Comparative Analysis of Direct and Indirect Methods for the Determination of Maximal Oxygen Uptake in Sedentary Young Adults

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Abstract

Background: Maximal oxygen uptake is a powerful prognostic indicator and a reliable measure of physical conditioning. It can be measured directly by cardiopulmonary exercise testing (CPET) or indirectly by formulas derived from conventional protocols.

Objective: We compared the VO2 max obtained by formula using exercise testing with Bruce protocol (BP) with the VO2 max obtained by CPET on the treadmill.

Methods: We selected 41 healthy, non-obese, physically inactive young volunteers, aged between 21 and 50 years, residents of Florianópolis, Brazil.

Results: Twenty-one women (52%) with mean age of 35.62 ± 8.83 years, and 20 males, with mean age of 32.5 ± 7.18 years participated in the study. Statistically significant differences were found for VO2 max between the two methods (BP - 42.31 ± 5.21 ml/kg/min vs. CPET - 30.46 ± 5.50 ml/kg/min, p < 0.0001). The Bruce formula overestimated the result by 34.1% (BP - 45.95 ± 3.94 ml/kg/min vs. CPX - 34.27 ± 4.20 ml/kg/min, p < 0.0001) for men, and by 44.8% (BP - 38.84 ± 3.72 ml/kg/min vs. CPX - 26.83 ± 3.90, p < 0.0001) for women. A moderate correlation was observed between the methods (r = 0.65). When classifying the results according to the table of aerobic capacity of the American Heart Association, the agreement was null (kappa = 0.0034; Pearson chi2 = 0.001).

Conclusion: VO2 estimated by BP is not capable of demonstrating the true aerobic capacity in these individuals, while CPET is an important tool for early detection of diminished functional capacity in sedentary young men and women. (Int J Cardiovasc Sci. 2019;32(4):362-367)

Keywords: Cardiovascular Diseases; Exercise Test; Oxygen Consumption; Adolescent; Physical Fitness; Sedentarism.

Maximal oxygen uptake is a powerful prognostic indicator and a reliable measure of physical conditioning. It can be measured directly by cardiopulmonary exercise testing (CPET) or indirectly by formulas derived from conventional protocols. We compared the VO2 max obtained by formula using exercise testing with Bruce protocol (BP) with the VO2 max obtained by CPET on the treadmill. We selected 41 healthy, non-obese, physically inactive young volunteers, aged between 21 and 50 years, residents of Florianópolis, Brazil. Twenty-one women (52%) with mean age of 35.62 ± 8.83 years, and 20 males, with mean age of 32.5 ± 7.18 years participated in the
study. Statistically significant differences were found for VO₂ max between the two methods (BP - 42.31 ± 5.21 ml/kg.min vs. CPET - 30.46 ± 5.50 ml/kg.min, p < 0.0001). The Bruce formula overestimated the result by 34.1% (BP - 45.95 ± 3.94 ml/kg.min vs. CPX - 34.27 ± 4.20 ml/kg.min, p < 0.0001) for men, and by 44.8% (BP - 38.84 ± 3.72 ml/kg.min vs. CPX - 26.83 ± 3.90, p < 0.0001) for women. A moderate correlation was observed between the methods (r = 0.65). When classifying the results according to the table of aerobic capacity of the American Heart Association, the agreement was null (kappa = 0.0034; Pearson chi² = 0.001). Conclusion: VO₂ estimated by BP is not capable of demonstrating the true aerobic capacity in these individuals, while CPET is an important tool for early detection of diminished functional capacity in sedentary young men and women.

Methods

Fifty healthy, non-obese and physically active individuals were invited to participate in the study. All were residents of Florianópolis city, Brazil. Nine individuals declined to participate, and 41 were then included. Participants were randomly assigned to CPET on a treadmill (Inbramed® 1999, Brazil), with ramp protocol (ErgoPC Elite version 3.3.6.2, 1999, Micromed®, Brazil) and gas analyzer (Metalyzer®, 2004, Germany) or to the BP (ErgoPC13 version 2.4.8.5, 1998, Micromed®, Brazil), with a 48 interval between the tests. The formula used to estimate VO₂ by the BP was the one available in the most popular ergometry software in Brazil: physically inactive men - VO₂ = (TIME (min) x 2.9) + 8.33. Women - VO₂ = (TIME (min) x 2.74) + 8.03. The estimated predicted VO₂ for each individual was estimate by the formulas (mL/Kg.min):3,5

- Men: VO₂ = 60 – 0.55 x age (years);
- Women: VO₂ = 48 – 0.37 x age (years).

All tests were performed by an experienced cardiologist, qualified to perform ergometric test and CPET. Treadmill tests were carried out following the Brazilian Society of Cardiology guidelines on ergometric and cardiopulmonary tests. VO₂ max was considered as the highest VO₂ reached during stress (VO₂ peak). After direct or indirect measurement of VO₂ participants were classified by cardiorespiratory fitness using the American Heart Association table and grouped into four groups – low, moderate, high and very high. All participants signed the informed consent form and the study protocol was approved by the ethics committee of the institution.

Statistical analysis was performed using the Stata SE 9 and the Microsoft Excel software. The Student’s t-test was used to compare means between matched samples. Correlation was analyzed by Pearson correlation. Agreements were analyzed using weighted kappa statistic. A p ≤ 0.05 was set as statistically significant.

Results

Twenty-one (52%) of the 41 individuals included were women. Mean age was 34.1 ± 8.12, varying from 21 to 50 years. Mean body mass index (BMI) was 24.5 Kg/m² ± 3.34, and mean weight and height was 72.8 ± 15.7 kg and 1.73 ± 0.11 m, respectively. Mean VO₂ max was 42.31 ± 5.21 mL/Kg.min for the BP and 30.46 ± 5.50 mL/Kg.min for the CPET with ramp protocol, p < 0.0001. Analysis by sex (Figure 1) revealed significant difference between
VO₂ max estimated by the BP and the CPET (38.85 ± 3.72 mL/kg.min versus 26.83 ± 3.90 mL/kg.min, respectively, p < 0.0001) for women, and for men (45.94 ± 3.94 mL/kg.min versus BP 34.26 ± 4.21 mL/kg.min, respectively, p < 0.0001) The BP overestimated VO₂ max by 44.8% for women and by 34.1% for men compared with the CPET.

No difference was found in maximal effort, measured by maximal heart rate (HRmax) between the tests. During the BP and CPET, HR max was 184.8 ± 9.47 vs 183.1 ± 10.03, respectively, for men, and 179.8 ± 11.68 versus 180.8 ± 12.63, respectively, for women, p = NS).

There was a moderate correlation between the two methods (r = 0.65), and the agreement between the tests regarding cardiorespiratory fitness was null (Figure 2) (Kappa = 0.0034 and chi-square = 0.001). Most participants showed high or very high cardiorespiratory fitness by the BP and moderate or low cardiorespiratory fitness according to the CPET.

**Discussion**

Cardiorespiratory fitness has been shown to be an important prognostic marker of morbidity and mortality in young, older, healthy individuals with heart diseases. Most studies have classified individuals according to their performance in ergometric tests. In Brazil and in the USA, the ergometric test on the treadmill has been widely used, and the BP is the main test performed.

Although individual risk to stress tests may be stratified by test duration, functional capacity may be overestimated in young adults, even in physically inactive ones. In this regard, when age range is used for risk stratification, conventional stress test is not an accurate test to evaluate functional capacity. Sedentary habits have long-term, cumulative effects, and several studies have shown that it is never too late to decrease the risk by improving physical fitness.

In most computer programs for exercise stress testing in Brazil, VO₂ is estimated using the BP formula, and used to classify subjects according to cardiorespiratory fitness. Our study showed an important overestimation of the indirect assessment of VO₂ by the BP.

In 1973, Bruce et al., studied 295 physically active or inactive adults by exercise testing on the treadmill, and direct analysis of gases, from which derived the formulas currently used. Ong et al., measured VO₂ max by CPET and compared it with that obtained by cycle ergometer test (prediction equations). The formulas overestimated the results by 13.74% for men and 10.55% form women. Fairbarn et al., evaluated 231 non-athletes aged from
20 to 80 years by cycle ergometer test and found a difference in VO\textsubscript{2} max measured by the equations of 36.17% and 26.47% for men and women, respectively, with higher values obtained by the equations. Neder et al.\textsuperscript{18} conducted a study with 120 physically inactive volunteers and observed an increment in VO\textsubscript{2} by 14.71% among men and 22.29% among women. Most studies have used the cycle ergometer test for this comparison, and reported VO\textsubscript{2} values 5-11% lower than those obtained from treadmill tests. However, in the American continent, the treadmill exercise test is the most commonly performed, mainly the BP.\textsuperscript{19} In our study sample, results obtained from the treadmill test were even higher, maybe because we have used a treadmill ergometer. Similar to our study, Fairbam et al.\textsuperscript{17} also reported the biggest differences in VO\textsubscript{2} max among men, although they used an ergometer cycle to assess aerobic capacity. In a nation-wide Brazilian study published in 2011, Peserico et al.\textsuperscript{20} assessed aerobic capacity in trained female runners, by measuring VO\textsubscript{2} max both by direct method and indirectly by Foster’s formula (1996) using a treadmill ergometer. The authors found that VO\textsubscript{2} was significantly underestimated when estimated by the prediction formula as compared with direct analysis of gases, indicating substantial limitations of the approach in determining functional capacity in these individuals.\textsuperscript{20} Most of previous studies reported contrasting results, showing an overestimation of the VO\textsubscript{2} max indirectly estimated by regression and conventional ergometer test, regardless of the protocol and type of ergometer used.\textsuperscript{21,22} Also, according to Santos\textsuperscript{21} and Rondon et al.,\textsuperscript{22} the results of VO\textsubscript{2} max obtained by indirect measurement are influenced by cardiorespiratory fitness of the study subjects. In these studies, greater VO\textsubscript{2} max values, estimated by the ACSM formula, were higher in individuals with poor cardiorespiratory fitness than in those with moderate fitness. These findings suggest that both the type of exercise test protocol and the type of prediction formulas may affect VO\textsubscript{2} estimation, by either overestimating or underestimating the true values. Our study was the first to perform treadmill ergometer exercise test in a group composed of both men and women, young and older subjects, physically active and inactive individuals for a comparative analysis of VO\textsubscript{2} max directly measured by CPET with that estimated by formulas.

VO\textsubscript{2} prediction equations derive from studies conducted in North America and Europe. Thus, the results may not be extended to other populations, as pointed by Ong et al.\textsuperscript{15} The formula used in the BP\textsuperscript{1} was
developed in a North American population in the 70’s. When applied to the Brazilian population, the formula was found to overestimate VO\textsubscript{2} max values. According to Neder et al., this difference is common in studies using prediction equations for VO\textsubscript{2} max. We have recently published reference values for CPET in our population, and a direct and unequivocal measurement of VO\textsubscript{2} gives us the chance to evaluate actual cardiorespiratory fitness of each individual by sex and age range.

The fact that the tests were performed on different days, using different protocols (Bruce versus ramp) may have been a limitation of this study. However, the hemodynamic parameters obtained from the tests were not significantly different, allowing us to infer that there was a similar cardiorespiratory and physical performance by the subjects in both tests. In the present study, we found a significant discrepancy in the classification of cardiorespiratory fitness by the AHA and by the VO\textsubscript{2} prediction formulas. The BP is more widely used for VO\textsubscript{2} calculation in clinical practice in Brazil than spiroergometric tests. Therefore, a possible overestimation of VO\textsubscript{2} values by the BP results in an erroneous evaluation of the cardiorespiratory fitness of the individuals. This, in turn, may represent a lack of opportunity to advise young individuals about the negative effects of a sedentary lifestyle and a low cardiorespiratory capacity.

Conclusion

The assessment of aerobic capacity is an important risk stratification tool in young, physically inactive subjects. Prediction formulas of VO\textsubscript{2} max, derived from cycle or treadmill exercise tests using the BP, are not able to reproduce the true cardiorespiratory capacity in this population, overestimating it. The present study draws attention to the need for an accurate measurement of fitness in this group by CPET, aiming at enabling early warning of these individuals about the risks of a sedentary lifestyle.

Author contributions

Conception and design of the research: Rocha Neto AM, Herdy AH. Acquisition of data: Rocha Neto AM, Herdy AH, Souza P. Analysis and interpretation of the data: Rocha Neto AM, Herdy AH, Souza P. Statistical analysis: Rocha Neto AM, Herdy AH, Souza P. Obtaining financing: Rocha Neto AM. Writing of the manuscript: Rocha Neto AM, Souza P. Critical revision of the manuscript for intellectual content: Rocha Neto AM, Souza P.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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