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Original Article

Cardiorespiratory responses in maximal cycle ergometry in cardiac rehabilitation

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Abstract:
The aims of the present study were to measure maximal cycle ergometry cardiorespiratory responses of individuals participating in a cardiac rehabilitation program and to investigate the relation between oxygen uptake (VO_2) and heart rate (HR) at ventilatory thresholds (VT1 and VT2). Forty-seven sedentary subjects (age: 65.8 ± 9.9 years; BMI: 28.24 ± 4.01 kg/m^2), who entered in a cardiac rehabilitation program, performed a maximal cycle ergometry test. The test was performed on a cycle ergometer with a continuous incremental protocol, with a cadence of 60 rpm. The load increased every minute until exhaustion. The expired gases were continuously measured by Aerosport VO_{2000} analyzer. The VO_2 mean values were 12.54 ± 3.52 ml.kg^{-1}.min^{-1} at VT1 and 14.16 ± 3.58 ml.kg^{-1}.min^{-1} at VT2 (VO_2 peak = 14.20 ± 3.5 ml.kg^{-1}.min^{-1}). The HR at VT1 was 106.5 ± 21.3 bpm, at VT2 was 113.5 ± 20.7 bpm and at maximal exertion was 115.5 ± 20.0 bpm. It was found that the relation between the three moments of the VO_2 and HR measurements and heart rate were more significant than the relationship between the variables studied ($p < 0.05$). We conclude that there is a relation between VO_2 and HR variables. The characterization of a behavioral profile of the investigated cardiorespiratory variables for sedentary individuals with coronary artery disease can stratify the risk to start the exercise practice for these individuals, and to indicate in what clinical and functional state these individuals were.
Key Words: Heart disease, ventilatory threshold, oxygen consumption, oxygen uptake, heart rate.

Introduction

During the last decades, it has been documented that physical inactivity may precede the development of coronary artery disease (CAD). On the other hand, physically active individuals have a 50% lower risk of acquiring CAD. Physical training has been used alone or as part of cardiac rehabilitation programs to improve physical capacity (Erbs, Linke, & Hambrecht, 2006). In fact, regular physical activity in healthy people is an effective way of primary prevention of coronary disease, since it directly modifies the sedentary lifestyle as an independent risk factor for such pathology and indirectly the lipid, glycemic and body composition variables. In the patient with an established CAD, the secondary prevention is even more vigorous, with the most drastic changes possible of the reversible risk factors for the evolution of the disease (Mendonça, Ito, Bartholomeu, Tinucci, & Forjaz, 2004; Ornish *et al*., 1998). This way, the practice of physical exercises is currently stimulated as a prophylactic and therapeutic part of all risk factors for CAD (Moreira, Souza, Schwingel, Sá & Zoppi, 2008; Ricardo & Araújo, 2006). As a result, more people are looking for cardiac rehabilitation services, requiring information about the entire exercise process and prescription of exercise for this population (Pate, Prat, & Blair, 1995).

Cardiac rehabilitation is a complex intervention that may involve therapies such as nutritional and psychological counseling, guidance on risk factors and drug administration. However, much of the success of the cardiac rehabilitation programs is due to exercise-based therapy, which is considered the central strategy of these programs (Araujo *et al*., 2004). Exercise-focused cardiac rehabilitation was associated with a 20 to 30% reduction in mortality rates compared to usual care without regular exercise (Ricardo & Araújo, 2006).
Myocardial infarction or cardiac death affects one American every 34 seconds. About 80% of these cases are attributed to modifiable behaviors, such as lack of exercise. Regular physical exercise decreases morbidity and mortality in patients with CAD through systemic and specific adaptations in the cardiac system. It increases the

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demand for myocardial oxygen acting as a stimulus to increase coronary blood flow and oxygen supply, thus reducing the risk of myocardial infarction and angina (Bruning & Sturek, 2015).

However, there remains an obstacle in the application of these results in clinical practice. This is due, in large part, to the methodological limitations, conflicting results of the studies on this subject, and the difficulty in obtaining individuals for the tests (Nunes *et al*., 2017). Hence, it is important to observe some aspects in cardiopulmonary fitness tests, such as beginning with low intensity and decreasing the execution time to avoid the effects of cumulative fatigue (Nunes *et al*., 2016).

Therefore, the objectives of the present study were to measure maximal cycle ergometry cardiorespiratory responses of individuals participating in a cardiac rehabilitation program and to investigate the relation between oxygen uptake (VO_2) and heart rate (HR) at different ventilatory thresholds (VT1 and VT2).

Material & methods

Sample

The sample consisted of 47 male subjects (age: 65.8 ± 9.9 years; BMI: 28.24 ± 4.01 kg/m^2), selected from the database of effort tests of a service of Evaluation, Exercise and Cardiac Rehabilitation in the city of Rio de Janeiro, Brazil. The patients were intentionally selected and were submitted to a maximum ergospirometry test. The 47 subjects of the sample were classified according to the New York Heart Association (NYHA). Thus, 27 were class 3, 12 were class 4, four were class 2, and three were class 1 (Bard, Gillespie, Clarke, & Nicklas, 2008).

The sample was limited to sedentary individuals with CAD, who underwent a maximal ergospirometric test to join the rehabilitation service's exercise program. Individuals who were not sedentary when they entered the rehabilitation service or who had other preexisting diseases were excluded from the present study. All subjects were informed of the objectives, benefits, risks, procedures, and evaluations of the study. Those who agreed to participate signed an informed consent form in accordance with the guidelines regarding human research delineated in the Resolution 466/2012 of the National Health Council and the Declaration of Helsinki.

Tools

For the ergometric test, a continuous incremental cycle ergometer protocol (Cateye ergociser model EC 1600, Osaka, Japan) was used. The subjects maintained the rate of 60 rpm. The warm-up consisted of two minutes, the first minute without a load so the subjects could adapt to the cycle ergometer and the second minute with an increase of 0.5 kg.m^{-1} of the load. From this point, the test itself was started with 1.0 kg.m^{-1} of load and increments of 0.2 kg.m^{-1}.min^{-1} until reaching voluntary exhaustion. Therefore, the initial load at the first minute was 60 W (60 rpm x 1.0 kg.m^{-1}) and increments of 12 W.min^{-1} were provided continuously up to the maximum stress (Nunes *et al*., 2009).

Expired gases were measured continuously by an Aerosport VO_{2000} analyzer (Medgraphics, St. Paul, Minnesota, USA), where the gaseous samples were collected and measured every 10s during the test. The analysis was made through oxygen and carbon dioxide detectors. The respiratory exchange rate, the volume of oxygen consumed per minute (VO_2) and volume of carbon dioxide produced per minute (VCO_2) were standardized and calculated directly by the device (Nunes *et al*., 2009).

Ventilatory threshold 1 (VT1) is marked by an accented increase in CO_2 concentration in relation to O_2 consumption, detectable by breaking the linearity of the VCO_2 versus VO_2 curve by the V-Slope method. This occurs around 70% of VO_2 max and 80% of HR max (Akalan, Robergs, & Kravitz, 2008; Rikli & Jones, 2008).

The second ventilatory threshold (VT2) was determined by the V-Slope method by visual inspection of the second breakdown of the VT curve linearity and/or by the continuous increase point of the curve with VT/VCO_2 linearity (Akalan *et al*., 2008; Rikli & Jones, 2008).

Electrocardiogram (ELITE Software, Micromed biotechnology, Brazil) showed the heart rate at the second ventilatory threshold (HRT2) and maximal heart rate (HR max) at the end of the exercise test. At the highest intensity point, the maximum load (Wmax) and VO_2 max were defined. During the test, the perceived exertion was measured (Borg, 1982) and was verified during each intensity change.

Procedures

For all tests, participants responded to an anamnesis and the Physical Activity Readiness Questionnaire (PAR-Q) (Shephard, 1988). Subjects were asked to get a full night's sleep and to not engage in any type of physical activity on the day prior to testing. They were also instructed to abstain from caffeine and alcohol for a minimum of 24 hours prior to testing and to abstain from food, drinks, and nicotine for 2 hours prior to all laboratory tests. Absolute and relative contraindications for carrying out a stress test were observed, such as the criteria for interrupting the test. It included: elevation of diastolic blood pressure (DBP) up to 140 mmHg in hypertensive patients; persistent systolic blood pressure (SBP) higher than 10 mmHg with increased load, marked increase of SBP up to 260 mmHg; clinical manifestation of chest discomfort, exacerbated by increased load or associated with electrocardiographic changes of ischemia, ataxia, dizziness, pallor, cyanosis, and pre-syncope (Araujo *et al*., 2004). The moments that preceded the test included completing and signing the consent form and measuring height and body mass in accordance with the guidelines of the International Society for the Advancement of Kinanthropometry (Marfell-Jones, Olds, Stewart, & Carter, 2006).

Statistical analysis

Measures of central tendency were used as mean and dispersion measures through the standard deviation (SD). The Shapiro-Wilk test was used in order to observe the distribution of the normality curve, ascertaining whether it has a significant degree of homogeneity and symmetry (Morrow, Jackson, Disch, & Mood, 2003). The percentile norm was used as a reference for health-related physical fitness patterns in comparing values of VO_2 and HR curves (Nunes *et al*., 2009). Pearson's correlation was also used to verify the statistical association between the variables studied. From this correlation coefficient, it was possible to identify the magnitude and direction of the correlation between the variables (Thomas & Nelson, 2012). The value of $p = 0.05$ was used for the statistical significance.

Results

Table 1 shows the values of the variables analyzed in the present study. These values may indicate the low effort capacity of the individuals, which could be explained by the pathology that they are affected.

Table 1. Mean and standard deviation of the variables analyzed in the sample (n = 47).

Variables	Mean	SD
VO_2 in VT1 ($ml.kg^{-1}.min^{-1}$)	12.54	3.52
VO_2 in VT2 ($ml.kg^{-1}.min^{-1}$)	14.16	3.58
VO_2 peak ($ml.kg^{-1}.min^{-1}$)	14.20	3.5
HR in VT1 (bpm)	106.5	21.3
HR in VT2 (bpm)	113.5	20.7
HR max (bpm)	115.5	20.0

SD = standard deviation; VO_2 = oxygen uptake; VT = ventilatory threshold; HR = heart rate.

The percentages of VO_2 and HR in the two ventilatory thresholds studied, and their respective P25, P50, and P75 percentiles are shown in figure 1. This behavior of the cardiorespiratory variables studied plotted can permit the identification of the profile of this population.

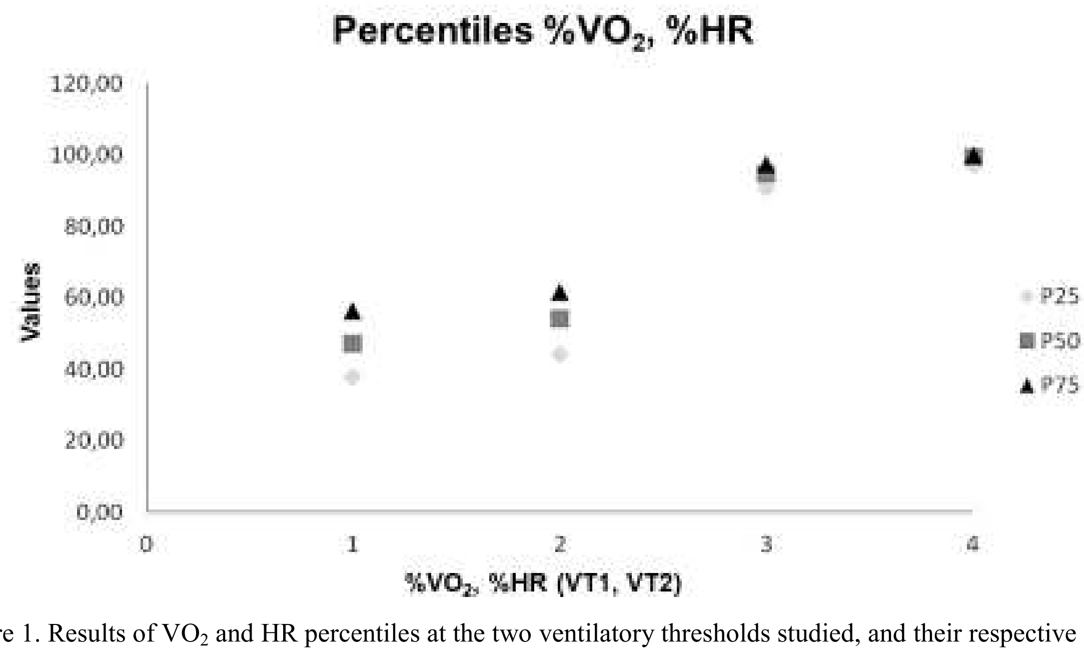

Figure 1. Results of VO_2 and HR percentiles at the two ventilatory thresholds studied, and their respective percentiles P25, P50, P75.
VO_2 = oxygen uptake; HR = heart rate; VT = ventilatory threshold.

Table 2 presents the Pearson correlation between VO_2 and HR variables at different intensities (VT1, VT2 and maximal effort). It was found that the relation between the three moments of VO_2 and HR measurement was more significant than the relation between the variables evaluated ($p = 0.05$).

Table 2. Pearson correlation between VO_2 and HR at different intensities.

	VO_2 peak	VO_2 VT1	VO_2 VT2	HR max	HR VT1
VO_2 VT1	0.905				
VO_2 VT2	0.991	0.915			
HR max	0.566	0.539	0.580		
HR VT1	0.500	0.596	0.533	0.920	
HR VT2	0.557	0.536	0.576	0.992	0.931

VO_2 = oxygen uptake; VT = ventilatory threshold, HR = heart rate.

Discussion

During the research, several articles with different methodologies, populations or pathologies were found in the present study. The objective was to characterize the studied population and to verify the relationship between the variables mentioned here.

A study of the relationship between heart rate recovery after exercise and maximal oxygen uptake in sedentary patients with type 2 diabetes showed that heart rate recovery after exercise can be considered a physical fitness index, a useful tool for the evaluation of the combination of cardiovascular fitness and autonomic function. In conclusion, the regular exercise aimed at increasing VO_2max also has a beneficial effect on autonomic nervous system function, which is reflected in improved heart rate recovery after exercise. Important findings are that the individuals in the present study are cardiopathic and regular physical exercise practitioners and may be prone to obtain the benefits cited in the above study as the improvement of cardiovascular fitness. (Cataldo *et al*. 2014).

Another study verified the improvement of the performance of subjects submitted to a cardiac rehabilitation program. After an initial sub-maximal evaluation, applied training and an evaluation at the end, the individuals obtained an increase in oxygen consumption and at the same time a reduction of heart rate. Corroborating with the present study on the importance of cardiac rehabilitation for the improvement of cardiorespiratory function. (Grove, Jones, & Connolly, 2017).

An article sought to verify the relationship between maximal heart rate and maximum VO_2 of obsessive and nonobese individuals. The results were similar between the groups ($r = 0.83$, obesity, $r = 0.87$ normal weight). However, in the present study, we found a $r = 0.56$ in the same parameter, maximal heart rate and maximal VO_2, which was lower than in the population cited by the above study, perhaps explained by the use of beta blockers by heart disease patients (Miller, Wallace, & Eggert, 1993).

In the same line of reasoning, a study (Byrne & Hills, 2002) verified the relationship between the percentage of maximal HR and percentage of maximum VO_2 for training in obese individuals. It was verified that this relation was significantly higher than in the recommendations of the ACSM after the maximum effort test. Therefore, the indirect guidelines of the ACSM guidelines for special populations, such as obese and heart patients, are important, but they do not replace direct evaluations such as an exercise test, anamnesis, and clinical exams (Byrne & Hills, 2002).

Another study verified the relationship between the studied physiological parameters only this time with elite cyclists, it was concluded that the intensity scale recommended by the ACSM underestimates the intensity of exercise in elite cyclists obtained by direct tests for analysis in this population in both submaximal and maximum intensities, both in heart rate and in oxygen consumption. Increasing the importance of applying an exercise test in the cardiopathy population that was studied at present to obtain safety in the application of physical activities in a more appropriate way as the only form of evaluation for the prescription (Lounana *et al*., 2007).

Weber *et al*. (1982) reported that muscle work requires the integration of cardiopulmonary mechanisms for gas exchange and O_2 delivery. In patients with chronic heart failure, the response of these mechanisms and the pattern of O_2 (VO_2) use and gas exchange during exercise may be impaired as the severity of heart failure is increased, and a progressive decrease in physical capacity. This fact may characterize that cardiac reserve and functional status in patients with chronic heart failure has affected performance. Thus giving greater importance to assessments of cardiorespiratory capacity and its ventilatory thresholds during exercise as performed in the present study.

One study examined changes in submaximal exercise performance and ventilatory response to exercise in patients with chronic heart failure. The expired gas analysis was performed continuously during each test at baseline and at the end of the study. The exercises increased maximal oxygen uptake and reduced blood lactate levels during submaximal exercise. The training-induced decrease in lactate accumulation was accompanied by a decrease in carbon dioxide production, respiratory exchange rate, and ventilation during submaximal exercise (Sullivan, Higginbotham, & Cobb, 1989). The alteration of these parameters discussed in the aforementioned study makes us believe in the importance of a second evaluation to test whether the population of the present study was also reached such results.

Using a few physiological parameters, another study emphasized the role of ventilatory efficiency during exercise (VE/VCO_2 Slope) and maximal oxygen consumption (VO_2 max) as important predictors of mortality in heart failure patients (Bard *et al*., 2008). The study involved 355 individuals, being 255 males between 40 and 60 years of age, with the VO_2 peak of 17.3 ± 5 $ml.kg^{-1}.min^{-1}$. In the current study, only males, 47 in total, with a broader age group, with a minimum of 40 years and a maximum of 85 years, were included. Thus, reaching different age groups, it was also verified that even with the mean age of 65.8 years being greater than the study analyzed here, VO_2 peak had a similar mean of 14.2 ± 3.5. $ml.kg^{-1}.min^{-1}$ (Bard *et al*., 2008).

Another reference predicts that individuals with VO_2 peak inferior to 10 $ml.kg^{-1}.min^{-1}$ indicates an important predictor of cardiac events, and higher than 16 $ml.kg^{-1}.min^{-1}$ indicates greater survival chances in these patients. Guimarães *et al.* (2008) evaluated 391 subjects with heart failure, 229 of whom used beta-blockers and 162 who did not use. The Naughton protocol was used to evaluate VO_2 peak. However, all the individuals of the present study used beta-blockers. Another difference was the use of the ramp protocol, which allows individualizing the evaluation of VO_2 peak, thus, the results are more accurate. In this comparison, 15% of individuals with a high risk of new cardiac events, that is, below 10 $ml.kg^{-1}.min^{-1}$, 28% with better survival prognosis, with VO_2 peak higher than 16 $ml.kg^{-1}.min^{-1}$, and 57% with moderate risk, with values ranging from 10 to 16 $ml.kg^{-1}.min^{-1}$. The mean age of the current study being 65.8 years old, being well above the mean age of 49 years of the studied group.

Bennett, Riegel, Bittner and Nichols (2002) reported the validity and reliability of the functional classification of the NYHA instrument in patients with heart disease. It was stated that the classes of this instrument are a valid measure of the functional state of the individual. However, the reproducibility of the system has not been well established in the literature, and it is suggested that the system should not be used as the sole evaluation method for studies in patients with heart disease. With this in view, it was agreed to use this mode of functional classification, the ergospirometer test and the information on the clinical history of the subjects.

It was taken into account that during exercise, an increase in the respiratory rate amplifies the oscillations of blood pressure (BP). According to Cottin, Le Moing, Filliau, Martin and Papelier (2010), this phenomenon is generally intensified when the exercise rate exceeds the ventilatory thresholds. The authors evaluated the ventilatory thresholds of trained individuals, suggesting the usefulness of this tool in conditioning programs with sedentary individuals or with pathologies, predicting the risk of serious events during the daily practice of exercising (Cottin *et al*., 2010).

The cardiopulmonary stress test with gas exchange measurement to evaluate peak oxygen consumption (VO_2 peak) provides the gold standard result of cardiorespiratory fitness. Scott *et al.* (2015) evaluated and identified high reliability of this test to measure VO_2 peak ($r = 0.92$; $p <0.001$; ICC 0.900), ventilatory threshold ($r = 0.88$; $p < 0.001$; ICC = 0.927), and maximal heart rate ($r = 0.95$; $p < 0.001$; ICC = 0.944). This study included 40 patients with prostate cancer in the early phase (age = 59 ± 7 years). Although the pathology is different from the present in the individuals in this study, this very current report gives us some assurance that the stress test used to verify the aforementioned physiological parameters was the most indicated for the studied population.

Pereira *et al*. (2010) evaluated the anaerobic threshold of 16 individuals with heart failure (age: 45.9 ± 9.7 years). An ergospirometric treadmill test was performed using the ramp protocol using two methods: visual-graph and V-Slope, with results of 15.10 ± 3.20 $ml.kg^{-1}.min^{-1}$ and 16.15 ± 3.63 $ml.kg^{-1}.min^{-1}$ respectively. In the present study, the V-Slope method was used, with a result of 10.08 ± 3.60 $ml.kg^{-1}.min^{-1}$. The present study emphasizes that both methods showed high agreement when contrasted. It suggests that both methods can be used in the assessment of the anaerobic threshold in this population.

Based on the discussion of the results, a post-training re-evaluation is necessary, or changes in the methodological analysis so that different results may be obtained with contributions that can be more significant to the scientific community.

Conclusions

The results obtained by the individuals belonging to the sample were in the majority of the cases smaller compared to other studies, perhaps explained the long physical inactivity, age and the clinical condition of the individuals who participated in our study, can justify these differences.

The literature has shown the importance of the relationship between the physiological parameters VO_2 and HR as predictors of mortality, indicators of performance improvement, fitness levels and functional status of individuals belonging to special groups, such as obese patients with heart failure.

We have also seen studies that compared direct evaluation methods such as the maximum exertion tests with indirect estimates, based on the guidelines of each physiological parameters studied here, concluding that they are underestimated and can lead individuals to perform activities under their physical conditions, highlighting the importance of performing ergospirometry.

The characterization of a behavioral profile of the investigated cardiorespiratory variables for sedentary individuals with CAD can demonstrate that it is possible to stratify the risk to start the exercise practice for these individuals, and to indicate in what clinical and functional state these individuals were.

As a recommendation for future studies, we believe that it is important to compare these findings with data after a training period of the same subjects, to verify if there were any changes in the physiological variables studied here.

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