Exercise Training in Children After Correction of Ventricular Septal Defect : The effect on rate-pressure product and work capacity

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ABSTRACT

This study was designed to assess the effect of aerobic training on rate-pressure product (RPP) and exercise tolerance in children operated up to repair ventricular septal defect (VSD). Thirty patients with average age of 11 ± 0.2 years was enrolled in this study. The results of continuous progressive bicycle exercise test (James protocol) collected from 15 children who participated in exercise training was compared with age matched control group. The average RPP x 10^{-2} was 122.12 ± 12 bpm x mmHg in training group and 101.99 ± 16.9 bpm x mmHg in control group, with a significant difference ($P<0.005$). The mean value of total work (TW) were 1528.12 ± 480.49 kg.m. and 900.33 ± 347.83 kg.m. in training and control groups respectively with a significant difference ($P < 0.005$). The findings of the present study suggest that aerobic training enhanced cardiac performance and improved the work capacity in children who underwent closure of VSD.

INTRODUCTION

Ventricular septal defect (VSD) is the most common form of congenital heart disorder and involves the muscular or membranous portion of the septum. The defect may occur indepen-dently or be associated with other lesions. There are four common sites for VSD which are due to malformation of the ventricular septum or to failure of fusion between the ventricular septum, the proximal bulbar septum and the atrio-ventricular endocardial cushions[9]. The haemodynamic consequences of a ventricular septal defect are largely determined by its size. Early correction lessens damage to the pulmonary vascular bed. Exercise tolerance after VSD repair is very variable and depends on the extent of any residual deficit, arrhythmias and pulmonary vascular resistance. Reports on postoperative function suggest that, while many patients will have a good outcome, in general, their exercise tolerance is less than that of age matched controls. Unless residual shunt or arrhythmias are present, participation in sport and exercise is encouraged. An exercise test may be useful to identify activity induced arrhythmias[16].

It was mentioned that myocardial oxygen consumption (MVO_2) can not be measured directly by non-invasive techniques. However, it can be estimated from its relationship to a combination of its major determinants; heart rate (HR), intramyocardial tension, and myocardial contractility. In the clinical setting, MVO_2 may be estimated from the relationship of the product of the HR and systolic blood pressure (SBP) termed rate-pressure product (RPP). The relationship between MVO_2 and RPP with a correlation coefficient of 0.90 was shown to be consistent with and independent of variations in type, intensity and duration of exercises. Also, it was been demonstrated in a group of individuals with cardiovascular disease[1,20].

A previous study[10] was designed to assess changes in physical work capacity in children who were operated upon to repair heart defect, as a result of aerobic training intervention. The measurred maximum oxygen consumption (VO_{2max}), rate-pressure product (RPP) and total work (TW) was increased significantly after training. It was also found that the improvement in RPP was significantly correlated to improvement in TW. Thus it was concluded that the increase in physical work capacity was attributed mainly to enhancement of cardiac performance. However, this study did not substantiate whether improvement occurred as a result of physical training or as a spontaneous recovery after correction of the heart defect.

The present study was designed to assess the effect of physcial training in children with corrected VSD on their work capacity and rate pressure product.

METHODS

Subjects

Thirty patients with age ranged from 9 to 12 years (with a mean value of 11 ± 0.2) participated in this study. They were selected from Outpatient Clinic of Cardiac Surgery at National Heart Institute in Cairo. All of them had been operated for correction of VSD. There were only two selection criteria; (1) the patient had no residual shunt and (2) they were haemodynamic stable, nearly, after six months of operation. They were divided into two equal groups, a training group whom had been participated in training program, and the other group did not involve in any physical activity (control group). Their characteristics are presented in table (1)

Table (1) Characteristics of all patients

Variable		Training group	Control group	P value
Average Age in yr.		10 ± 0.9	11 ± 0.1	>.05
BSA	1.2 m^2	4 (M) and 2 (F)	5 (M) and 2 (F)	>.05
	1.9 m^2	6 (M) and 3 (F)	5 (M) and 3 (F)	
Resting HR (bpm)		90.97 ± 11.82	88.83 ± 11.24	>.05

Yr = Year, BSA = body surface area, m = meter, M = male, F= female, HR = heart rate in beat per minute.

Exercise Test Procedure

Each patient was entitied to a general explanation of the laboratory equipment and test procedure. Each patient had been instructed to avoid food intake for at least 2 hours before the study and to wear comfortable clothing and shoes (perferably gym shoes). All subjects willingly performed the exercise without the presence of parents, friends or relatives in the laboratory. Cardiopan ER 330 was used for recording a conventional 12- lead ECG before exercise, in the supine and standing positions with and without hyperventilation. The blood pressure was measured in the right arm in all subjects with programmed air compression cuff system (Diascope 2 VISMO). The cuff was tightly wrapped around the right arm and completely enclosed with an elastic bandage. For each measurement of blood pressure, the subject was instructed to relax the right arm at his or her side while pedaling ergometer (Corival 300).

Each subject underwent a continuous progressive bicycle exercise test, described by James et al., (1976)[11]. The subject pedalled at a constant speed (60-70 rpm) on the ergometer while the work load increased automatically every three minutes. ECG leads were scanned for alterations of the ST segment every minute. Heart rate and blood pressure were recorded every one to two minutes. The exercise continued to the level of exhaustion, which identify the peak level of voluntary effort. The exercise also was discontinued if one or more of the following signs or symptoms appeared.

(1) The onset of serious dysrhythmias e.g., ventricular tachycardia, supraventricular tachycardia.

(2) Appearance of potential hazards to the patient, such as.

a) Symptoms as pain, headache, dizziness, syncope, excessvie dyspnea and fatigue precipitated by exercies.

b) ST segment depression or elevation greater than 3mm relative to the base line during exercise.

c) Excessive rise in blood pressure with systolic pressures exceeding 150 mmHg and distolic pressures exceeding 90 mmHg.

For safety, the patients were instentaneously monitored for blood pressure, heart rate and electrocardiographic changes, with the patient in supine position, immediately and every 5 minutes for 20 minutes after cessation of the exercise.

Training procedure

For each subject in training group, the appropriate training heart rate depends on the resting heart rate (HR_{rest}) and maximum heart rate (HR_{max}) which were obtained from the exercise test. Karvonen's formula (1957)[12] were used to determine the intensity of exercise (TI).

$$TI = HR_{rest} + (HR_{max} - HR_{rest}) \times 60\ \%.$$

The training program was conducted every other day for 3 months. The exercise session consisted of two bouts of pedaling bicycle ergometer (CARE) and one bout of arm crank exercise (Monark). Enough rest time was allowed between exercise bouts. The exercise consisted of 3 to 5 minutes warm up, a training period gradually increased up to 30 minutes during which the heart rate was maintained continuously in intensity zone, and a 5 to 10 minutes cool-down period. At the end of the third month, the exercise test procedure was repeated for the training group, and were done for control group.

Data collection and Manipulation

Maximum systolic blood pressure (SBP) in mmHg. and maximum heart rate (HR_{max}) in beats/min were recorded during the exercise test performance. The myocardial oxygen consumption (MVO_2) were predicted from the rate pressure product (RPP).

The total work (TW) performed to an exhaustive level during continuous exercise test was calculated as the sum of the products of work load (kg.m/min) and exercise time in minutes at each level reached in exercise program I, II or III . It is expressed in (kg.m).

The RPP and TW of the training group (who had participated in training program) were compared with RPP and TW of the age matched control group by paired t-test. The acceptance level of significant was 0.05.

RESULTS

In the present study, the effect of aerobic training on myocardial oxygen consumption and work capacity in children with intracardiac repair of ventricular septal defect were investigated. The data collected from childern after 3 months of training were compaired with the matching control group who did not participate in any atheletic activity.

As shown in table (2) and figure (1) the mean of maximum heart rate in beats/min was 162.19 ± 10.3 in the training group and in control group it was 144.13 ± 9.96 beats/min. This shows a significant difference between both groups ($p < 0.005$). The difference in maximum systolic blood pressure between the training and control groups was significant ($p < 0.005$) where it was 153.95 ± 9.49 mmHg and 140.99 ± 13.33 mmHg in training and control groups respectively. Since so, the calculated predictor of myocardial oxygen consumption showed a significant difference ($p < 0.005$). The average of rate pressure product (RPP x 10^{-2}) was 122.12 ± 12 beats/min. x mmHg. in training group and 101.99 ± 16.9 beats/min. x mmHg. in control group Fig. (1).

As revealed from table (2) and figure (2) the mean values of total work were 1528.12 ± 480.49 Kg.m. and 900.33 ± 347.83 Kg.m. in the training and control groups respectively with a significant difference ($P < 0.005$) between both groups.

Table (2) Mean and standard deviation of studied parameters in both group:

Variable	Training Group	Control Group	P value
HR_{max}(bpm)	162.19 ± 20.3	144.13 ± 19.96	< 0.005
SBP_{max} (mmHg)	153.95 ± 19.49	140.99 ± 13.33	< 0.005
RPP x 10^{-2} (bpm x mmHg)	122.12 ± 2	101.99 ± 1.69	< 0.005
T.W. kgm.m.	1528.12 ± 480.49	900.33 ± 347.83	< 0.005

HR_{max} = maximum heart rate,bpm = beat per minute,
SBP_{max} = maximum systolic blood pressure, mmHg = millimeter mercury,
RPP = rate pressure product, TW= total work, kg.mm= kilogram meter.

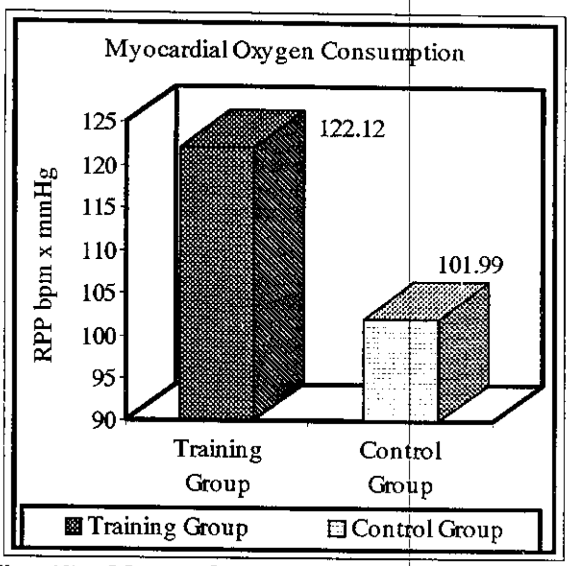

Fig. (1): Mean of myocardial oxygen consumption in both groups.

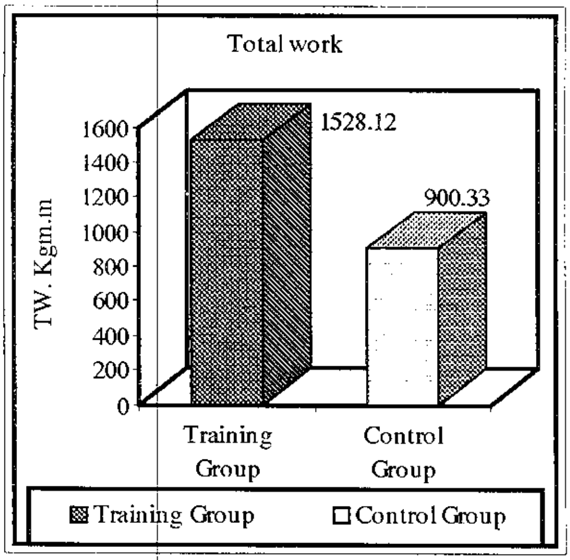

Fig. (2): Mean of work capacity in both groups.

DISCUSSION

Comparison of rate-pressure product and total work capacity of children with intracardiac repair of VSD, who had involved or not involved in the exercise training program, revealed that children in the training group had a significantly greater RPP and TW than those of the control group. This indicated that the physical training resulted in improvement of cardiac performance and work capacity.

Because of the essentially aerobic metabolism of the myocardium, changes in myocardial oxygen consumption correlate highly with work of the heart. Measuring the myocardial oxygen consumption allow the evaluation of physical training intervention on the ability of the heart to perform work. The RPP was widely used to evaluate the myocardial oxygen cost in response to different therapeutic agents, in a variety of patients[5,14]. The results of the present study showed that children participated in an exercise training program had an increase in myocardial oxygen cost concomitant with increase in HR_{max}, and SBP_{max}, than children in the control group. Thus the heart is capable of developing a greater intraventricular pressure while preforming at a greater rate. It may be postulated that the physical training program resulted in enhanced contractility and mecha-nical effeciency of myocardial muscle.

These postulations are in agreement with the findings of many investigators[5,6,7,8]. It was reported that the left ventricular contractile function and regional wall motion abnorm-alities improved in coronary artery diseased (CAD) patients in response to training, despite of attainment of a higher heart rate during maximal exercise. It is unlikely that left ventricular wall tension was lower after training because systolic blood pressure and end-diastolic volume were higher and end-systolic volume was unchanged at peak exercise. Furthermore, the authors reported that patients who have adopted to the training program, attained a higher concentration of plasma nore-pinephrine during maximal exercise, which per se raises myocardial O_2 demand. Thus, the improvement in left ventricular contractile function in patient with CAD as a response to training program was not likely due to a lower myocardial oxygen requirement but rather to an improvement in myocardial oxygenation[7]. Latter on, the same authors, found a significant decrease in RPP during submaximal exercise at constant VO_{2max} after progressive endurance training in sedentary older men. During maximal exercise, the subjects attained a higher systolic blood pressure after training than before training[8]. Coats et, al,[5] stated that the increased stroke volume after training in chronic heart failure patient is consistent with the training response in normal subjects. The mechanism of which is not established. It may represent enhanced diastolic recoil and/or a true increase in left ventricular mass and contractile performance. The enhanced stroke volume response was due to an increased end-diastolic volume, a decreased end-systolic volume or both. The magnitude of systolic shortening, the net result of altered preload and after-load cannot be understood without assessing both parametars. Recently, it was found that patients with dilated cardio-myopathy can improve their functional capacity with training. Whereas, patients who do not exercise have a tendency to further reduction in their exercise capacity. The improvement in aerobic work capacity (VO_{2max}) is significantly correlated with improvement in left ventricular diastolic function[3].

The results of the present study revealed that the children in training group had greater work capacity than the control group. This may be achieved through improvements in both maximal cardiac performance, as elucidated above, and peripheral adaptations. These peripheral adaptations include an increase in systemic arteriovenous oxygen difference at peak exercise, which may be attributable in part to a redistribution of cardiac output to working skeletal muscles and through altered skeletal muscle metabolism[15,19] .

Comparison of cardiopulmonary function in patients who had underwent atriopulmonary (AP) or total cavopulmonary connection (TCPC) Fontan procedures indicated that the two groups of patients had similar maximum exercise performance but different physiological adaptations to exercise. Many of Fontan patients were in normal range of maximum work capacity. The AP patients developed a markedly abnormal arteriovenous oxygen difference that was significantly greater than that of TCPC patients or control subjects at all workloads. This mechanism is important to their ability to sustain exercise despite a cardiac output significantly lower than TCPC patients. The physiological response to exercise in TCPC group was quite different. These patients had a higher effective pulmonary blood flow with a lower arteriovenous oxygen difference and a respiratory pattern significantly different from that of AP patients. Exercise performance in some patients who have underwent the TCPC procedure may be limited by an inability to enhance cardiac output by increased respiratory movement. However, they may still be able to increase oxygen extraction and increase their arteriovenous oxygen difference by an exercise training program[18]. It was suggested that training program in our study may enhance a compensatory mechanisms which operate to improve exercise tolerance in patients with closure of VSD.

The investigrtors supposed that the training program used in this study has a training stimulus to elicite enhancement in cardiac performance in childern operated on to correct congenital anomaly of the heart (VSD). The results of the present study go hand in hand with those described by Longmuir et al.[13], who recommended that a simple exercise training program, conducted early in the postoperative period would appear essential to the achievement of appropriate levels of physical activity for children with congenital heart defects, and these benefits were maintained up to five years postoperatively without further intervention. Children who did not receive a postoperative training program remained significantly below their healthy peers. Moreover, the rseults of the present study corresponed to those observed by Balfour, et al.[2], in that children who participated in cardiac rehabilitation program exhibited a significant change in their hemodynamics and exercise tolerance after completing the program. It was found that, no complications occurred during exercise training or testing. It can be concluded that supervised exercise training at moderate intensity is safe and produces significant and beneficial changes in hemodynamics and exercise tolerance in children after cardiac surgery.

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الملخص العربي

تأثير التمرينات البدنية على استهلاك القلب للأكسجين والقدرة البدنية للأطفال بعد إصلاح ثقب ما بين البطينين

يهدف البحث الى تقييم تأثير التمرينات البدنية على كمية الأكسجين المستهلك بعضلة القلب وكذلك القدرة البدنية عند الأطفال بعد الاصلاح الجراحى لثقب ما بين البطينين.

وشملت الدراسة ثلاثين طفلا أجريت لهم جراحة لاصلاح ثقب ما بين البطينين وتم تقسيمهم الى مجموعتين ، وقد اشتركت المجموعة الأولى فى برنامج تمرينات هوائية مقننة بينما لم يشترك مرضى المجموعة الثانية فى أى برنامج علاج طبيعى.

وقد استخدم برنامج -جيمس- لقياس أقصى معدل لنبض القلب والضغط الإنقباضى للقلب ولتحديد القدرة البدنية عند كل من المجموعتين وأظهرت الدراسة الإحصائية وجود فروق ذات قيمة إحصائية بين المجموعتين ، حيث كان استهلاك عضلة القلب للأكسجين (حاصل ضرب نبض القلب فى الضغط الإنقباضى) وكذلك القدرة البدنية لمرضى المجموعة الأولى أعلى من مثيله فى المجموعة الأخرى.

ويستدل من ذلك على أن التمرينات الهوائية تحسن أداء القلب وتزيد من القدرة البدنية للأطفال بعد إصلاح ثقب ما بين البطينين.