Chula Med J Vol. 53 No. 1 January-February 2009

Effects of elastic chest wall restriction on lung function after aerobic exercise training

Monchai Chottidao*
Opas Sinphurmsukskul* Thyon Chentanez*

Chottidao M, Sinphurmsukskul O, Chentanez T. Effects of elastic chest wall restriction on lung function after aerobic exercise training. Chula Med J 2009 Jan – Feb; 53(1): 39 - 49

Objective : *To investigate ventilatory responses and adaptation on exercise training with elastic chest wall restriction.*

Participants : *Twenty-four healthy males, aged 18 - 22 years-old, were participants in this study.*

Design : *Restrict-randomly divided into three experimental groups: strapped chest group (SC), non-strapped chest group (NC) and control group (CG) were comparative randomized design study.*

Method : *In the exercise groups, the subjects underwent exercise at the same intensity (70 - 80% MHR), frequency (3 time/week) and duration (60 min) for four consecutive weeks. Data collection included anthropometrics measurement (body weight, height, body mass index and circumference of the chest) before and after exercise training program. Respiratory functions include lung volumes and flows (FVC, $FEV_{1.0}$, $FEV_{1.0}$/FVC, FIVC, PEFR, MVV, MV_T and RR) were also measured each week during the training periods.*

---

*College of Sports Science and Technology, Mahidol University

Results : *The results showed that maximal voluntary ventilation in the SC group was significantly higher than the non-strapped chest group at the 4th week of training. The NC group had significantly lower levels of MV_T at the 2nd and 3rd of training period compared with the CG group. Respiratory rate of the CG subjects were significantly higher than those of the NC group.*

Conclusion : *In conclusion, resistance exercise training with elastic chest wall devices shows increases in the strength of the respiratory muscles as seen by the increase MVV and MV_T while RR decreases. Nevertheless, future researcher are still needed. They should cover a longer exercise period, larger elastic strapping with other methods and higher intensity loading on the chest, and different sports and gender groups.*

Keywords : *Thoracic restriction, maximal voluntary ventilation, maximal tidal volume.*

Reprint request: Chottidao M. College of Sports Science and Technology, Mahidol University,
999 Phuttamonthon 4 Road, Salaya, Nakhon Pathom 73170, Thailand.

Received for publication. November 6, 2008.

มนต์ชัย โชติดาว, โอภาส สินเพิ่มสุขสกุล, ได้ออน ชินธเนศ. ผลของการใช้ยางยืดรัดรอบอกต่อประสิทธิภาพการทำงานของปอดภายหลังการฝึกแบบใช้ออกซิเจน. จุฬาลงกรณ์เวชสาร 2552 ม.ค. – ก.พ.; 53(1): 39 – 49

วัตถุประสงค์ : *การวิจัยเชิงทดลองนี้มีวัตถุประสงค์เพื่อศึกษาการเปลี่ยนแปลงการตอบสนองของระบบหายใจต่อการออกกำลังกาย โดยมีแรงต้านที่กระทำต่อทรวงอก*

กลุ่มตัวอย่าง : *นักกีฬาเพศชาย ที่มีสุขภาพดี จำนวน 24 คน อายุระหว่าง 18 - 22 ปี*

รูปแบบการวิจัย : *รูปแบบของการวิจัยครั้งนี้เป็นการศึกษาแบบเปรียบเทียบ*

ระเบียบวิธีการวิจัย : *รูปแบบของการวิจัยครั้งนี้ แบ่งการศึกษาออกเป็น 3 กลุ่มตามการฝึก ได้แก่ กลุ่มออกกำลังกายใช้ยางรัดที่อก กลุ่มออกกำลังกายไม่ใช้ยางรัดที่อก กลุ่มไม่ออกกำลังกาย โดยออกกำลังกายที่ความหนัก 70 - 80% ของอัตราการเต้นของหัวใจสูงสุด 3 วันต่อสัปดาห์ และใช้เวลา 60 นาทีต่อวัน ระยะเวลารวม 4 สัปดาห์ ก่อนและหลังการวิจัยทำการวัดสัดส่วนรูปร่างของร่างกาย (ชั่งน้ำหนัก วัดส่วนสูง และวัดเส้นรอบวงทรวงอก) ทดสอบการทำงานของระบบหายใจ (อัตราการหายใจเข้า - ออก ปริมาตรหายใจออกมากสุด 1 วินาที ปริมาตรหายใจออกมากสุดใน 1 วินาทีต่ออัตราการหายใจเข้า-ออก ปริมาตรอากาศหายใจเข้า อัตราการหายใจออกสูงสุด ปริมาตรหายใจเข้า - ออกสูงสุด 12 วินาที ปริมาตรหายใจเข้า - ออกสูงสุดแต่ละครั้ง และอัตราการหายใจต่อนาที)*

ผลการศึกษา : *ผลการศึกษาพบว่า ปริมาตรหายใจเข้า-ออกสูงสุด 12 วินาทีของกลุ่มออกกำลังกายโดยใช้ยางรัดที่อกมีค่าเพิ่มขึ้นอย่างมีนัยสำคัญเทียบกับกลุ่มออกกำลังกายโดยไม่ใช้ยางรัดที่อก ปริมาตรหายใจเข้า-ออกสูงสุดแต่ละครั้งของกลุ่มออกกำลังกายไม่ใช้ยางรัดที่อกมีค่าลดลงอย่างมีนัยสำคัญในสัปดาห์ที่ 2 และ 3 ส่วนอัตราการหายใจต่อนาทีของกลุ่มออกกำลังกายโดยใช้ยางรัดที่ทรวงอกมีค่าลดลงอย่างมีนัยสำคัญเทียบกับกลุ่มออกกำลังกายโดยไม่ใช้ยางรัดที่อก*

ผลสรุป : *จากผลการทดลองสรุปได้ว่าการออกกำลังกายโดยมีแรงต้านที่กระทำต่อทรวงอก ทำให้กล้ามเนื้อหายใจแข็งแรงมากขึ้น จะเห็นได้จากปริมาตรหายใจเข้า-ออกสูงสุด 12 วินาทีและปริมาตรหายใจเข้า-ออกสูงสุดแต่ละครั้งเพิ่มขึ้น ในขณะที่อัตราการหายใจต่อนาทีลดลง สำหรับงานวิจัยในครั้งต่อไปน่าจะเพิ่มระยะเวลาของการฝึกหาวิธีการรัดทรวงอกและเพิ่มแรงต้านในแบบอื่น ๆ ศึกษาวิจัยในกลุ่มกีฬาและเพศที่แตกต่างออกไปเป็นต้น*

คำสำคัญ : *แรงต้านต่อทรวงอก, ปริมาตรหายใจเข้า-ออกสูงสุด 12 วินาที, ปริมาตรหายใจเข้า-ออกสูงสุดแต่ละครั้ง*

Respiratory functions in mammals require the integration of two essential components to permit the flow and transfer of gases between the external atmosphere and the blood.(1) Respiratory muscles are skeletal muscles that are morphologically and functionally similar to locomotor muscles. Their primary task is to displace the chest wall and, therefore, more gas come in and go out of the lungs to maintain arterial blood gas and pH homeostasis.(2) Although several other respiratory muscles are associated with whole-body exercise (i.e., the external intercostals, scalenes, and sternocleidomastoid muscles), the diaphragm is the primary inspiratory muscle and the most effective pressure generator to increase alveolar ventilation, and thus provides the best index of respiratory system muscle functions. (3) D'Urzo et al. (1985)(4) investigated the effect of elastic loading on the ventilatory pattern during progressive exercise, were measured in eight healthy subjects, reported the minute ventilation (V_E) was decreased significantly by the elastic load. Barnas et al. (1991)(5) investigated regional chest wall impedance by strapping on the lower rib cage and the abdomen. They found that the increase in the magnitude of impedance was correlated with the increase of the body segment in the electromyographic activity of the diaphragm. It is believed that any external load applied on the chest wall may affect the respiratory muscles and cause displacement of the chest wall, particularly in pre-pubertal children. In addition, factors affecting respiratory muscles such as age, sex and gender have been reported. Exercise training is known to induce adaptation of many systems such as the musculoskeletal and cardiovascular systems. Yerk et al. (1985)(6) also found an improve in maximal voluntary ventilation (MVV) and maximal exercise ventilation (VEmax) after endurance exercise training. Fanta et al. (1983)(7) investigated the effect of training on lung function. Training protocols included maximal inhalation to total lung capacity (TLC), held for 10 seconds and then exhaled to functional residual capacity (FRC) 20 times daily for 6 weeks. After training, they found a significant increase in vital capacity (VC), total lung capacity (TLC), and forced expiratory volume in one second ($FEV_{1.0}$). Since, there is few reports regarding the effectiveness of respiratory muscle resistant training during aerobic exercise training, the present study has sought to fill this gap. This study was aimed to investigate ventilatory responses, respiratory performance and adaptations to exercise training with elastic chest wall restriction between the strapped chest and non-strapped chest groups. Moreover, changes in the lung volumes, lung function and maximal voluntary ventilation as a result of exercise training were also observed.

Methods

Twenty-four male Sports Science students participated in this investigation and their ages ranged from 18 - 22 years. The participants were restrict-randomly divided into three groups. Group I (n = 9) participated in elastic strapped chest exercise; group II (n = 7) participated in non-elastic strapped chest exercise; and, group III (n = 8) were control. The study protocol is a comparative randomized design, which of 4 weeks on aerobic exercise training

The elastic chest strap was Esmarch Bandage (VBM, Germany). Its strapping harness comprised a 5 cm wide and 90 cm length 1 strapping wrap circumference of the upper chest. The subjects were

Table 1. Initial anthropometrics characteristics of chest strapped, non-strapped chest and control group. Data were presented as means ± SE.

Group	Strapped Chest	Non -Strapped Chest	Control
Age (yr)	19.22 ± 0.22	19.71 ± 0.18	19.75 ± 0.41
Weight (kg)	60.33 ± 1.19	62.86 ± 1.47	66.00 ± 3.12
Height (cm)	172.56 ±1.55	172.14 ± 1.30	170.50 ± 1.39
Circumference of normal chest (cm)	81.89 ± 0.31	81.43 ± 1.15	79.88 ± 1.09
Circumference of full chest (cm)	86.44 ± 0.38	85.57 ± 1.07	83.88 ± 1.13

Statistically significant differences indicated as $p < 0.01$

lower than both the strapped chest and the non-strapped chest groups in exercise training period ($p < 0.05$).

Absolute lung volume and capacities were measured, on weekly basis, during the four weeks. The control 's $FEV_{1.0}$ tended to be significantly lower than both strapped chest and non-strapped chest groups on the initial, 2nd, 3rd and 4th week ($p < 0.05$) except that only 1st week was significantly lower in the control group than the strapped chest group ($p < 0.05$) (Table 2). When compared this variable within the group, only forced expiratory in 1.0 second ($FEV_{1.0}$) of the non-strapped chest group increased significantly in the 3rd week of exercise training ($p<0.05$).

The sedentary group was found to have significantly lower forced vital capacity (FVC) than both the strapped chest group ($p<0.05$) and non-strapped chest group ($p<0.05$) on the 3rd and 4th week, while the non-strapped chest group was significantly higher than the control group on the 2nd week ($p<0.05$) (Table 2). Furthermore, the control group was significantly lower than the strapped chest group on the 1st and 2nd week ($p<0.05$). Ratio of forced expiratory in 1.0 second and forced vital capacity ($FEV_{1.0}$/FVC) were significantly different between the strapped chest and the control groups on the initial and the 3rd week ($p<0.05$). Moreover, the non-strapped chest group was significantly higher than the control group at the 3rd week of exercise training ($p < 0.05$) (Table 2). In addition, when compared within the group, there was no markedly difference of all groups ($p > 0.05$).

When compared these peak expiratory flow rate (PEFR) across the group during exercise training period, the control 's PEFR tended to be significantly lower than both the strapped chest and non-strapped chest groups on the 1st, 2nd, 3rd, and 4th week ($p <0.05$) (Table 2). Within the same group comparison, the strapped chest group was increased significantly in the 4th week of exercise training ($p < 0.05$). The non-strapped chest group was increased significantly at the 3rd week ($p < 0.05$). Besides, the control group was increased significantly in the 2nd week of exercise training ($p < 0.05$). Forced inspiratory vital capacity (FIVC) of the control group was significantly lower than both the strapped chest and non-strapped chest groups on the 1st and 4th week ($p < 0.05$). When compared this variable within the group, no significant difference in all groups was observed ($p < 0.05$) (Table 2). Relative maximal voluntary ventilation (MVV) is illustrated in Table 2. There was significantly lower MVV of the control group than both strapped chest and non-strapped chest groups on the 1st, 2nd, 3rd and 4th week ($p < 0.05$). Moreover, the strapped chest group was significantly higher than non-strapped chest group at the 4th week of exercise training ($p < 0.05$). When compared within the group, it was found that no significant difference in all groups ($p > 0.05$).

Table 2. Comparison of lung function study among 3 groups at initial and during training period. Data were collected at each week and presented at BTPS (means ± SE).

Parameter	Training period (week)	Strapped Chest	Non -Strapped Chest	control
$FEV_{1.0}$ (L)	Initial	4.18 ± 0.12^{a}	4.08 ± 0.19^{b}	3.48 ± 0.11
	1	4.19 ± 0.18^{a}	4.02 ± 0.23	3.63 ± 0.10
	2	4.04 ± 0.19^{a}	4.15 ± 0.18^{b}	3.58 ± 0.06
	3	4.13 ± 0.16^{a}	4.31 ± 0.19^{*,b}	3.53 ± 0.06
	4	4.30 ± 0.14^{a}	4.05 ± 0.15^{b}	3.63 ± 0.07
FVC (L)	Initial	4.24 ± 0.15^{a}	3.91 ± 0.19	3.55 ± 0.14
	1	4.32 ± 0.17^{a}	4.12 ± 0.23	3.75 ± 0.14
	2	4.12 ± 0.19	4.36 ± 0.18^{*,b}	3.72 ± 0.08
	3	4.25 ± 0.16^{a}	4.41 ± 0.16^{*,b}	3.60 ± 0.11
	4	4.38 ± 0.14^{a}	4.17 ± 0.15^{*,b}	3.64 ± 0.11
$FEV_{1.0}$/FVC	Initial	0.97 ± 0.011	0.93 ± 0.020^{b}	0.97 ± 0.010
	1	0.98 ± 0.008	0.98 ± 0.007	0.96 ± 0.016
	2	0.98 ± 0.006	0.95 ± 0.009	0.96 ± 0.017
	3	0.98 ± 0.007^{a}	0.97 ± 0.015^{b}	0.92 ± 0.023
	4	0.99 ± 0.003	0.97 ± 0.011	0.97 ± 0.012
PEFR (L/S)	Initial	8.17 ± 0.51	7.10 ± 0.44	6.72 ± 0.21
	1	8.62 ± 0.52^{a}	8.54 ± 0.46^{b}	6.11 ± 0.42
	2	9.12 ± 0.58^{a}	8.90 ± 0.35^{*,b}	6.38 ± 0.32
	3	9.61 ± 0.51^{*,a}	9.16 ± 0.40^{*,b}	6.09 ± 0.14*
	4	10.16 ± 0.55^{*,a}	9.03 ± 0.45^{*,b}	5.59 ± 0.44*
FIVC (L)	Initial	3.97 ± 0.09	3.72 ± 0.15	3.63 ± 0.13
	1	3.97 ± 0.12^{a}	3.86 ± 0.21	3.45 ± 0.15
	2	4.17 ± 0.48	4.07 ± 0.33	3.46 ± 0.22
	3	3.81 ± 0.13	3.84 ± 0.16	3.45 ± 0.10
	4	3.86 ± 0.14	4.14 ± 0.34^{b}	3.49 ± 0.13
MVV (L/MIN)	Initial	172.60 ± 10.02	170.47 ± 12.16	136.76 ± 1.75
	1	176.02 ± 9.78^{a}	176.45 ± 4.65^{b}	135.81 ± 2.50
	2	183.37 ± 9.80^{a}	173.17 ± 5.94^{b}	136.06 ± 4.06
	3	187.76 ± 9.48^{a}	170.05 ± 11.15^{b}	134.76 ± 2.96
	4	192.90 ± 5.92^{a,c}	174.88 ± 5.35^{b}	136.13 ± 4.59

Table 2. Comparison of lung function study among 3 groups at initial and during training period. Data were collected at each week and presented at BTPS (means ± SE). (Continued)

Parameter	Training period (week)	Strapped Chest	Non-Strapped Chest	control
MV_T(L)	Initial	1.47 ± 0.07	1.24 ± 0.11	1.20 ± 0.04
	1	1.61 ± 0.10^{a}	1.41 ± 0.05^{b}	1.10 ± 0.05
	2	1.76 ± $0.16^{*,a}$	1.35 ± 0.07^{c}	1.06 ± 0.05
	3	1.86 ± $0.14^{*,a}$	1.38 ± 0.14^{c}	1.15 ± 0.04
	4	1.63 ± 0.12^{a}	1.38 ± 0.07	1.23 ± 0.05^{*}
RR (L/MIN)	Initial	127.12 ± 7.07^{a}	143.47 ± 6.87	141.15 ± 3.75
	1	121.56 ± 5.59^{a}	141.32 ± 4.18^{c}	142.40 ± 6.19
	2	116.01 ± 6.38^{a}	131.32 ± 4.72^{c}	140.65 ± 3.80
	3	108.23 ± $6.34^{*,a}$	135.61 ± 5.28^{c}	139.27 ± 2.20
	4	108.23 ± 3.00^{a}	133.47 ± 6.42^{c}	131.66 ± 3.08

* Significantly different from its corresponding initial values of the same group, $p<0.05$; a significantly different between strapped chest and control at the same period, $p<0.05$; b significantly different between non-strapped chest and control at the same period, $p<0.05$; c significantly different between strapped chest and non-strapped chest at the same period, $p<0.05$.

Chest strapping's MV_T tended to be significantly higher than the control group on the 1st, 2nd, 3rd and 4th week of exercise study ($p < 0.05$), whereas the non-strapped subjects were significantly different from those of the control group at the 1st week ($p < 0.05$). Moreover, the strapped chest group was significantly higher than the non-strapped chest group in the 2nd and 3rd week ($p < 0.05$) (Table 2). In addition, when compared within the group, there was significant difference of the strapped chest group on the 2nd and 3rd week of exercise training ($p < 0.05$). Respiratory rate (RR) of the control group found to have significantly lower than the strapped chest group on each week of training ($p < 0.05$) (Table 2). Furthermore, respiratory rate of non-strapped chest group was significantly higher than the strapped chest group on the 1st, 2nd, 3rd and 4th week of exercise study ($p < 0.05$). When compared within the group, only RR of the strapped chest group decreased significantly in the 3rd week of training ($p < 0.05$).

Discussion

These studies examined the effects of elastic chest wall restriction on lung function after aerobic exercise training. The present study showed the strapped chest subjects had greater maximal voluntary ventilation (MVV), maximal tidal volume (MV_T) and respiratory rate (RR) than those of the non-strapped chest group ($p<0.05$).

These findings were inconsistent with previous studies: William et al. (2002)(8) reported the effect of inspiratory and expiratory muscles training in competitive triathletes and marathon runners that the subjects demonstrated no significant increase in FVC, $FEV_{1.0}$, $FEV_{1.0}$/FVC, PEFR and FIVC. Legg S, et al. (2004) (9) reported that a university bag load 6 kg, one with two shoulder straps and the other with a single strap worn across the shoulders and the chest. There were no significant differences of $FEV_{1.0}$, FVC, $FEV_{1.0}$/FVC and PEFR in the two groups.

In the present study, however, we have demonstrated that chest strapping had greater maximal voluntary ventilation (MVV), maximal tidal volume (MV_T) and respiratory rate (RR) than a non-strapped chest. This certainly indicates that loads applied to the rib cage, which restrict its mechanics, and increase in average inspiratory airflow. Furthermore, the response to rib cage restriction is graded so that greater increase in muscle activity is produced with more severe restriction. In contrast to the effects of rib cage restriction, inspiratory muscle activity as measured by occlusion pressure did not alter by restriction of abdominal expansion, which presumably interferes more with diaphragm than the intercostals muscle movement. Moreover, although rib cage restriction decreased the tidal volume and duration of inspiration and expiration and altered the pattern of breathing, restriction of abdominal excursion did not. Selective restriction of either the rib cage or the abdominal movement was associated with compensatory increases in the tidal volume of the unhindered portion of the chest wall. Robison et al. (1982) (10) studied the effects of running on respiratory muscle function found that, at the end of a 20-week program, subject's demonstrated a significant increase in MVV. William et al. (2002) (8) studied the effect of inspiratory and expiratory muscle training in competitive triathletes and marathon runners found significant increase in maximal V_E and maximal V_T as well as a decrease in RR at maximal exercise.

Conclusions

Overall, it can be concluded that elastic strap devices or exercises with different thoracic restrictions do elicit change in the pulmonary muscles functions. Elastic chest strapping or resistance exercise training increased the strength of the respiratory muscles as seen by the increase in maximal voluntary ventilation (MVV) and maximal tidal volume (MV_T) as well as decreasing in respiratory rate (RR) during four weeks of exercise training.

The use of exercise training with different thoracic restrictions and elastic strap devices, in the present study is effective as a method for conditioning the resistance exercise training in athletic subjects. This modified apparatus may be a useful device for pulmonary resistance muscle training in sports science and rehabilitation medicine especially asthma, chronic restrictive pulmonary disease and chronic bronchitis.

As long as sports scientists and coaches strive to push the limits of athlete's performance every method of training will be explored. Pulmonary resistance training with athletes is relatively new, and has received minimal research. Furthermore, more studies should be done with a longer exercise-training period, comparing with elastic straps in other methods and intensity loading on the chest, different sports and gender groups.

References

1. Farkas GA, Cerny FJ, Rochester DF. Contractility of the ventilatory pump muscles. Med Sci Sports Exerc 1996 Sep; 28(9):1106 -14
2. Powers SK, Criswell D. Adaptive strategies of respiratory muscles in response to endurance exercise. Med Sci Sports Exerc 1996 Sep; 28(9):1115 - 22
3. Nickerson BG, Kneens TG. Measuring ventilatory muscle endurance in humans as sustainable inspiratory pressure. J Appl Physiol 1982 Mar; 52(3): 768 - 72
4. Derenne JP, Macklem PT, Roussos C. The respiratory muscles: mechanics, control, and pathophysiology. Am Rev Respir Dis 1978 Jul;118(1):119 - 33
5. Barnas GM, Mills PJ, MacKenzie CF, Skacel M, Smalley AJ, Watson RJ, Loring SH. Regional chest wall impedance during nonrespiratory maneuvers. J Appl Physiol 1991 Jan; 70(1): 92 – 6
6. Yerg JE II, Seals DR, Hagberg JM, Holloszy JO. Effect of endurance exercise training on ventilatory function in older individuals. J Appl Physiol 1985 Mar; 58(3): 791 - 4
7. Fanta CH, Leith DE, Brown R. Maximal shortning of inspiratory muscles: effect of training. J Appl Physiol 1983 Jun; 54(6): 1618 - 23
8. Amonette WE, Dupler TL. The effects of respiratory muscle training on VO_2 max, the ventilatory threshold and pulmonary function. J Appl Physiol 2002 May; 5(2): 29 - 35
9. Legg S, Cruz C. Effect of single and double backpacks on lung function. Ergonomics 2004 Feb; 47(3): 318 - 23
10. Robinson EP, Kjeldgaard JM. Improvement in ventilatory muscle function with running. J Appl Physiol 1982 Jun; 52(6): 1400 - 6