²¹) stated that, “Decreased expiratory muscle weakness may lead to respiratory complications because of ineffective cough, retention of secretions, and inability to maintain a clear airway.” Baker et al.¹⁸) noted that, “Increasing the strength of the expiratory muscles may also assist in the development of higher alveolar pressure during cough production.” Sapienza et al.⁴⁶) also wrote, “It is assumed that peak expiratory airflow rate during cough will increase if an expiratory strength training protocol increases the expiratory driving pressures.” Thus, EMT-induced increases in PE_{max} should theoretically improve pulmonary function related to expiratory flow.

Numerous studies^{10, 12, 13, 15, 16, 18, 22, 31, 32}) have reported that EMT does not affect pulmonary function related to expiratory flow, and FFR training taking into account velocity specificity⁴⁷) in the present study had no effect on pulmonary function. Chiara et al.²²) explained the reason why EMT did not change the pulmonary function in MS patients as follow. First, above a certain

transpulmonary pressure at a given volume, flow does not increase with driving pressure. Second, if a change in the lung tissue occurs over time because of a disease process such as MS, then strengthening the respiratory muscles would have limited influence on the pulmonary function. Third, the ratio of cough peak flow to the corresponding time to peak (rise-time) in MS patients was lower than healthy controls. These factors do not apply to the healthy individuals because FVC is a normal value, the lung tissue does not change pathologically, and the ratio of cough peak flow to the rise-time is high relatively. Subjects in this study were healthy students with normal expiratory muscle strength, and were thus able to generate very fast expiratory flow rates. As a result, rather than expiratory muscle strength, lung elasticity and airway resistance could regulate pulmonary function related to expiratory flow. In healthy individuals, despite increased expiratory muscle strength or fast contraction of expiratory muscles, lung elasticity might influence alveolar pressure, and expiratory flow might be limited to resistance of the airway, which restricts diameter expansion in the expiration phase.

In conclusion, EMT in healthy subjects at both NFR and FFR increased PE_{max}, but neither method improved pulmonary function, including PCF, suggesting that velocity-specific muscle strengthening by EMT does not contribute to changes in pulmonary function related to expiratory flow.

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