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นิพนธ์ต้นฉบับ
ORIGINAL ARTICLE

ประสิทธิภาพเครื่องฝึกชนิดต้านทานการหายใจต่อความแข็งแรงและความทนทานของกล้ามเนื้อหายใจ

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บทคัดย่อ

ความแข็งแรงและทนทานของกล้ามเนื้อหายใจมีความสำคัญเพราะทำหน้าที่คล้ายปั๊มในการนำอากาศให้ไหลเวียนเข้าสู่และออกจากปอดได้อย่างต่อเนื่อง ทั้งนี้เพื่อให้ร่างกายสามารถมีกิจกรรมทางกายที่ต่อเนื่องเป็นระยะเวลานานๆ จึงมีความจำเป็นต้องฝึกกล้ามเนื้อหายใจทั้งในคนป่วยและคนสุขภาพปกติเพื่อให้ดำรงสมรรถภาพทางกายที่ดี มีเทคนิคและการพัฒนาอุปกรณ์การฝึกเพื่อเพิ่มสมรรถภาพปอดหลายอย่างได้ถูกนำมาใช้อย่างมีข้อจำกัด ส่วนมากเน้นการฝึกตามปริมาตรความจุปอด ความเร็วการไหลเวียนอากาศ อุปกรณ์เหล่านี้มักมีข้อจำกัดในการประดิษฐ์เพราะไม่สามารถแก้ไขปัญหาความชื้นและอุณหภูมิในอากาศที่หายใจเข้าขณะนั้น ซึ่งรบกวนการฝึกโดยอาจก่อให้เกิดอาการระคายคอทำให้ฝึกไม่ได้นาน เพื่อศึกษาผลของการฝึกกล้ามเนื้อหายใจต่อความทนทานและความแข็งแรงของกล้ามเนื้อหายใจด้วยเครื่องฝึกความต้านทานการหายใจที่ออกแบบเพื่อลดปัจจัยข้างต้นโดยมีมาตรวัดบอกความต้านทาน มีการปรับความชื้นและอุณหภูมิ เป็นอาสาสมัครหญิง (อายุเฉลี่ย = 22.50 ± 2.64 ปี) จำนวน 20 คน แบ่งอย่างอิสระเป็นกลุ่มควบคุม (10 คน ไม่ได้รับการฝึก) และกลุ่มทดลอง (10 คน ได้รับการฝึก) โปรแกรมการฝึกกล้ามเนื้อหายใจด้วยเครื่องฝึกความต้านทานการหายใจที่ระดับความหนัก ร้อยละ 40 ของค่าความดันสูงสุดของกล้ามเนื้อหายใจเข้าของแต่ละคน 20 วงรอบ/ชุด (พัก 10 วินาทีทุก 2 วงรอบ) 5 ชุด/วัน 3 วันต่อสัปดาห์ ต่อเนื่องเป็นระยะเวลา 6 สัปดาห์ เป็นการฝึกความต้านทานแบบก้าวหน้าทุกสัปดาห์จากการประเมินความดันสูงสุดของกล้ามเนื้อหายใจเข้า ทำการวัด ค่าความแข็งแรงของกล้ามเนื้อหายใจเข้าและออกสูงสุด (แทนด้วยค่าความดันสูงสุดของกล้ามเนื้อหายใจเข้าและออกตามลำดับ) วัดค่าความทนทานของกล้ามเนื้อหายใจ (ใน 12 วินาที) ที่สัปดาห์ที่ 1 (ก่อนฝึก), 3 และ 6 ในกลุ่มควบคุมไม่มีการเปลี่ยนแปลงของความทนทานและความแข็งแรงของกล้ามเนื้อหายใจเข้าตลอดช่วงระยะเวลาฝึก ขณะที่กลุ่มทดลองมีค่าความทนทานและความแข็งแรงของกล้ามเนื้อหายใจเข้าเพิ่มขึ้นอย่างต่อเนื่องตลอดระยะเวลาที่ได้รับการฝึก โดยค่าความทนทานของกล้ามเนื้อหายใจในกลุ่มทดลองเมื่อเปรียบเทียบกับสัปดาห์แรก (115.79±3.36) เพิ่มขึ้นอย่างมีนัยสำคัญทางสถิติในสัปดาห์ที่ 3 (124.42±3.74; $P < 0.05$) และ 6 (128.02±3.91; $P < 0.05$) ตามลำดับ และค่าความแข็งแรงของกล้ามเนื้อหายใจเข้าในกลุ่มทดลองเมื่อเปรียบเทียบกับสัปดาห์แรก (79.60±2.57) เพิ่มขึ้นอย่างมีนัยสำคัญทางสถิติ ในสัปดาห์ที่ 3 (95.60±3.68; $P < 0.05$) และ 6 (103.20±3.57; $P < 0.05$) ตามลำดับ ในขณะที่ค่าความแข็งแรงของกล้ามเนื้อหายใจ

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ออกของทั้งสองกลุ่มไม่มีการเปลี่ยนแปลง นอกจากนี้ยังพบว่ากลุ่มทดลองไม่ได้แสดงหรือระบุอาการคอแห้งในระหว่างการศึกษา และเมื่อเปรียบเทียบระหว่างกลุ่ม พบว่าทั้งค่าความทนทานและความแข็งแรงของกล้ามเนื้อหายใจเข้า มีความแตกต่างอย่างมีนัยสำคัญทางสถิติที่สัปดาห์ที่ 3 และ 6 ($P < 0.05$) โดยในกลุ่มทดลองมีค่ามากกว่ากลุ่มควบคุม การศึกษานี้แสดงให้เห็นว่าการฝึกกล้ามเนื้อหายใจด้วยเครื่องฝึกความต้านทานการหายใจที่ออกแบบนี้สามารถเพิ่มทั้งความทนทานและความแข็งแรงของกล้ามเนื้อหายใจได้ โดยไม่มีอาการที่อาจเป็นอุปสรรคในการทดลอง

คำสำคัญ: การฝึกกล้ามเนื้อหายใจ, ความทนทานของกล้ามเนื้อหายใจ, ความแข็งแรงของกล้ามเนื้อหายใจ, ความดันสูงสุดของกล้ามเนื้อหายใจเข้า

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ORIGINAL ARTICLE

Effectiveness of respiratory resistance training device on respiratory muscles strength and endurance

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Abstract

Respiratory muscle strength and endurance play critical roles, like a pump, to continuously ventilate air in and out from the lungs. This makes the body possible to prolong physical activity. Respiratory muscle training is, therefore, necessary for either unhealthy or healthy persons. Various techniques and equipment on respiratory muscle training have been developed with some limitations. Most equipment focused on lung volumes and capacities and flow rates, in which environmental humidity and temperature had not been taken into account. These limitations cause sore throat and frequently bring training to an end. To investigate the effectiveness of respiratory resistance training device, specifically developed with humidity and temperature adjusted to overcome the above limitations, on strength and endurance. Twenty female volunteers (average age = 22.50 ± 2.64) were randomly divided into control (n = 10, no training) and experimental (n = 10, training) groups. The latter group was continuously trained using respiratory resistance training device at 40% of each individual maximal inspiratory pressure (MIP, represents inspiratory muscle strength) for 20 cycles/set (pause 10 sec for every 2 cycles), 5 sets/day, 3 days/week for 6 weeks. To make progression, new MIP was estimated and inspiratory resistance was readjusted on weekly basis for maintain load at 40%MIP. Respiratory muscle strength (inspiratory pressure via MIP and expiratory pressure via MEP) and endurance (via 12 sec maximal voluntary ventilation) were tested on week 1 (pre-training), 3 and 6. The Control group showed no significant change of both respiratory muscle endurance and inspiratory muscle strength. While the training group had higher respiratory muscle endurance and inspiratory muscle strength throughout the studying period. Respiratory muscle endurance in training group was significant higher at week 3 (124.42±3.74; $P < 0.05$) and 6 (128.02±3.91; $P < 0.05$) when compared to initial levels (115.79±3.36). Inspiratory muscle strength was significant higher at

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week 3 (95.60±3.68; $P < 0.05$) and 6 (103.20±3.57; $P < 0.05$) respectively when compared to initial levels (79.60±2.57). Whereas, the expiratory muscle strength was not changed in both groups. In addition, training group did not show signs/symptoms of sore throat. Comparison between groups revealed that the training group developed higher respiratory endurance than the control group at week 3 and 6 ($p<0.05$). respiratory resistance training device developed in this study exhibits its effectiveness on respiratory muscles for both strength and endurance with no complication.

Keywords: Respiratory muscle training, Respiratory muscle endurance, Respiratory muscle strength, Maximum inspiratory pressure

Introduction

Respiratory muscle fatigue is one of the major physiological limiting factors in either healthy or unhealthy persons which impair oxygen delivery to all body parts.[1-3] This, in turn, causes reduction of exercise capacity as well as quality of life.[1, 4] Recent investigations reveal that specific respiratory muscle training such as endurance and strength training can improve functional capacity and exercise performance[5] of either athletes[3, 6] or general population.[7, 8] Respiratory muscle training can be performed, mostly, with flow resistive devices.[7, 9-14] As flow rate is dynamic function of both chest wall and lung tissues, this indicator did not directly reflect respiratory muscle ability. Reports from the last decade specify maximal inspiratory and maximal expiratory pressures (MIP and MEP) as indicators for respiratory muscle strength.[15] However, handheld devices used for respiratory training have limitations. Regularly, respiratory resistant and endurance training protocol needed the continuous breath in and out for a long period. Some training devices could cause dry-sore throat because they did not have humidifier in the system. Another training device (e.g. Breathe Max) can prevent sore throat during training but the visual feedback target pressure from this device is approximate because the system uses water level scale to determine the intensity of training. To eliminate the above limitations, the development of a new respiratory muscle training device is needed. Therefore, the hypothesis of this study is that the new device with pressure scale and a humidifier-temperature control unit in the system would make possible for subjects to sustain effective respiratory muscle training. The purpose of this study is to investigate the effectiveness of the newly designed respiratory resistance training device on respiratory muscle endurance and strength.

Materials AND Methods

Subjects

Twenty Thai healthy females, age between 19-26 yrs, voluntarily participated in this study. All subjects were undergraduate and graduate students in physical therapy of Mahidol university. They were randomly divided into training (T) and control (C) groups. All subjects had no abnormal pulmonary functions. In addition, they did not involve in any aerobic exercise programs or any other physical training prior to/during participation in this study. All experimental procedures were explained clearly and informed consents were signed. This study was approved by the ethical committee of Mahidol university (MU 2007-44).

Respiratory resistance training device:

The respiratory resistance training device was designed by the Project of Research and Development of Biomedical Instrumentation, Institute of Molecular Biosciences, Mahidol University. Using an air filter (**Figure 1A**), the subjects breathed via a two-way low-resistance non-rebreathing valve (Hans Rudolph, USA). Inspiratory training was conducted using the closed solenoid valve (**Figure 1B**) connected to the inspired pressure gauge where control shutter was designed to sustain for 5 seconds. Subjects performed progressive inhalation up to target pressure, as shown by inspired pressure gauge (**Figure 1C**) and held. Within the inspired tube, air was heated and humidified.

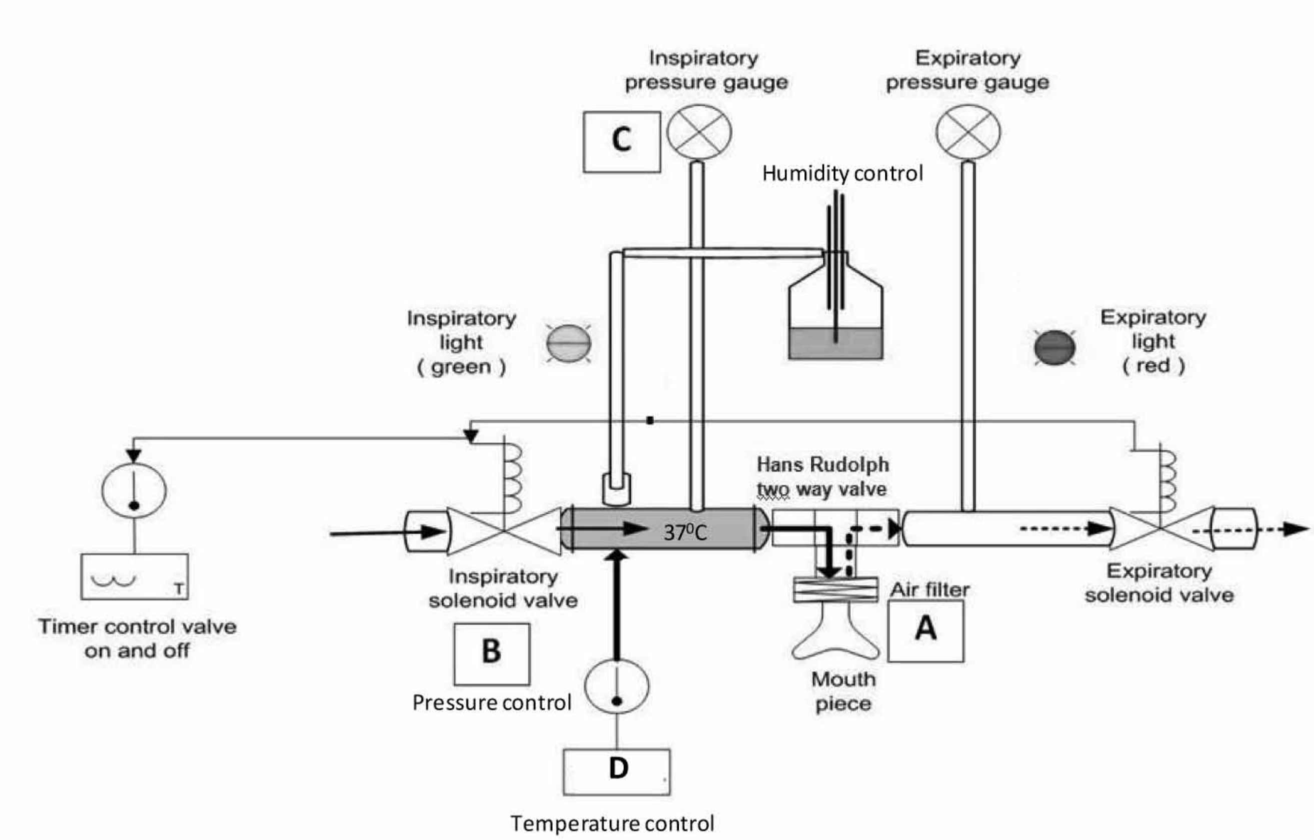

Figure 1 Diagram of respiratory resistance training device composes of units of air filter (A), inspiratory solenoid valve (B), inspiratory pressure gauge (C), and temperature control (D). Inspired airflow with adjusted resistant is conducted from B to be heated and humidified then into the lungs via breathing valve. Expired air is expelled out with no resistance.

Respiratory variables: Respiratory muscle endurance was represented by maximal voluntary ventilation in 12 seconds (MVV). The MVV was performed using a spirometer (CosMed, Italy). Respiratory muscle strength was represented by maximal inspiratory and expiratory pressures (maximal inspiratory pressure; MIP and maximal expiratory pressure; MEP). The MIP and MEP were estimated separately, with 5-minute resting period, using a portable hand-held mouth pressure (Micro Medical). In MIP and MEP, subjects were encouraged to perform maximal inspiratory and expiratory efforts at residual volume and total lung capacity respectively. The highest value of three measurements with 5% variability was recorded. All variables were measured at pre-training, week 3 and 6.

Inspiratory muscle endurance training

Subjects in T group were trained with the respiratory resistance training device at 40 % MIP, which was selectively displayed on the inspired pressure gauge when the green shutter was pushed (**Figure 2**) where individual's breathing resistance was reset on a weekly basis. Sets of respiratory training, from room air, were conducted at 2 consecutive cycles with 10 seconds pause period. Subject was separately trained for 10 sets per session for 5 sessions and 3 days/ week for 6 weeks. All training processes took approximately 45 minutes.

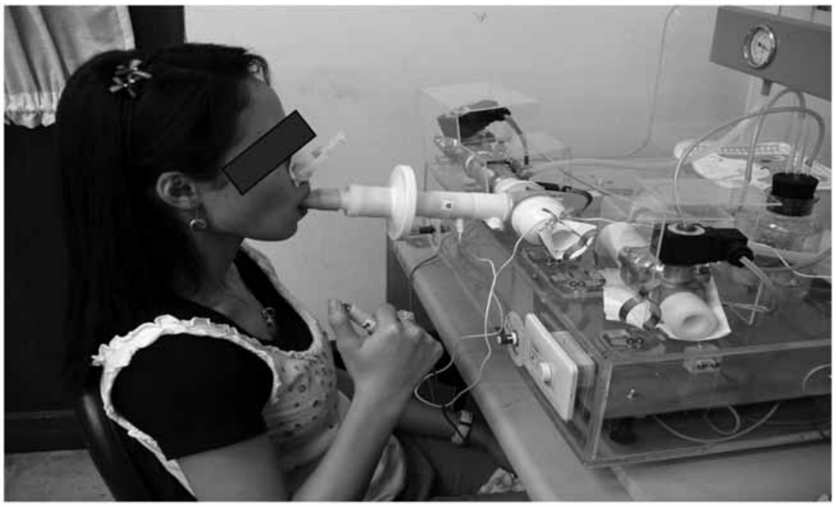

Figure 2 Respiratory resistance training device. Subject presses control button to start the experiment.

Statistical Analysis

Kolmogorov Smirnov goodness of fit test was used to test the distribution of data. All variables (MVV, MIP and MEP) showed normal distribution. Repeated-measures analysis of variance (Two-way mixed ANOVA) was used to test the differences of MVV, MIP and MEP of pre-training, week 3 and 6 in each group and between groups. The Bonferroni was used for post-hoc test. The statistical significance was set at P-value < 0.05. Data were presented as means and standard error of the means.

Results

Anthropometric data (ages, weights, heights, BMI, waist-to-hip ratio and physical activity score) and pulmonary function (FVC, FEV_1, FEV_1/FVC and PEF) showed no significant difference between two groups ($P > 0.05$) (**Table 1**).

Table 1 Physical characteristics and pulmonary function of subjects. Values were presented as mean ±SD.

Variables	Training (n=10)	Control (n=10)	P - value
Anthropometry			
Age (years)	22.50 ± 2.64	22.50 ± 2.64	1.000
Weight (kg)	52.10 ± 4.28	52.00 ± 4.92	0.962
Height (cm)	160.40 ± 5.32	160.40 ± 4.48	1.000
BMI (kg/m^2)	20.27 ± 1.75	20.23 ± 1.79	0.959
W/H ratio	0.77 ± 0.02	0.78 ± 0.03	0.858
Physical activity score	20.20 ± 2.10	19.00 ± 1.76	0.183
Pulmonary function			
FVC (L)	3.04 ± 0.25	2.82 ± 0.31	0.088
FEV1 (L)	2.76 ± 0.23	2.61 ± 0.27	0.180
FEV1/FVC (%)	90.40 ± 5.08	92.10 ± 4.43	0.436
PEF (L/sec)	7.01 ± 1.35	6.67 ± 0.98	0.531

Abbreviations: W/H = waist-to-hip ratio; FVC = forced vital capacity;
FEV_1 = forced expiratory volume in one second; PEF = peak expiratory flow rate

Table 2 Comparison of absolute value of MVV, MIP, MEP between the training and control groups in pre-training, 3rd week and after 6th week. Values are presented as means ± SEM.

	Training group (n = 10)			Control group (n = 10)		
	Pre-training	**3rd wk**	**6th wk**	**Pre-training**	**3rd wk**	**6th wk**
MVV (L/min)	115.79 ± 3.36	124.42 ± 3.74[a]	128.02 ± 3.91[ab]	109.42 ± 3.23	110.35 ± 3.46[c]	111.04 ± 3.51[c]
MIP (cmH_2O)	79.60 ± 2.57	95.60 ± 3.68[a]	103.20 ± 3.57[ab]	74.70 ± 2.33	75.90 ± 1.59[c]	77.20 ± 1.87[c]
MEP (cmH_2O)	92.80 ± 5.43	95.10 ± 3.68	94.80 ± 5.02	87.60 ± 2.39	86.30 ± 2.56	87.20 ± 2.29

a: significant different within group from pre-train (initial) ($P < 0.05$)

b: significant different within group between 3rd and 6th week ($P < 0.05$)

c: significant different between groups at the same period of time ($P < 0.05$)

Prior to training, no significant differences between the T and C groups of all variables including, MVV, MIP and MEP was shown ($P > 0.05$).

Within group comparison, all parameters in C showed no significant differences from its initial value (pre-training) and throughout the 6-weeks period. In T group, MVV progressively increased, from its initial, at 3rd week ($P < 0.05$) and further increased at 6th week ($P < 0.05$). In this group, MIP significantly increased at 3rd ($P < 0.05$) and 6th week ($P < 0.05$) when compared to its initial MIP level. However, MEP of both C and T group showed non-significant change for the entire period of the study.

Between groups comparison revealed the statistically differences of MVV ($P < 0.05$) and MIP ($P < 0.001$) between groups at 3rd and 6th week after training. In addition, T group did not show any sign or symptom of sore throat (**Figures 3** & **4**)

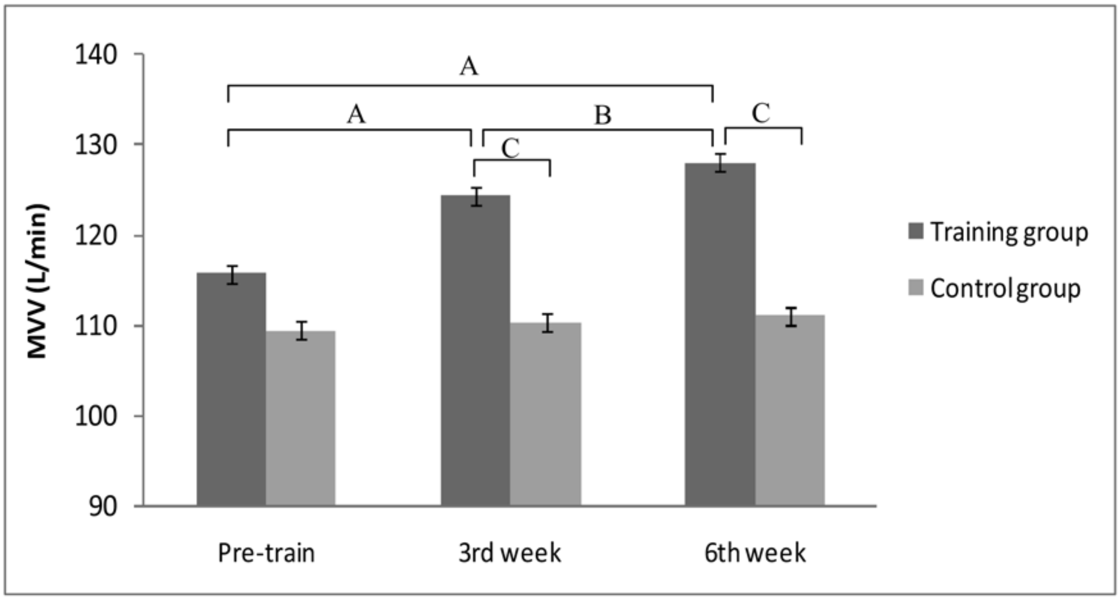

Figure 3 Comparison of maximal voluntary ventilation (MVV) in means ± SD between the training and control groups in pre-training, 3rd week and after 6th weeks.

a: significant different within group from pre-train (initial) ($P < 0.05$)

b: significant different within group between 3rd and 6th week ($P < 0.05$)

c: significant different between groups at the same period of time ($P < 0.05$)

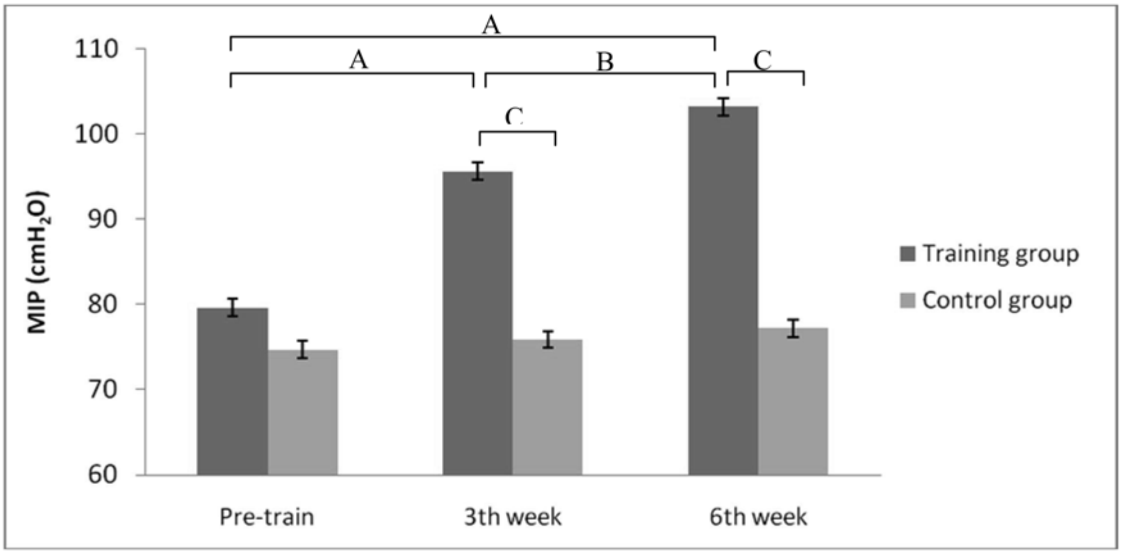

Figure 4 Comparison of maximal inspiratory pressure (MIP) in means ± SD between the training and control groups in pre-training, 3rd week and after 6th weeks.

a: significant different within group from pre-train (initial) ($P < 0.05$)

b: significant different within group between 3rd and 6th week ($P < 0.05$)

c: significant different between groups at the same period of time ($P < 0.05$)

Discussion

As part of respiratory muscle training (RMT), the present study showed that after 6 week of inspiratory muscle training (IMT), there was significant changed of MVV and MIP which were progressively and continuously increased by 10.57 % and 29.90 % respectively. IMT using pressure-loaded device had been previously demonstrated[10] in which water-loaded device improved MIP in healthy young females. Interestingly, the present study proved that the respiratory resistance training device with humidifier and temperature equip its efficacy for respiratory muscle training. Indeed, the improvement of respiratory muscle endurance after IMT in this study could be explained by either structural or functional adaptations. Improvements of inspiratory muscle strength after training showed similarity to other skeletal muscles which is generally attributed to increase in muscle mass and muscle protein within muscle fibers.[10, 16-18] Increase in muscle mass in respiratory muscle is shown as its ability to generate pressures at any lung volumes, in particular at the lowest (residual volume) and the highest (total lung capacity) lung volumes after training. This was proved by Ramirez-Sarmiento and colleague in 2002[19] who did biopsies of the external intercostal muscles of COPD patients to evaluate structural adaptation by RMT at 40-50% MIP. There were significant increases in the proportion of type I fibers (38%) and the size of type II fibers (21%) in the external intercostal muscles after RMT their study. Increment of activities of aerobic enzymes, oxidative capacity, mitochondrial density and capillary density are reported.[4, 10, 16, 17, 20] Additionally, higher diaphragm's ability might be explained by the remarkable increase of blood flow in muscle fibers type I during RMT.[21] These adaptations of aerobic capacity are not only detected in diaphragm muscle but also in the external intercostal muscles from inspiratory muscle endurance training.[21] Sonne and Devis in 1982[9] demonstrated that MVV increased in training group by 13% when compared to the pre-training status. Their training programs required COPD patients to exercise 30 minutes/day, everyday for 6 weeks by using a resistive device. In the present study, it was performed in normal healthy adults where the 10.57% change of MVV was shown.

Duration and intensity of respiratory muscle training affect on varieties of adaptation. Clanton and associates in 1985[10] reported that MIP increased by 34% following 10 weeks of training. The respiratory muscle training (RMT) consisted of 50% MIP using a threshold loading device (threshold valve with water load) 3 days/week for 10 weeks in healthy females with the age range 18-22 years. The training device in Clanton and associates' study had constant load and visual feedback as in the present study. However, the improvement of MIP by Clanton and associates was higher than our study that might be the difference of training duration of their study had longer than our study (10 weeks vs 6 weeks). Therefore, the improvement of inspiratory muscle strength should be due to the difference of the training protocols. Larson and colleagues in 1988[22] results showed significant increases in respiratory muscle strength and endurance from inspiratory muscle endurance training using the pressure threshold breathing device at 30% MIP. The exercise loading was adjusted by increasing the training load approximately 3 cmH_2O at every 10 cmH_2O increasing of MIP in order to maintain the training load at 30% MIP throughout the training period. They described that the respiratory muscle strength could be increased from the endurance training and the increased load during training would be an influencing improvement factor of inspiratory muscle strength. Lisboa and co-workers in 1994[23] determined the effect of respiratory training by threshold loading device at 30% MIP on respiratory strength and endurance.

Considering changes in MIP of training group, it was found that this change in pre-train - week 3 was larger than that of week 3 – week 6. It is possible that during the first 4 weeks of training strength was gained more rapidly from neural adaptation than structural adaptation.[24] After 4 weeks, strength was gained gradually by increasing their muscle size (hypertrophy).

This study showed significant increase in both MVV and MIP but MIP increase was more prominent than MVV. This study used the pressure parameter to indicate intensity (40% MIP). The intensity of pressure could refer to force that directly affected to muscle strength while MVV or the endurance parameter is mostly depended on subject's flow rate. Up to now, there is still no direct protocol or parameter to determine respiratory muscle endurance. This would lead to the strength increase was more potent than the increase of the endurance.

In particular, MEP of both control and treated groups were similarly unchanged throughout the period of study. This might be caused by the specificity of training program because training program in the present study was only conducted for inspiratory muscles training.

In the present study, we could confirm an effectiveness of this training device for enhancing respiratory muscle functions in healthy subjects. The advantages of this training device are 1) there was no signs/symptoms of sore throat during and after using the device 2) the device had clear visual feedback (C in Figure 1) which can induce the subjects to achieve the targets with no difficulty. In addition, no other adverse affects were reported by the subjects. This study is limited in females only so it should be investigated in males at different ages and in unhealthy subjects. For further studies, should be considered on expiratory muscle training and exercise performance. In addition, this device should also be conducted in elderly, athletes and respiratory distress patients.

Conclusion

This study had successfully proven that the designed respiratory resistance training device effectively which can improve respiratory muscle endurance and strength of inspiratory muscle in healthy subjects.

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