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Inspiratory muscle training improves pulmonary functions and respiratory muscle strength in healthy male smokers

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ABSTRACT

The aim of the present study is to investigate the effects of inspiratory muscle training (IMT) on pulmonary function and respiratory muscle strength of both healthy smokers and nonsmokers. Forty-two healthy males (16 in the IMT smokers group [IMT_S], 16 in the IMT nonsmokers group [IMT_N], and 10 in the placebo group) participated in the present study. Using a randomized, double-blind, placebo-controlled design, IMT_S and IMT_N underwent 4 weeks of 30 breaths twice daily at 50% (+5% increase each week) of maximum inspiratory pressure (MIP), while the placebo group maintained 30 breaths twice daily at 15% MIP using an IMT device. The data were analyzed with repeated measures for one-way analysis of variance, 3 × 2 mixed factor analysis of variance, and least significant difference tests. Respiratory muscle strength (MIP and maximal expiratory pressure [MEP]) and pulmonary functions significantly improved after a 4-week period (between the pre and posttests) in the IMT_N and IMT_S groups ($p < 0.05$). The mean difference and percentage differences showed significant alterations in the respiratory muscle strength, forced and slow pulmonary capacities, and pulmonary volume between the IMT_N and IMT_S groups ($p < 0.05$). There were significant changes in the expiratory muscle strength (MEP), slow vital capacity (SVC), and forced pulmonary measurements (forced expiratory volume after 1 s and maximal voluntary ventilation) between IMT_N and IMT_S groups in favor of smokers ($p < 0.05$). These results show that greater improvements occurred in smokers after IMT. Increased respiratory muscle strength may be the underlying mechanism responsible for this improvement. Additionally, the benefits of IMT were greater in smokers than nonsmokers. This difference between smokers and nonsmokers may potentially be explained by higher influence of exercise on smokers' lung microbiome, resulting in greater reversal of negative effects.

1. Introduction

Inspiratory muscle training (IMT) is described as a remarkable exercise that exerts significant load on inspiratory muscles to strengthen the muscles of respiration (Silva et al., 2013). Incremental increase in respiratory muscle strength can enhance pulmonary function (Beckerman et al., 2005). Respiratory muscles show hypertrophy after proper training and load the skeletal muscles (Gibala et al., 2006; Egan and Zierath, 2013). IMT is generally used to treat people who suffer from asthma, chronic obstructive pulmonary disease (COPD), and airflow limitation (Beckerman et al., 2005; Weiner et al., 2004). Lately, sport scientists are studying this training to examine resulting acute or chronic changes (Volianitis et al., 2001; Griffiths and McConnell, 2007; Arnall et al., 2014).

Reductions in blood lactate concentration, heart rate, and perception of breathing and limb effort may occur due to IMT (McConnell and Sharpe, 2005; Chiappa et al., 2008). If the inspiratory muscles do not fatigue, breathing energy is reduced, making it possible to maintain a more efficient, deep, and slow breathing pattern (McConnell, 2011). These findings highlight the importance of IMT.

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Previous studies conducted on healthy subjects (McConnell and Romer, 2004), patients with pulmonary disease (Beckerman et al., 2005), healthy athletes (Arnall et al., 2014), disabled athletes (Wuyam, 2009), obese individuals (Tenório et al., 2013), hypertensive patients (Ferreira et al., 2013), elderly smokers (Jun et al., 2016), and the healthy elders (Rodrigues et al., 2018), have also demonstrated the benefits of IMT. However, there is limited information regarding the effects of IMT on pulmonary functions in healthy male smokers. To our knowledge, this is the first study to assess the effect of IMT in healthy male smokers.

The purpose of the present study is to examine the influence of 4 weeks of IMT on pulmonary function and respiratory muscle strength in smokers and nonsmokers. We hypothesize that IMT will attenuate the deleterious effects of smoking on respiratory muscle strength and pulmonary functions.

2. Materials and methods

2.1. Experimental design

The study incorporated a randomized, double-blind, and placebo-controlled design. The study design included one familiarization session followed by two testing sessions (pre- and post-tests) for all subjects. During the familiarization session, they experienced laboratory-based tests of pulmonary function, maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) tests, and IMT procedures. During the second (pretest) and third (posttest) sessions, they undertook all tests. The IMT program (4 weeks 7 days per week) was implemented between the pre and posttest period in all subjects. Subjects were randomly assigned to the experimental (IMT_N: nonsmoker experimental group, n = 16; IMT_S: smoker experimental group, n = 16) or placebo (smoker control group, n = 10) groups. Subjects in the experimental groups (IMT_N and IMT_S) performed the IMT procedure at 50% of MIP (+5% load increase each week and MIP test repeated on the first training day of every week), and placebo group subjects performed the IMT procedure at 15% of MIP. The IMT sessions (performed between 10:00 and 12:00) and the pre and posttest measurements (acquired between 16:00 and 18:00) were applied at the same time each day. The present study was designed and implemented in accordance with the Declaration of Helsinki (World Medical Association, 2013). Approval was obtained from a local clinical research ethics committee.

2.2. Subjects

A total of 42 healthy male subjects volunteered to participate in this study (Table 1). The aim of the study was explained to all subjects and written informed consent was obtained from all subjects at the familiarization session. The IMT_S and placebo groups included subjects who had smoked more than 15 cigarettes per day for at least 5 years. The IMT_N subjects had never smoked during their life. Exercise and high-intensity physical activity were not allowed before the trials. Subjects avoided alcohol, caffeine, and exercise in the 24 h prior to testing. However, smokers in both the experimental and control groups were permitted to continue smoking. The placebo group was used to compare smokers with and without IMT. The nonsmoker experimental group (IMT_N) was used to determine whether IMT produced different effects in smokers versus nonsmokers.

Table 1
Descriptive characteristics of subjects (Means ± SD).

	IMT_S (n = 16)	IMT_N (n = 16)	Placebo (n = 10)
Age (years)	24.13 ± 6.34	23.31 ± 3.52	23.90 ± 1.45
Height (cm)	173.38 ± 5.81	172.69 ± 6.88	177.00 ± 7.29
Weight (kg)	72.31 ± 8.15	69.75 ± 9.70	73.05 ± 8.46
BMI (kg/m^2)	24.07 ± 2.66	23.31 ± 2.14	23.28 ± 1.90
Smoking	> 15 cigarettes/day	Never smoke	> 15 cigarettes/day
MIP (cmH_2O)	115.63 ± 35.21	104.59 ± 32.17	100.30 ± 22.92

BMI, body mass index; MIP, maximal inspiratory pressure; SD, standard deviation; IMT_S, inspiratory muscle training smoker group; IMT_N, inspiratory muscle training nonsmoker group.

2.3. Procedures

2.3.1. MIP and MEP measurements

MIP and MEP were measured with a portable hand-held mouth respiratory pressure meter (MicroRPM, CareFusion Micro Medical, Kent, UK), according to the 2002 guidelines of the American Thoracic Society and European Respiratory Society (2002). After the appropriate filters and holders were fixed, the nose airway was closed with a clip. MIP measurement started with the residual volume, while MEP was started with total lung capacity. The measurements were repeated between the 2 best findings until there was a 5% difference, and the average was recorded in cm H_2O (Polkey et al., 1995).

2.3.2. Pulmonary function assessment

Pulmonary function tests were conducted using a spirometer (CPFS/D USB Spirometer, MGC Diagnostics, Saint Paul, MN, USA), according to the 2002 guidelines of the American Thoracic Society and European Respiratory Society (2002). Forced vital capacity (FVC), forced expiration volume in one second (FEV1), ratio of FEV1/FVC, maximal voluntary ventilation (MVV), slow vital capacity (SVC), and inspiratory capacity (IC) were recorded using pulmonary function test (Miller et al., 2005). The best measurements were recorded (Magadle et al., 2007).

2.3.3. Inspiratory muscle training procedure

A specific inspiratory training device (POWER®Breathe Classic, IMT Technologies Ltd., Birmingham, UK) was used for IMT. Experimental group subjects (IMT_N and IMT_S) performed the IMT procedure at 50% of MIP (with +5% load increase each week and MIP test repeated on the first training day of every week), and placebo group subjects performed IMT procedure at 15% of MIP. The IMT procedure included 30 × 2 dynamic inspiratory efforts (with 1 min interval) daily for 4 weeks (Kilding et al., 2010). This procedure was chosen because it has been previously studied in healthy individuals (Karsten et al., 2018).

2.4. Statistical analyzes

The SPSS version 22.0 (SPSS Inc., Chicago, IL) program was used for statistical analyzes. The data were expressed as the mean, standard deviation, effect size, and percentage of the mean difference. The effect sizes were obtained from partial eta-squared data. The Shapiro-Wilk test was used to assess normality. Significance was defined as $p \leq 0.05$. To determine the difference between groups for one dependent variable (IMT effect), one-way analysis of variance (ANOVA) was used. Least significant difference (LSD) correction was used to analyze percent difference of mean between groups. In order to determine the significance of IMT on MIP, MEP, and pulmonary function measurements, 3 × 2 mixed factor ANOVA and LSD correction were performed on the pretest, posttest, and mean differences of the 3 groups.

3. Results

Table 2 shows the analysis of pre- and post-tests, mean differences, and percent differences on MIP, MEP, and pulmonary function measurements in the intervention groups. After 4 weeks of the IMT program, significant increases in MIP, MEP, FVC, FEV1, MVV, SVC, and IC were observed in the IMT_S group ($p < 0.05$). MIP, MEP, FVC, FEV1, MVV, and IC in the IMT_N group were also significantly higher at posttest compared to the pretest session ($p < 0.05$). In the placebo group, MEP demonstrated a significant change between the pre and post-tests ($p < 0.05$). Respiratory muscles and pulmonary functions of the IMT_S

Table 2
Analysis of MIP, MEP, and pulmonary function measurements.

		IMT_S (n = 16)		IMT_N (n = 16)		Placebo (n = 10)	
		Mean ± SD	ES	Mean ± SD	ES	Mean ± SD	ES
MIP (cmH_2O)	Pre-test	115.13 ± 29.16	−0.79	104.94 ± 29.72	−0.67	104.30 ± 15.07	−0.27
	Post-test	137.09 ± 26.10[a]		124.94 ± 29.64[a]		108.65 ± 16.83	
	Mean Difference	21.97 ± 14.97[b]		20.00 ± 14.20[b]		4.35 ± 7.26	
	Percent Diff. (%)	21.75 ± 17.66[b]	–	21.27 ± 15.95[b]	–	4.20 ± 6.58	0.21
MEP (cmH_2O)	Pre-test	138.91 ± 20.63	−1.04	124.41 ± 20.69	−0.56	116.65 ± 18.06	−0.59
	Post-test	159.41 ± 18.71[a]		136.44 ± 22.27[a]		126.30 ± 14.52[a]	
	Mean Difference	20.50 ± 9.04[b,c]		12.03 ± 4.76[b]		9.65 ± 9.31	
	Percent Diff. (%)	15.49 ± 7.87[b,c]	–	9.80 ± 4.41[b]	–	9.20 ± 9.91	0.14
FVC (L)	Pre-test	4.42 ± 1.28	−0.49	4.09 ± 0.95	−0.86	4.89 ± 1.21	−0.05
	Post-test	4.92 ± 0.65[a]		4.78 ± 0.63[a]		4.95 ± 1.00	
	Mean Difference	0.50 ± 1.00[b]		0.69 ± 0.99[b]		0.06 ± 0.89	
	Percent Diff. (%)	18.38 ± 30.60[b]	–	22.20 ± 28.88[b]	–	5.05 ± 28.72	0.05
FEV1 (L)	Pre-test	3.73 ± 0.94	−0.81	3.58 ± 0.64	−0.62	3.71 ± 1.02	−0.20
	Post-test	4.33 ± 0.47[a]		3.96 ± 0.59[a]		3.92 ± 1.03	
	Mean Difference	0.60 ± 0.90[bc]		0.39 ± 0.56		0.22 ± 0.83	
	Percent Diff. (%)	23.50 ± 35.21[b,c]	–	12.44 ± 16.76	–	9.43 ± 26.10	0.05
FEV1/FVC (%)	Pre-test	86.19 ± 13.02	−0.22	90.31 ± 18.09	0.53	78.59 ± 21.46	−0.05
	Post-test	88.44 ± 5.97		83.01 ± 6.55		79.66 ± 15.29	
	Mean Difference	2.26 ± 14.66		−7.30 ± 15.38		1.07 ± 14.36	
	Percent Diff. (%)	5.80 ± 24.50	–	−5.31 ± 15.90	–	6.42 ± 25.15	0.07
MVV (L/min)	Pre-test	149.19 ± 43.31	−0.93	150.25 ± 45.58	−0.45	160.10 ± 49.74	0.13
	Post-test	183.88 ± 29.91[a]		169.31 ± 39.22[a]		154.30 ± 36.65	
	Mean Difference	34.69 ± 25.56[b,c]		19.06 ± 21.55[b]		−5.80 ± 31.94	
	Percent Diff. (%)	29.46 ± 26.87[b,c]	–	16.83 ± 22.22[b]	–	−1.07 ± 22.86	0.18
SVC (L)	Pre-test	4.56 ± 0.95	−0.59	4.66 ± 0.96	−0.18	5.37 ± 0.76	0.31
	Post-test	5.10 ± 0.89[a]		4.84 ± 0.99		5.17 ± 0.53	
	Mean Difference	0.55 ± 0.83[b,c]		0.18 ± 0.39[b]		−0.21 ± 0.42	
	Percent Diff. (%)	14.75 ± 22.53[b,c]	–	4.28 ± 9.60[b]	–	−5.68 ± 5.63	0.18
IC (L)	Pre-test	3.27 ± 0.74	−0.25	2.87 ± 0.74	−2.26	3.56 ± 1.03	−0.05
	Post-test	3.45 ± 0.69[a]		3.03 ± 0.44		3.61 ± 0.85	
	Mean Difference	0.18 ± 0.77		0.17 ± 0.53		0.05 ± 1.19	
	Percent Diff. (%)	8.67 ± 22.70	–	9.80 ± 21.30	–	6.91 ± 36.01	0.00

[a] Significant difference between pre- and post-tests.
[b] Significant difference from placebo group.
[c] Significant difference from IMT_N group; SD, standard deviation; ES, effect size; IMT_S, inspiratory muscle training smoker group; IMT_N, inspiratory muscle training nonsmoker group; MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; FVC, forced vital capacity; FEV1, forced expiratory volume in one second; MVV, maximal voluntary ventilation; SVC, slow vital capacity; IC, inspiratory capacity.

and IMT_N subjects improved after the IMT program, where as those of the placebo subjects did not (Table 2).

Mean and percent differences demonstrated different effects of IMT among the 3 groups in the Fig. 1. Significant mean and percent differences were found in MIP, MEP, FVC, FEV1, MVV, and SVC between the IMT_S and placebo groups ($p < 0.05$). In addition, significant differences were observed in MIP, MEP, FVC, MVV, and SVC between the IMT_N and placebo groups ($p < 0.05$). Comparing the mean and percent differences between the IMT_S and IMT_N groups revealed significant differences in MEP, FEV1, MVV, and SVC in favor of the IMT_S group ($p < 0.05$). More significantly improvement observed, in expiratory muscle strength and pulmonary functions of the IMT_S subjects after the IMT program, than IMT_N subjects (Fig. 1).

4. Discussion

The aim of this study was to determine the influence of IMT on pulmonary function and respiratory muscle strength in smokers and nonsmokers using a randomized, double-blind, placebo-controlled experimental design. There were 2 major findings of the present study: (1)

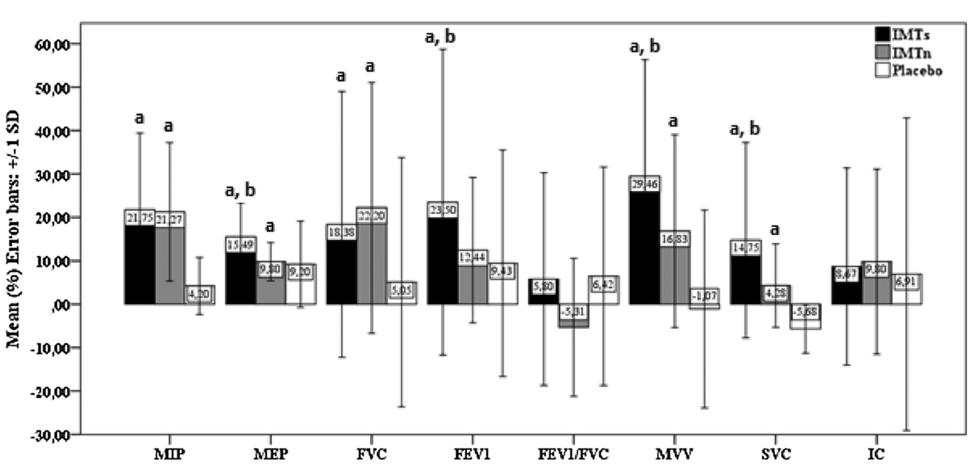

Fig. 1. Percent difference comparisons of groups. [a] significant difference from placebo group; [b] significant difference from IMT_N group SD, standard deviation; ES, effect size; IMT_S, inspiratory muscle training smoker group; IMT_N, inspiratory muscle training non-smoker group; MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; FVC, forced vital capacity; FEV1, forced expiratory volume in one second; MVV, maximal voluntary ventilation; SVC, slow vital capacity; IC, inspiratory capacity.

changes in expiratory muscle strength and pulmonary measurements following IMT were significantly higher in smokers than nonsmokers ($p < 0.05$) and (2) respiratory muscle strength and pulmonary functions significantly improved after 4-week IMT program ($p < 0.05$).

Although lungs are not free of microorganisms even when healthy, tobacco smoking negatively influences the pulmonary microbiome (Harris et al., 2007; Hilty et al., 2010; Huang et al., 2010; Rogers et al., 2004). The leading cause of COPD is exposure to tobacco smoke. COPD is characterized by largely irreversible airflow limitation, mucus hypersecretion, small airway fibrosis, and destruction of the alveolar space (Barnes et al., 2009). All of these characteristics may be affected by the pulmonary microbiome. Although all smokers do not develop COPD, they do express some of the aforementioned characteristics (Erb-Downward et al., 2011). Therefore, it may be hypothesized that exercise for the respiratory system may positively affect the pulmonary microbiome (Barton et al., 2018) and combat the negative effects of smoking (Han et al., 2014). This may be a possible mechanism underlying our finding that expiratory muscle strength and pulmonary measurements show significantly greater changes in smokers than nonsmokers.

Smoking in young people has increased, leading to early respiratory function problems (Tantisuwat and Thaveeratitham, 2014; Jun et al., 2016). The close association between smoking and pulmonary dysfunction is widely accepted (Roh et al., 2012). IMT enhances inspiratory muscle strength, resulting in increases in lung function and lung volumes after IMT (Volianitis et al., 2001; Arnall et al., 2014; McConnell and Lomax, 2006). It has been reported that an increase in cigarette consumption is associated with a progressive decrease in mean flow rates and increased obstruction (Kuperman and Riker, 1973; Lee and Fry, 2010). In the current study, respiratory muscle strength and pulmonary functions significantly increased in the IMT_S and IMT_N groups after participation in the IMT program. Other studies in the literature have shown that IMT improves the functioning of the respiratory system, thereby allowing more oxygen to enter the bloodstream with each breath while strengthening the respiratory muscles (Özdal, 2016a). Our study indicates that IMT significantly improves respiratory muscle strength. Stronger respiratory muscles delay or abolish inspiratory muscle fatigue (McConnell and Lomax, 2006; Özdal, 2016b; Özdal and Bostanci, 2018), enabling the necessary respiratory functions to be performed more easily (Weiner et al., 2004; Volianitis et al., 2001; McConnell, 2011; Özdal, 2016a). Our study also demonstrated increases in lung volumes. This is in agreement with prior investigations that showed IMT significantly increased FVC, FEV1, IC, as well as respiratory capacity of long-term male smokers (Roh et al., 2012; Seo et al., 2015) and nonsmokers (Özdal, 2016a; Enright et al., 2004). Increased lung volumes have previously been associated with stronger neck muscle and upper thorax to the inspiratory muscle (Tenório et al., 2013). Therefore, our present findings regarding pulmonary response can be explained by increases in inspiratory muscle strength.

The positive effects of exercise on the lungs are well known (Yilmaz and Özdal, 2019). Forced pulmonary parameters depend on the performance of respiratory muscles (Gupta and Sawane, 2012). Improvement in the strength of the diaphragm, the most important respiratory muscle, positively affects expiratory forced volume and capacity (Weiner et al., 2003). Also, the chronic adaptation of the pulmonary system to exercise is related to decreased muscle stiffness, improved nerve conduction velocity, improved contractile activity, increased metabolic enzyme activity in respiratory muscles (Wright and Johns, 1961; Ranatunga et al., 1987; Proske et al., 1993), and increased elasticity of the lungs and chest wall (Gupta and Sawane, 2012; Lakhera et al., 1984). These perspectives can explain the mechanism of our other finding that respiratory muscle strength and pulmonary functions significantly improve after the 4-week IMT program.

In conclusion, 4 weeks of IMT significantly improved the respiratory muscle strength and pulmonary function of smokers. The mechanism responsible for this improvement is probably associated with increased respiratory muscle strength. On the other hand, smokers had higher increments in respiratory muscle strength and pulmonary functions than nonsmokers. The mechanism related to the difference between smokers and nonsmokers may potentially be explained by greater influence of exercise on smokers' lung microbiome in reversing the negative effects of smoking.

5. Limitations

The spirometer that was used did not calculate other some important pulmonary parameters such as forced expiratory flow, peak expiratory flow, forced inspiratory flow, and peak inspiratory flow. Also, our study design needs a nonsmoker placebo group for eliminating evaluation limitations.

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