ORIGINAL ARTICLE

Behavior of Oxygen Consumption During a Cardiac Rehabilitation Session

Comportamiento del consumo de oxígeno durante una sesión de rehabilitación cardíaca

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ABSTRACT

Background: The aim of this study was to analyze the response of oxygen consumption in patients with dilated cardiomyopathy during a cardiac rehabilitation session.
Methods: This was an observational, cross-sectional, relational analytical study. Ten male patients with dilated cardiomyopathy and moderate to severe ventricular dysfunction were included in the study. Patients were evaluated in the laboratory and during a rehabilitation session using a Medgraphics VO 2000 portable gas analyzer. The rehabilitation session consisted in 10 minutes of stationary bike exercises, step, coordinaton stairs, and muscle strength using dumbbells for biceps and shoulder, a quadriceps stretcher and a dorsal muscle machine.
Results: Mean age was 57.4±14.6 years, weight 91.4±22.2 kg and height 168.1±6.2 cm. In the laboratory, VO_2max was 21.8±7.3 ml/kg/min, respiratory exchange rate (RER) (VCO_2/VO_2) 1.05±0.09, ventilated volume 65.7±18.5 L/min and heart rate in VO_2max 127.8±23.8 beats/min. Rehabilitation session duration was 37.5±10 min with peakVO_2 14.6±3 ml/kg/min (69.9±16.7 % VO_2max). The correlation coefficient between VO_2max and time with VO_2 <50% VO_2max (min) was 0.662 min (p=0.037) and between peakVO_2 in rehabilitation and time in RER between 0.85-1 (min) was 0.787 (p=0.007).
Patients with better fitness exercised in the low-intensity zone. As exercise increased, the minutes in moderate intensity also increased.
Conclusion: The study showed that patients reached peakVO_2 in sessions below the maximum values obtained in the laboratory. Even though any dose of training in these patients was more beneficial than physical inactivity, cardiac rehabilitation session design and planning, taking into account intrasession exercise intensities, could generate greater impact on mortality, rehospitalizations and quality of life.

Key words: Oxygen consumption - Cardiac rehabilitation - Dilated cardiomyopathy

RESUMEN

Objetivo: estudiar el comportamiento del consumo de oxígeno en pacientes con miocardiopatía dilatada durante una sesión de rehabilitación cardíaca (RHC).
Material y métodos: diseño observacional, transversal, analítico relacional. Muestra: 10 pacientes masculinos con miocardiopatía dilatada, con deterioro de moderado a grave de la función ventricular. Se evaluó a los pacientes en laboratorio y en una sesión de rehabilitación mediante un analizador de gases portátil Medgraphics® VO 2000. La sesión de rehabilitación consistió en ejercicios en bicicleta fija de 10 minutos, step, escalera coordinativa, fuerza con mancuerna para bíceps y hombros, cuádriceps en camilla y dorsales en máquina.
Resultados: Edad (años) 57,4 ± 14,6. Peso (kg) 91,4 ± 22,2. Talla (cm) 168,1 ± 6,2. Laboratorio: VO2max relativo (ml/kg/min) 21,8 ± 7,3. Tasa de intercambio respiratorio, RER (VCO_2/VO_2)1,05 ± 0,09. Volumen ventilado (L/min) 65,7 ± 18,5. Frecuencia cardíaca (lat./min) en VO_2max 127,8 ± 23,8. Sesión: Duración (min) 37,5 ± 10. VO_2pico (ml/kg/min) 14,6 ± 3 (69,9 ± 16,7 % del VO_2max). Coeficiente de correlación entre VO_2max y tiempo con VO_2 < 50% del VO_2max (min) 0,662 (p = 0,037) y entre VO_2pico en rehabilitación y tiempo en RER entre 0,85-1(min) 0,787 (p = 0,007).
Los pacientes con mejor aptitud ejercitaron en zona de baja intensidad. Al aumentar el esfuerzo, aumentaron los minutos en intensidad moderada.
Conclusión: Se constató en este estudio que los pacientes alcanzaron un VO_2pico en las sesiones inferiores a sus máximos obtenidos en laboratorio. Si bien cualquier dosis de entrenamiento en estos pacientes es más beneficiosa que la inactividad física, el diseño y la planificación de las sesiones de RHC, valorando las intensidades de trabajo intrasesión, podrían generar mayor impacto en la mortalidad, las reinternaciones y en la calidad de vida.

Palabras clave: Consumo de oxígeno – Rehabilitación cardíaca – Miocardiopatía dilatada

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INTRODUCTION

Cardiac rehabilitation (CRH) programs based on planned exercises supplement cardiological treatment, improve functional capacity and physical fitness. Cardiac rehabilitation not only improves survival, reducing mortality approximately by 20%, (1) but also the patient's and his family's quality of life.

Almost a century ago, the first indications for the recovery of cardiovascular patients consisted in bed rest and complete proscription of any physical exercise; nowadays, they are based on physical activity.

At the beginning of the 21st century, Anderson et al. carried out an extensive review of articles concerning improved morbidity, mortality and quality of life in patients with cardiovascular disease after infarction or bypass surgery, who underwent CRH including physical exercise. This meta-analysis involved 63 studies with 141 486 patients revascularized after myocardial infarction with a mean follow-up of 12 months and a control group.

The study reported a reduction of cardiovascular mortality in the groups that exercised with relative risk (RR) of 0.74, 95% CI 0.64-0.86, though without a decrease in all-cause mortality.

They also observed a significant reduction in hospitalization, as well as an improvement in quality of life. (2)

Systematic exercise evidenced an increase in the physical fitness of these patients, which was confirmed with O_2 consumption (VO_2) assessment. (3, 4) The ergometric test quantifies tolerance to exercise, helps in exercise prescription and allows the evaluation of therapeutic effectiveness. (5) Exercise increases VO_2max, improves peripheral blood flow and endothelial function, increases vagal tone, and decreases the sympathetic tone and proinflammatory cytokines. (6)

Measurement of VO_2max, or else, peakVO_2, allows establishing individual goals. Exercise can be indicated as a percentage of peakVO_2, reserve VO_2, or taking into account the anaerobic threshold. (7) In the case of anaerobic threshold (ventilatory), associated with increased blood lactate, its estimation can be performed through indirect measurements as the ventilatory equivalent or the respiratory exchange rate (RER). (8)

There are different proposals of CRH exercises. For example, considerations between fractionated and continuous exercises show that the former has the advantage of improving peakVO_2 and left ventricular ejection fraction. However, both methods are effective to assess the influence on cardiovascular risk factors (lipid profile, blood glucose level and body weight), and recovery of heart rate and endothelial function. (9)

But regardless the exercise systematic used, it is important to have control and follow-up variables of the interventions, which means, knowing the physiological behavior of patients with respect to physical fitness variables, as for example, through VO_2 assessment during CRH sessions. This can provide objective data to make a more specific exercise prescription and, also monitor the efficacy of the program. The objective of this work was thus to study the response of VO_2 in patients with dilated cardiomyopathy (DCM) during a CRH session.

METHODS

This was an observational, cross-sectional, relational analytical study. Ten patients with DCM, presenting moderate to severe left ventricular systolic function impairment, with ejection fraction <40% and compensated heart failure at the onset of the program, were included in the study.

Patients were receiving angiotensin-converting enzyme inhibitors, betablockers, acetyl-salicylic acid, eplerenone or spironolactone. They were evaluated in a laboratory of the city of Moron in the province Buenos Aires, Argentina, during 2018, using an ergometric test; then, the patient was evaluated in an exercise session of the CRH program.

A Medgraphics VO 2000 portable gas analyzer, measuring 10.5 × 5 × 14 cm and weighing 740 g, and analyzing O_2 and CO_2 production with +0.1% and +0.2% precision, respectively, was used. The data were averaged at 10 s intervals.

The test was incremental in the treadmill using the modified Brice protocol. The CRH session consisted in stationary bike warm-up with increasing load, initiating at 100 or 150 kgm, according to the tolerance to exercise, during the first 10 to 15 min, followed by a series of three activities: step, minitramp and coordination stairs. Finally, muscle strength was worked out with dumbbell exercises for biceps and shoulders, a quadriceps stretcher and a dorsal muscle machine.

Weight and height were measured and the body mass index was calculated. VO_2max (ml/min) was measured in the laboratory and peakVO_2, VCO_2 (ml/min), ventilation volume (L/min), heart rate (bpm), and time in rehabilitation (minutes) were assessed during the CRH session. Respiratory exchange rate (RER), relative VO_2, percent VO_2max, time in the CRH session with intensities <50%, between 50%-65% and >65% VO_2 (in minutes) and time in the CRH session with RER <0.85, between 0.85-1 and >1 (in minutes) were calculated.

The data were recorded in an Excel for Windows spreadsheet. The Shapiro-Wilk normality test for small samples (n <50) showed that most variables had a normal distribution ($p \geq 0.05$), except for age ($p=0.008$), time to rehabilitation ($p=0.002$), VO_2 >65% ($p=0.007$) and RER <0.85 ($p=0.023$).

The coefficient of variation was used to test parameter stability. In all cases, the level of significance was established for $p<0.05$. IBM SPSS Statistics 20.0 (IBM Coro., Armor, New York) was used statistical analyses.

Ethical considerations

The study was performed in compliance with Resolution 1480/11 of the National Ministry of Health of Argentina: "Good Practice Guideline for Clinical Investigations on Human Beings". Participation was voluntary and an informed consent was requested. Medical staff was present during laboratory evaluations and exercise sessions in the CRH gym.

RESULTS

Table 1 describes sample variables with their mean and standard deviation.

Table 2 shows the comparison between variable values obtained in the laboratory and in the CRH session.

Table 3 compares VO_2 values obtained in the laboratory and in the CRH session.

DISCUSSION

VO_2max is the maximum capacity of the organism to use inspired air oxygen. It is expressed in absolute (ml/min) or relative values with respect to weight (ml/kg/min) and is represented by the VO_2 plateau that appears in an incremental test despite load is still increasing.

However, this does not always happen and, therefore, peak exercise VO_2 (peakVO_2) is considered in functional assessments, as the expression of maximum functional capacity. Moreover, as a test, it satisfies the most essential criteria to be considered as an indirect clinical endpoint. (10) Patients with chronic heart failure present values of oxygen consumption generally below 25 ml/kg/min and those with moderate or severe left ventricular dysfunction may present even lower values, as for example peakVO_2 between 10 and 20 ml/kg/min. (11)

In this study, mean oxygen consumption was 21.8±7.3 ml/kg/min, and all patients had dilated cardiomyopathy with left ventricular ejection fraction <40%.

VO_2max in this group of patients positively correlated with time of CRH with VO_2<50% VO_2max, indicating that as VO_2max increased, the minutes patients exercised at a level <50% VO_2max also increased. This means that these patients, with better fitness, exercised in a zone of low intensity, wasting the opportunity of exercising in one at higher intensity.

Respiratory exchange rate, that is the relationship between oxygen consumption and CO_2 production (VCO_2/CO_2) is an objective measure of maximum exercise performed. A RER >1.10 indicates a good tolerance to physical exercise in a CRH program; a RER <1.00, in the absence of electrocardiographic or hemodynamic abnormalities reflects submaximal cardiovascular exercise for patients with pulmonary diseases. (12)

The present work shows how peakVO_2 in CRH positively correlated with CRH session time with RER between 0.85 and 1, a range in which use of carbohydrates as substrate is growing and ranges from 50 % to 100%, and the prominence of free fatty acids starts to be lost as the main fuel. This implies that as the exercise capacity increases, the minutes in submaximal

Table 1. Patient characteristics

Variables	Mean ± SD
Age (years)	57.4 ± 14.6
Weight (kg)	91.4 ± 22.2
Height (cm)	168.1 ± 6.2
BMI (body mass index, kg/m^2)	32.3 ± 7
LAB relative VO_2 (ml/kg/min)	21.8 ± 7.3
LAB absolute VO_2max (ml/min)	1986.5±740.6
LAB VCO_2	2094.2 ± 849.4
LAB RER	1.05 ± 0.09
LAB ventilation volume (L/min)	65.7 ± 18.5
LAB heart rate (bpm)	127.8 ± 23.8
CRH time (minutes)	37.5 ± 10
CRH relative VO_2 (ml/kg/min)	14.6 ± 3
CRH VO_2 as % VO_2max	69.9 ± 16.7
CRH absolute VO_2 (ml/min)	1230.8 ± 235.9
CRH VCO_2 (ml/min)	1137.3 ± 232.3
CRH RER	0.93 ± 0.12
CRH ventilation volume (L/min)	38.6 ± 8
CRH time with VO_2 <50% (min)	25.6 ± 13.1
CRH time with VO_2 50%-65% (min)	7.8 ± 5.8
CRH time with VO_2 >65% (min)	3.8 ± 5
CRH time with RER <0.85 (min)	7.8 ± 6.8
CRH time with RER 0.85-1 (min)	14.7 ± 6.1
CRH time with RER >1(min)	14.5 ± 12.6

CRH: cardiac rehabilitation. **RER**: rate of respiratory exchange. **LAB**: laboratory

Table 2. Comparison between mean variable values obtained in the laboratory and the cardiovascular rehabilitation session

Variables	Units	Mean	p
LAB rel. VO_2max	ml/kg/min	21.80	0.003
CRH rel. peakVO_2		14.60	
LAB abs. VO2max	ml/min	1986.50	0.007
CRH abs. peakVO_2		1230.80	
LAB VCO_2	ml/min	2094.20	0.004
CRH VCO_2		1137.30	
LAB RER		1.0480	0.028
CRH RER		0.9270	
LAB ventilation volume	L/min	65.70	0.001
CRH ventilation volume		38.60	

LAB: Laboratory. **CRH**: Cardiac rehabilitation. **RER**: Rate of respiratory exchange; **abs**: absolute; **rel**: relative. All pairs of variables compared had significant differences between means (p<0.05), and lower p values for VO_2, VCO_2, RER and ventilation volume attained during rehabilitation.

Table 3. VO_2 in the laboratory and in cardiovascular rehabilitation

Patient	LAB VO_2 (ml/min)	CRH VO_2 (ml/min)	% LAB
1	1044	1044	100
2	1887	1504	80
3	1083	805	74
4	2456	1455	59
5	1670	1086	65
6	1767	1577	89
7	1550	1174	76
8	2293	1246	54
9	2687	1326	49
10	3428	1804	53

LAB: laboratory. **CRH**: cardiac rehabilitation.
Pearson's correlation coefficient between VO2 max and time with VO_2 <50% VO_2max (min) was 0.662 (p=0.037), and between peakVO_2 in rehabilitation and time with RER between 0.85-1 (min) 0.787 (p=0.007).

Fig. 1. Patients in cardiac rehabilitation session carrying a portable gas analyzer

intensity also increase.

It is important for the objective of the session to be clear, because only the intensity of exercise is associated with VO_2max improvement after CRH, (13) and only absolute VO_2max improvements are associated with decreased mortality. (14) This suggests the need for the patient to exercise at a previously planned, adequate intensity, with a personalized exercise prescription. (15) On the one hand, a RER >1 translates exercise related with hyperventilation and the buffer effect on lactate derived from muscular activity. (16) It should always be borne in mind that exercise tolerance may be limited by different factors, beyond cardiorespiratory diseases, as for example, loss of muscle mass or sarcopenia. (17)

Knowledge of VO_2 prior to CRH helps to prescribe the exercise, taking into account other comorbidities. The Dutch guideline on cardiac rehabilitation (7), suggests that to train resistance, exercise can be continuous or gradually increased from 50 to 80% peakVO_2, but also maximum or intermittent (submaximal) interval trainings can be considered, some of which are known as High Intensity Interval Training (HIIT). (18,19)

The benefit of training at higher intensities has been reported with this method; (20) for example, 4 series of 4 minutes at 80-90% peakVO_2 or reserve heart rate, with an active recovery of 3 minutes at 30-50% peakVO_2. (7) On the other hand, the Mayo Clinic recommends aerobic exercises during most days of the week at 50 to 75% peakVO_2 and moderate intensity resistance exercises, 2 to 3 times a week. (21) In this case a combination of activities was carried out, with initial continuous bicycle training and then, intermittent exercise series, ending with muscle stimulation, resulting in an average VO_2max that was 69.9±16.7% of that attained in the laboratory

Achttien suggests that patients with peakVO_2 >10.5 ml/kg/min, but <17.5 ml/kg/min (3-5 METs/40-80W) would benefit with 1 or 2 daily sessions of 15-minute training; and patients with peakVO_2 >17.5 ml/kg/min (≥5METS/≥80W) would be able to perform 20 to 30-minute sessions 2-3 times a week, (7) which was the exercise load of patients evaluated in this investigation.

Lastly, although we know that this type of rehabilitation is safe and effective, as shown by various meta-analyses (22) and controlled studies, (23) it should be recalled that some authors, as De Schutter et al., postulate that there is a group of patients who are non-responders to exercise (20% of patients in CRH), with a threefold increase in mortality (responders: 8%, low responders: 17% and non-responders: 22%; $p < 0.001$), characterized by age, female sex, diabetes and waist circumference, (24) who should draw even more attention and a personalized therapeutic indication.

Finally, the conclusion of this study should be interpreted with caution due to the low number of cases. Studies with larger number of patients and follow-up evaluations could confirm the adequate levels of peakVO_2 percentages for this population of patients with heart failure. Session design using these parameters could be more specific to attain the desired results.

CONCLUSIONS

It is known that patients with chronic heart failure and limited peakVO_2 can benefit with an exercise program. This study showed that patients peakVO_2 during sessions was lower than maximum values obtained in the laboratory. Although in these patients any dose of training is more beneficial than physical inactivity, the design and planning of CRH sessions considering intrasession training intensities, will generate greater impact on mortality, reinterventions and quality of life. Consequently, planning of this therapeutic opportunity should be optimized to achieve a correct prescription of intensity, volume and frequency. Same as with any drug, a *little* can be innocuous and a *lot* can be counterproductive. Exercise prescription needs adequate knowledge to be effective.

Conflicts of interest

None declared.

(See authors' conflicts of interest forms on the website/ Supplementary material)

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