Effect of Exercise Training Intensity on Ventilatory Efficiency in Patients with Coronary Artery graft

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ABSTRACT

Ventilatory efficiency is defined by ventilation relative to carbon dioxide (Co_2) production. In most patients as in normal subjects, ventilatory efficiency improves with exercise. The present study was conducted to investigate the most effective exercise intensity in improving the ventilatory efficiency in patients with coronary artery bypass graft (CABG). Thirty male patients, with age ranged from 50 to 60 years old (53.71 ± 3.42 years), had been operated for CABG, two months at least after the operation, they assigned into three groups, according to the intensity of exercise training program, which had been conducted for three months. Cardiopulmonary exercise testing was performed before and after training program. Ventilatory efficiency during exercise was expressed as the ratio of ventilation to CO_2 output (ventilatory equivalent of CO_2) at the anaerobic threshold (AT), and the slope of VE versus VCO_2. The mild training intensity did not induce significant change in ventilatory efficiency while produced significant change in exercise crpacity indices (VO_{2max}, AT, and O_2 pluse). While training at moderate or severe intensity produced a significant change in all parameters. It was concluded that moderate and severe intensity of exercise training could induce improvement in ventilatory response to exercise in patients with CABG.

Key words: *Exercise training intensity – Ventilatory efficiency – Coronary artery graft.*

INTRODUCTION

Exercise training after coronary arterial bypass grafting (CABG) surgery is known to have several favorable effects. In these patients, training enhances exercise tolerance[1,11], activity of daily living and quality of life[14]. Additionally, shortness of breathing during exercise is often noted to have diminished after physical training[1]. Shortness of breathing is a major complaint when ventilation is accelerated during exercise. This exercise-induced hyperpnea can be assessed using cardiopulmonary exercise testing (CPXT), in which the slope of the relationship between minute ventilation and carbon dioxide output (VE/VCO_2 slope) has been proposed as a parameter for evaluating ventilatory response to exercise[5,13,32]. VE/VCO_2 slope represents the slope of the regression line with ventilation (VE) as the vertical axis and carbon dioxide production (VCO_2) as the horizontal axis[31]. It also represents how much a participant needs to ventilate to release a given amount of carbon dioxide (Co_2), and it was reported to be associated with exercise, capacity[38]. It was reported that VE/VCO_2 slope acquired during CPXT was 24 to 26 in normal subjects[7,26].

The regular exercise to manage coronary vascular disease (CVD) is widely accepted throughout the medical community[4]. There are numerous studies in the literature that address the relationship between either intensity or weekly amount of exercise capacity, as outlined in an evidence-based symposium[24] on dose-response physical activity and health. However, investigations that have attempted to identify a threshold or minimum exercise intensity for eliciting improvement in physical work capacity and enhancing cardiorespiratory fitness, provide conflicting recommendations regarding the relationship between exercise intensity and cardiovascular adaptation[17,19,22,29]. Moreover the available literature concerned the ventilatory response to exercise training in patients with chronic heart failure (CHF) and pulmonary hypertension[20,37], only one study investigated the ventilatory efficiency in patients after CABG in response to short term exercise training[1]. So, the current study was conducted to investigate the role of exercise training intensity in improving ventilatory efficiency in patients after CABG.

SUBJECTS MATERIAL AND METHODS

I- Subjects

Thirty male patients with age ranged from 50 to 60 years old (53.71±3.42 years) were selected from the a attendance list of Cardiac Rehabilitation Center at National Heart Institute. They were randomly divided into three groups of equal number according to exercise training intensity used in rehabilitation process. All of them had been operated upon for coronary artery bypass graft (CABG), at least two months ago. No difference in left ventricular ejection fraction (EF%), which was evaluated using left ventriculography, was evident between the 3 groups (Table 1).

Table (1): Subjects criteria in different groups.

Group	Age (Yr)	Height (cm)	Weight (kg)	EF (%)
Mild ex	48.27 ± 5.1	168.6±2.59	86.5±3.92	50±5.5
Moderat ex	48.33±5.2	170.6±4.69	86.2±4.02	47.8±6.7
Severe ex	49.53±3.7	171.2±3.26	98±9.99	47.9±5.9

EF = ejection fraction ex= exercise training

None of these subjects had ejection fraction less than 40%; unstable angina; valve disorders; musculoskeletal disorders or other medical problems like hepatic or renal disorders. They were medically controlled particularly for blood glucose and blood pressure. All patients received aspirin, dipyridamole and nitrates; these medications were not altered throughout the period of the study.

II- Cardiopulmonary exercise testing (CPXT)

Patients underwent symptom-limited cardiopulmonary exercise testing with a respiratory gas exchange measurement. The CPXT was administrated 2-4 hours after a light meal. A personalized ramp protocol was used[38]. A 12-lead electrocardio gram (ECG), heart rate, and blood pressure were obtained at rest and at each minute during exertion. For breath-by-breath gas exchange measurements, an Oxycon-Prometabolic cart (Jaeger, Toennios, Germany) was utilized. Minute ventilation (VE), oxygen uptake (VO_2), carbon dioxide production (VCO_2) and other exercise variables were computer-calculated, breath-by-breath, interpolated second-by-second and averaged at 10 seconds intervals. Maximum oxygen consumption (Vo_{2max}) was defined as the highest VO_2 obsevered during the CPXT. Age, gender, and weight-adjusted predicted VO_2 values were also determined by using the regression equations of Wasserman et al.,[38]. Anaerobic threshold (AT) was determined using the V-slope method and expressed as a ratio of attained VO_2 at the onset of respiratory compensation, from the predicted normal value[3]. For the assessment of ventilatory efficiency; the VE/VCO_2 slope was measured by linear regression, excluding the non-linear part of the data after the onset of ventilatory compensation for metabolic acidosis[20]. Also ventilatory efficiency during exercise was expressed as the ratio of ventilation to Co_2 output at AT (VE/VCO_2@AT)[36,37]. The oxygen pulse (O_2 pulse) was determined as previously described[38]. The test procedures were reported with the same criteria after completion of the training program.

III- Training Procedures

Each subject participated in exercise training program for 12 weeks, three times per week. The program was designed in the form of circuit interval training mode. Each individual training intensity was calculated as training heart rate (THR) based on his maximum and resting heart rate obtained from CPET; according to Karvonen's formula[23].

$THR = HR_{rest} + (HR_{max} – HR_{rest}) \times TF$

Where HR_{rest} = resting heart rate in bpm.

HR_{max} = maximum heart rate in bpm.

TF = training fraction; it was 55 to 65% in mild training intensity, 65 to 75% in moderate intensity and 75 to 85% is severe training intensity.

Each exercise session consisted of three phases, that is, warm-up, active and cool-down phases. During the warm-up phase, the subject performed simple stretching exercise for all large muscle groups and jogging or walking for 5 to 10 minutes at TF equal to 30-40%. During the active phase, the subject was allowed to reach his pre-calculated training heart rate (THR) in bouts form with total time of 45 to 60 minutes. It is performed in circuit training using treadmill, bicycle and stair master. During interval between bouts, the speed or resistance of the apparatus was adjusted to decrease HR to reach the warm-up level (TF = 40%). The last phase was cool-down; which continued for 10 to 15 minutes; the workload decreased gradually until the HR and blood pressure returned nearly to resting level. Throughout the entire of training session, the patient was monitored for ECG and blood pressure.

IV- Data Collection and Statistical procedures

All data were expressed as the mean ± SD. Differences between CPXT variables before and after training in each group were assessed by a paired t-test, a value of $P<0.05$ was considered significant. The relative change of each variable due to different intensities of exercise training, where relative changes % were calculated from the following equation:

$$\text{Relation change \%} = \frac{\text{Post} - \text{Pre}}{\text{Pre}} \times 100$$

RESULTS

Through the present study comparison was made by paired t-test to compare the significance of difference between before and after among the three groups (mild intensity, moderate intensity and severe intensity groups) across the ventilatory efficiency parameters (slope of VE versus VCO_2, VE/VCO_2 at anaerobic threshold [ventilatory equivalent of CO_2 at anaerobic threshold] and exercise tolerance indices ($VO_{2\ max}$, AT, and O_2 pulse).

I- Ventilatory efficiency parameters

A- VE/VCO_2slope: Table (2) Fig (1)

The analysis of data exhibited a non significant difference between pre and post values of VE/VCO_2 slope in the mild intensity group. The mean relative change decreased by 6.86±5.6 in this group. However the moderate intensity and severe intensity groups showed a significant difference between pre and post values of VE/VCO_2Slope. The mean relative change of the slope decreased by 11.14±4.8 in the moderate intensity group and 7.73±3.8 in the severe intensity group.

Table (2): Statistical evaluation of the changes occurred in studied ventilatory efficiency variables (VE-VCO_2slope and VE-VCO_2 at AT) obtained from CPXT before and after training in the different groups as regards its relative changes.

Variable	Mild Group				Moderate Group				Severe Group			
	Pre	**Post**	**%**	**P**	**Pre**	**Post**	**%**	**P**	**Pre**	**Post**	**%**	**P**
VE-VCO_2 slope	36.75 ±0.43	35.43 ±0.96	↓6.86% ±5.6	>0.05	31.76 ±1.28	28.18 ±1.6	↓11.14 % ±4.8	<0.05	28.70 ± 2.0	26.4 ±9.6	↓7.73% ±3.8	<0.05
VE/VCO_2@AT	39.1 ±3.7	37.4 ±4	↓4.7% ±1.6	>0.05	36.26 ±1.19	28.6 ±7.9	↓11.1% ±2.26	<0.05	31.54 ±1.25	28.34 ±0.38	↓10.02 % ±2.9	<0.05

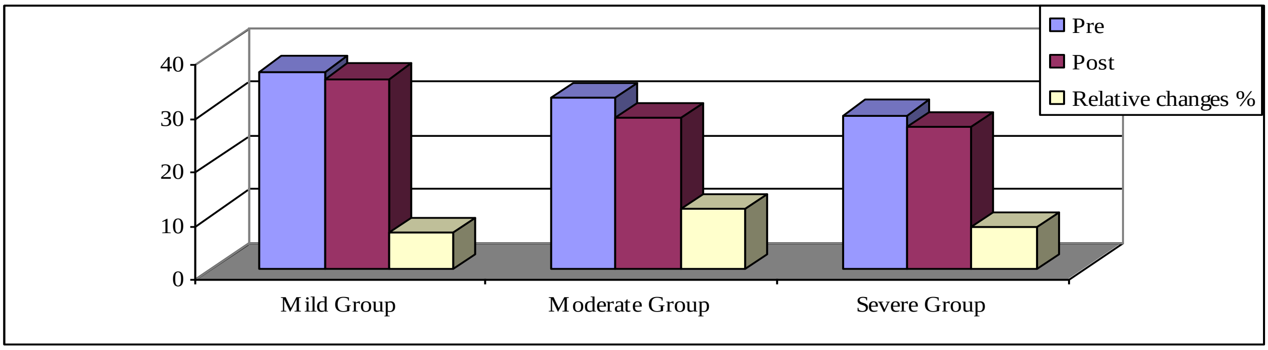

Fig. (1): Mean VE-VCO_2slope recorded before and after training in different training intensity groups and its mean relative changes %.

B- VE/VCO_2@AT: Table (2) Fig. (2)

The analysis of data exhibited a non significant difference between pre and post values of VE/VCO_2@AT in the mild intensity group. The moderate and severe intensity groups showed a significant difference between before and after. The mean relative change decreased by 4.7±1.6 in the mild intensity, while it decreased by 11.1±2.26 and by 10.02±2.9 in the moderate intensity and severe intensity groups, respectively.

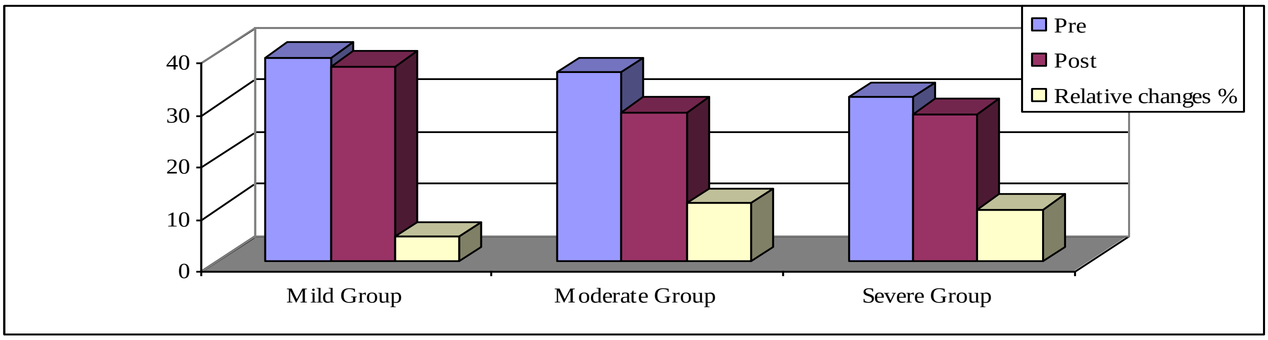

Fig. (2): Mean VE/VCO_2@AT recorded before and after training in different training intensity groups and its mean relative changes %.

II- Exercise tolerance indices

A- Peak oxygen consumption (peak VO_2 in ml/kg/min): Table (3), Fig. (3)

The analysis of data clarified a significant change in the difference between before and after training in all groups. The mean relative change increased by 7.4±2.35, 13.86 ± 8.2, and 44% ± 20.1 in mild, moderate and severe groups, respectively.

Table (3): Statistical evaluation of the studied exercise tolerance indices (Peak VO_2, AT, and O_2 pulse) before and after training in each group as regards its relative changes.

Variable	Mild Group				Moderate Group				Sever Group			
	Pre	**Post**	**%**	**P**	**Pre**	**Post**	**%**	**P**	**Pre**	**Post**	**%**	**P**
Peak VO_2 (ml/kg/min)	17.8± 3.0	18.2 ±2.8	↑7.4% ±2.35	<0.05	15.7 ±1.56	17.9 ±2.0	↑13.86 % ±8.2	<0.05	15 ±3.3	20.38 ±1.15	↑44% ±20.1	<0.05
AT (%)	46.1 ± 9.7	49 ±7.7	↑7.6% ±5.3	<0.05	47.6 ±5.3	55.2 ±7.0	↑15.86 % ±5.9	<0.05	41.2 ±5.1	55.1 ±5.6	↑34.17% ±5.58	<0.05
O_2 pulse (ml/bpm)	12.35 ±1.58	13.63 ±1.69	↑10.46 % ±3.28	<0.05	12.42 ±1.73	13.93 ±2.82	↑12.48 % 9.64	<0.05	13.18 ±2.84	16.76 ±2.61	↑29.22% ±13.16	<0.05

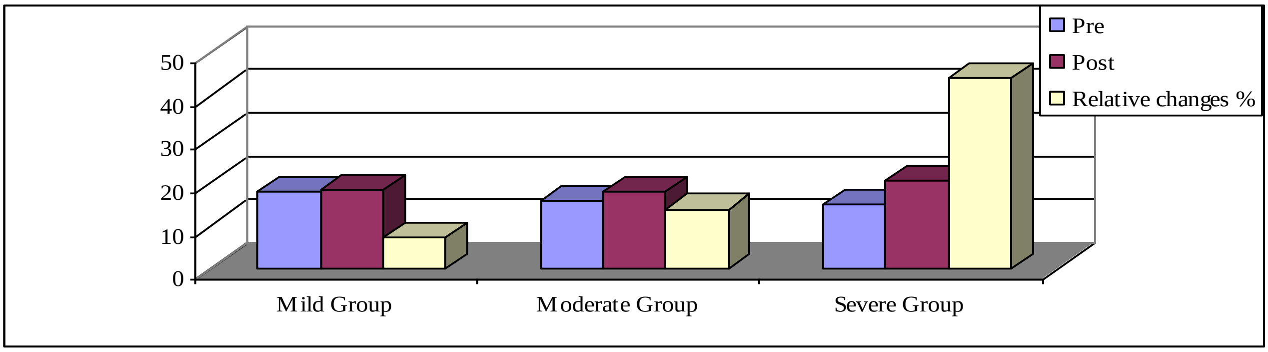

Fig. (3): Mean peak VO2 recorded before and after training in different training intensity groups and its mean relative changes %.

B- Anaerobic threshold (%): Table (3) fig (4).

The analysis of data showed a significant change between pre and post training in all groups. The mean relative change increased by 7.6±5.3 in the mild group, while increased by 15.86±5.9, and 34.17±5.58 in moderate and severe intensity groups, respectively.

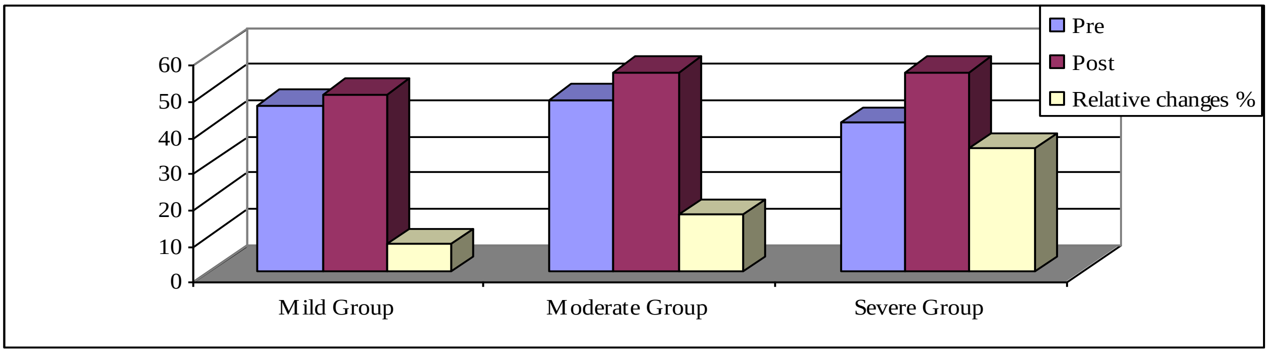

Fig. (4): Mean Anaerobic threshold (%) recorded before and after training in different training intensity groups and its mean relative changes %.

C- O2 pulse (mL/bpm): table (3) Fig. (5)

The analysis of data showed a significant change between pre and post training in all groups. The mean relative change increased by 10.46±3.28 in the mild group, while increased by 12.48±9.64, and 29.22±13.16 in moderate and severe intensity groups, respectively.

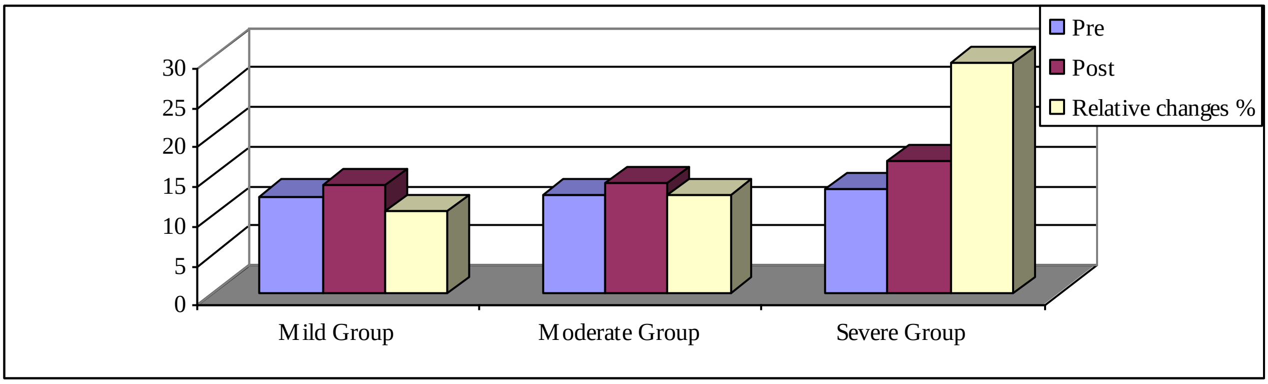

Fig. (5): Mean O2 pulse recorded before and after training in different training intensity groups and its mean relative changes %.

DISCUSSION

The purpose of the present study was to explorate the influence of exercise training intensity on ventilatory efficiency in patients after CABG after rehabilitation program. It was demonstrated that mild exercise training intensity (55 to 65% of heart rate resevere) could not induce significant improvement in ventilatory efficiency. The vigorous exercise training was more benefical than mild and moderate intensity.

For ventilatory efficiency indices, the results of the present study revealed that there was a decrease in the VE-VCO_2 slope (6.86%±5.6 in the mild intensity group, 11.14%±4.8 in moderate intensity group, and 26.4%+ 9.6 in severe intensity group), a decrease in VE/VCO_2@AT (4.7%±1.6 in mild intensity group, 11.1%±2.26 in moderate intensity group, and 10.02%±2.9 in severe intensity group). For exercise tolerance indices, the results of the present study revealed that there was an increase in the peak oxygen consumption (7.4%±2.35 in mild intensity group, 13.86%±8.2 in moderate intensity group, and 44%±20.1 in severe intensity group) an increase in the anaerobic threshold (7.6%±5.3 in mild intensity group, 15.86%±5.9 in moderate intensity group, and 34.17%±5.58 in severe intensity group) and an increase in O_2 pulse (10.46%±3.28 in mild intensity group, 12.48%±9.64 in moderate intensity group, and 29.22%±13.16 in severe intensity group).

The VE/VCO_2 at AT and the VE/VCO_2 slope have been both used to assess the degree of exercise hyperpnea and are often reported to be high in patients with chronic heart failure because they usually show exercise hyperpnea[12,30]. Also these values are related to the severity of chronic heart failure[35]. Several pathophysiological mechanisms for augmented ventilation have been suggested. Mathematically, the VE/VCO_2 slope is determined by three factors: the rate of CO_2 production, the ratio of physiological dead space ventilation to tidal ventilation (V_D/V_T), and partial pressure of carbon dioxide ($PaCO_2$)[20]. There fore, for a given VCO_2, an increase in VE/VCO_2 slope has multiple possible substrates; (i) an augmented central and/or peripheral command to ventilation, which drives the $PaCo_2$ below the physiological range; (ii) a large dead space which requires an increase in ventilation to maintain a normal $PaCO_2$; and (iii) an early occurrence of metabolic acidosis which demands ventilatory compensation[20]. Initial studies by Sullivan et al.,[35] reported that an increased V_D/V_T in the face of a persevered neural control of ventilation and normal blood gases, is responsible for the augmented VE/VCO_2 slope. In patients with heart failure due to different pathogenesis, Wasserman et al.,[39] reproduced the same findings, identifying structural changes intrinsic to the lung (restrictive lung changes) and reduced lung perfusion, as responsible for the occurrence of a high VD/VT and consequent ventilation perfusion mismatch. Moreover Adachi et al.,[1] suggested that a rapid shallow breathing pattern also plays an important role in inducing the steep VE/VCO_2 slope. Abnormal sensitivity of the skeletal muscle ergoreceptor or chemosensitivity has been proposed as a potential cause of exercise hyperpnea[8]. In the current study, it was found that exercise training resulted in improving ventilation efficiency. This may be attributed to reduced ventilation/perfusion mismatching[9], and/or peripheral adaptations[25]. Current guidelines of the American College of Sports Medicine[2], suggested that changes in cardiorespiratory fitness are independent of exercise intensity. While the present study, is designed to accommodate improvements in cardiorespiratory fitness (VO_2, AT and O_2 pulse) by prescribing exercise training intensities; is in agreement with controlled[18,28] and uncontrolled trails[10] demonstrating that high and moderate intensity training is more effective in increasing cardiorespiratory fitness and ventilatory efficiency than mild intensity training even with the same energy cost[15,33]. Collectively, these findings suggest that high and moderate intensities should be performed if the goal of training are to maximize cardiorespiratory fitness and ventilatory efficiency. The present study also suggests that the changes in parameters of CPXT are influenced by exercise intensity.

Mechanism by which indices of physical work capacity or cardiopulmonary fitness, were dependent on intensity of exercise training is unclear with the availalde knowledge. One possible mechanism might be through adaptations in autonomic control. As a consequence of aerobic training, sympathetic drive at rest is reduced and vagal tone is increased with potential effects on blood pressure, and other hemodynamic variables, resulted in an increase of the cardiopulmonary reserve during exercise, higher intensities elicit exponentially greater increases in symptathetic drives[34]. Thus one might hypothesize that vigorous intensity training would result in greater autonomic adaptations than mild intensity. This may contribute to reverse the pathophysiological factors which limits the cardiopulmonary fitness. The peripheral and central adaptations were suggested to increase cardiac out put[6,16,21]. In the current study, the peak O_2 pulse (peak VO_2/peak HR) which is known to indicate stroke volume at peak exercise[37,] was improved after physical training in similar fashion. Cardiac out put is related closely to patency of blood vessels, with decreased cardiac output, the blood vessels tend to constrict and vice versa. Vascular tone is regulated by the sympathetic nervous system, as well as by other vasoactive substances such as endothelial cell-derived compounds including nitric oxide, endothelin-1 and prostaglandin. It has been reported that nitric oxide production during exercise is attenuated in heart failure patients compared to normal subjects and that it recovers with exercise training[27]. The increase in cardiac output may also contribute to enhance lung diffusion capacity[1].

Conclusion

The ventilatory efficiency as assessed by VE/VCO_2 at anaerobic threshold and VE/VCO_2 slope were reproducible parameters in patients with ischemic heart disease. The vigorous and moderate exercise training is more effective than mild training. Mild exercise training could not elicit ventilatory efficiency in patients with CABG.

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الملخص العربي

تأثير شدة التمرين على معدلات تهوية الرئتين في مرضى ترقيع الشرايين

هدف هذه الدراسة هو بحث تأثير شدة التمرين على معدلات تهويئة الرئتين ومدلولات مدى تحمل التمرين (أقصى معدل لإستهلاك الأكسجين ، العتبة اللاهوائية ونبض الأوكسجين) في مرضى ترقيع الشرايين . ولقد أجريت هذه الدراسة على ثلاثين مريض من الذكور بعد حوالي شهرين فأكثر من أجراء العملية وتراوحت أعمارهم ما بين الخمسين والستين عاماً ولقد تم تقسيمهم إلى ثلاثة مجموعات متماثلة على حسب شدة التمرين (تمرين بسيط الشدة، تمرين متوسط الشدة وتمرين عالي الشدة) . وأظهرت نتائج هذه الدراسة عدم وجود زيادة ذات دلالة إحصائية في معدلات تهويئة الرئتين في المجموعة التي تلقت التمرين ذات شدة بسيطة ولكن أظهرت هذه المجموعة زيادة ذات دلالة إحصائية في مدلولات التمرين . كما أظهرت كلاً من المجموعتين التي تلقت التمرين ذات الشدة المتوسطة وذات الشدة المعالية زيادة ذات دلالة إحصائية في كلاً من مدلولات التمرين ومعدلات تهويئة الرئتين (زواية ميل العلاقة الخطية الممثلة بين معدلات التهوية وثاني أكسيد الكربون الناتج) . ولهذا يوصي باستخدام التمرينات ذات الشدة المتوسطة والعالية من أجل تحسين كفاءة الرئتين بعد عمليات ترقيع الشرايين .
الكلمات الدالة : التمرينات ذات الشدة المختلفة – معدلات تهويئة الرئتين – مرضى ترقيع الشرايين.