Equations for Predicting Aerobic Power (VO_2) of Young Brazilian Adults

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Abstract

Background: **VO_2 may be predicted with base on anthropometric and physiological parameters for determined populations.**

Objective: **To propose models for submaximal and maximal VO_2 prediction in young Brazilian adults.**

Methods: **A total of 137 volunteers (92 men) underwent graded maximal exercise test (GXT) in a cycle ergometer (Monark™, Br). Gas exchange and respiratory measurements were performed in an open circuit (Aerosport™ TEEM 100, USA). In another group, 13 volunteers underwent GXT and a square wave test (SWT) in order to evaluate the external validity of Neder et al's formula, ACSM's formula, and of Åstrand-Ryhming nomogram. The study design chosen was a cross-validation and the significance level was set at $p \leq 0.05$.**

Results: **For men during submaximal exercises, a mathematical model was deduced with base on workload, body mass, and age, which explained 89% of the VO_2 variation, with SEE (standard error of the estimate) = 0.33 $l \cdot min^{-1}$. For the maximum load in the male group, another model with the same variables explained 71% of VO_2 variation, with SEE = 0.40 $l \cdot min^{-1}$. For women, 93% of VO_2 variation could be explained, with SEE = 0.17 $l \cdot min^{-1}$, both in submaximal and maximal exercise, with only one equation by use e of the same independent variables.**

Conclusion: **The models derived in the present study proved to be accurate to predict submaximal and maximal VO_2 in young Brazilian adults. (Arq Bras Cardiol. 2010; [online]. ahead print, PP.0-0)**

Key words: **Maximal voluntary ventilation; physical exertion; exercise; exercise test.**

Introduction

Exercise tolerance is an important predictor of cardiovascular, pulmonary, metabolic, and muscle and joint health. The ability of muscles to take up oxygen during exercise is also an index of physical fitness[1]. In order to measure this parameter (VO_2), a continuous graded maximal exercise test (GXT) is usually performed in a treadmill or cycle ergometer[2]. In Brazil, treadmills are more frequently used; however many laboratories also use cycle ergometers, which are more adequate in the case of orthopedic lesions and lead to few artifacts on electrocardiogram and blood pressure measurement. Mechanical cycle ergometers are also more advantageous because of their lower cost and weight, and for not requiring electricity[3].

Aerobic capacity (VO_2) is an important measurement in exercise test because of its close correlation with cardiac output, according to Fick's principle, and its application in indirect calorimetry[1,4]. Indirect calorimetry is a noninvasive method used for VO_2 measurement by means of an ergospirometer[5]. Difficulty of access to and high costs of ergospirometric evaluation, however, cause predictive methods to be more frequently used than ergospirometry in the assessment of functional capacity[6]. Consequently, several equations have been proposed to estimate maximal and/or submaximal oxygen uptake based on easy-to-measure morphological and functional variables such as: body mass; age; gender; height; perceived exertion; walk time; run time; and load in watts[1,7-15]. These equations may be used to determine exercise intensity. However, these methods have considerable errors (15-20%)[1] which increase unpredictably when applied to populations different from the one used to develop them. And,to date, equations generally used in this country come from populations with anthropometric, cardiopulmonary and biomechanical characteristics different from those of the Brazilian population.

With the purpose of improving oxygen uptake prediction in our population, we conducted two studies. The objective of study 1 was to develop equations to predict VO_2 in GXT, at submaximal and/or maximal intensities, with external validity equal to or higher than that of the equations developed by Storer et al[15]. Study 2 had the purpose of comparing the external validity of the equations developed

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here with predictions obtained by ACSM[8], Neder et al[14], and Åstrand -Ryhming[16].

Methods

Study 1 - Model proposed for VO_2 prediction

The subjects of this study were 137 apparently healthy non-smoker, non-athlete adult volunteers. The subjects were classified according to their body mass and divided into two groups, by randomized systematic sampling. Seventy seven men (24 ± 5 years, 76.6 ± 10.9 kg, 178.4 ± 6.8 cm, VO_{2max} = 3.68 ± 0.74 $l{\cdot}min^{-1}$, W_{max} = 271 ± 57 watts and AnT = 1.63 ± 0.31) and thirty women (25 ± 6 years, 58.4 ± 6.9 kg, 162.7 ± 7.1 cm, VO_{2max} = 2.29 ± 0.48 $l{\cdot}min^{-1}$ and W_{max} = 184 ± 39 watts and AnT = 1.13 ± 0.22) were drawn for the internal validity group (*VI*); fifteen men (27 ± 7 years, 75.6 ± 9.3 kg, 176.9 ± 6.7 cm, VO_{2max} = 3.92 ± 0.70 $l{\cdot}min^{-1}$, W_{max} = 273 ± 44 watts and AnT = 1.67 ± 0.34) and fifteen women (25 ± 6 years, 59.3 ± 7.9 kg, 161.9 ± 8.1 cm, VO_{2max} = 2.22 ± 0.55 $l{\cdot}min^{-1}$, W_{max} = 182 ± 35 watts and AnT = 1.08 ± 0.23) comprised the external validity group (EV). Prior to undergoing the tests, the volunteers gave a written informed consent. The experimental study protocol was approved by our institutional Ethics Committee on Human Research. On the day before the test, the individuals were advised to refrain from engaging in strenuous physical activity (> 5 METs) and to keep a mixed diet. They were also advised to avoid caffeine and food in the three hours prior to the exercise.

Test protocol

The continuous graded maximal exercise (GXT) protocol[17] was adopted, consisting of an initial six-minute rest with the individual sitting on the cycle ergometer (Monark™, Brazil), followed by a four-minute warm-up of pedaling with no load, and by the progressive phase with increments by 10% in VO_{2max} per minute[18]. The maximum load was estimated by using anthropometric parameters[19]. The graded phase lasted between 8 and 12 minutes at most, and the pedal cadence was not changed during the exercise (approximately 1.23 Hz). Tests not interrupted by fatigue within the established time were disregarded.

The respiratory and gas exchange variables were recorded every 20 seconds and measured by a metabolic analyzer (Aerosport™ TEEM 100, USA) with a pneumotachograph (Hans Rudolph™, USA). Heart rate (HR) was measured by a cardiotachometer (Polar™ Vantage NV, Finland) every five seconds.

Equipment was calibrated before each test was performed. All tests were performed in the same cycle ergometer and the pedal cadence was controlled by means of an audiovisual metronome. The ergospirometer was calibrated by means of a certified gas mixture (AGA™, Brazil) containing 17.01% oxygen, 5.00% carbon dioxide, and balanced with nitrogen. Flow was calibrated by using a three-liter syringe (Hans Rudolph™, USA), and the cycle ergometer by using a 3-kg weight.

The tests were considered maximal when at least three of the following criteria were observed, according to Howley et al[4]: VO_2 plateau (increase $\leq$ 150$ml{\cdot}min^{-1}$ or 2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$); RER (respiratory exchange ratio) $\geq$ 1.15; HR_{max} $\geq$ 90% of age-predicted HR (220 - age); perceived exertion rate $\geq$ 18. Maximal volitional fatigue with inability to keep the pre-established rhythm. VO_{2max} was determined as the highest value obtained during maximal exertion. In the present study, the maximum load was defined as that observed at VO_{2max}. The anaerobic threshold (AnT) was established by using the V-slope method[20], by determining the inflexion point in the VO_2 x VO_2 curve[21]. The measurements mentioned were taken by two independent observers and AnT was the mean of the two observations.

Study 2 - External validity of ACSM[8], Neder et al[14] and Åstrand-Ryhming[16] VO_2 prediction models

Thirteen adult volunteers participated in the second study; of these, eight were men (24 ± 3 years, 81.5 ± 13.6 kg, 181.9 ± 5.6 cm) and five were women (22 ± 3 years, 63.2 ± 11.7 kg, 163.9 ± 2.2 cm), all apparently healthy, non smokers and non-athletes.

Test protocol

Following the same procedures for calibration and control used in study 1, the subjects underwent GXT and square wave test[1] (SWT) alternated within a period from one to 14 days. SWT comprised two loads, the first one submaximal (SWT_{sub}) and the second one maximal (SWT_{max}). The individuals cycled for six minutes at the submaximal load, and the mean HR measured in the last two minutes was used to estimate VO_{2max} by means of the Åstrand-Ryhming nomogram[16]. After a 10-minute rest with the individual sitting on the cycle ergometer and connected to the ergospirometer, the second load of 110% to 115% of the estimated load for VO_{2max} was started. The last load was controlled during the exercise in order to lead to exhaustion at between two and three minutes.

Statistical analysis

The statistical analysis was carried out by using the Statistical Package for the Social Sciences™ (SPSS, USA) and Microsoft Excel™ for Windows XP™ (USA). Descriptive statistics was used with mean ± standard deviation (SD). For group VI, regression equations were derived for VO_2 prediction at several exercise intensities. The external validity of the derived equations was tested in cross-validation by applying them to group EV. The values predicted and measured were compared by using the paired t test. The external validity of Storer et al's equation[15] for men and women (03M and 03F, respectively) proposed for the same GXT protocol were analyzed in group EV by using two-way ANOVA and post-hoc Tukey-HSD test. With the maximum values obtained in group VI, a specific regression equation was also derived to predict VO_{2max} for the male group. The external validity of this equation was tested in group EV, and the values predicted and measured were compared by using two-way ANOVA and post-hoc Tukey-HSD test, together with the maximum predicted values for the same group by using Storer et al's equation[15].

Bland and Altman's limits of agreement[22] were used between the measured and calculated results. The prediction error was also observed by means of the technical error of measurement (*s* = SD_{dif} ÷Ö2) and of the coefficient of variation (CV).

Values measured in GXT and SWT were compared by using two-way ANOVA; post-hoc Tukey-HSD test with VO_{2max} estimated by Åstrand-Ryhming nomogram[16] by using the workload (06M-NW and 06F-NW); and the VO_2 value measured (06M-NV and 06F-NV). Åstrand-Ryhming[16] normogram estimates corrected for age by using the equations proposed by Siconolfi et al[23] (07M and 07F) were also compared to the values measured. VO_{2max} and VO_2 accuracy, as estimated by recent (05M and 05f) and old equations (04M and 04F) proposed by ACSM[8], was checked. Neder et al [14] model (08M and 08F) for the Brazilian population was compared only to the values measured in SWT. The level of significance for all statistical tests was set at ≤ 0.05.

Results

Submaximal VO_2 values measured and Watt for group EV were 2.01 (±1.11) $l{\cdot}min^{-1}$ and 273 (±44) watts for men and 1.25 (±0.63) $l{\cdot}min^{-1}$ and 182 (±35) for women. The prediction equation for oxygen uptake derived for the male group was:

Equation 01M

VO_2 = -0.131 + (0.01103 x Watt) + (0.007786 x Body Mass) - (0.00617 x Age)

$R^2 = 0.89$ and $SEE = 0.33\ l{\cdot}min^{-1}$

For the female group:

Equation 01F

VO_2 = -0.461 + (0.01043 x Watt) + (0.007096 x Body Mass) + (0.01006 x Age)

$R^2 = 0.93$ and $SEE = 0.17\ l{\cdot}min^{-1}$

Where: R^2 = coefficient of determination; *SEE* = standard error of the estimate.

The results of the predictions through equations 01M, 01F, and 03F for submaximal values were not significantly different from the values measured in group EV. A significant difference between the submaximal values measured and predicted was detected for equation 03M (p = 0.02). Likewise, at peak exercise, equations 01F and 03F did not show significant differences between the values measured and predicted. Equations 01M and 03M, in turn, showed significant differences when used for VO_{2max} prediction (p = 0.001 and p = 0.04, respectively). The external validity of equations 01M, 03M, 01F and 03F are shown in Figures 1 and 2. In order to determine the quality of equations 01M and 01F at other intensities, the values measured and predicted at three submaximal loads were compared. No significant differences were found for equation 01M at 40% VO_{2max} (p = 0.40), 60%VO_{2max} (p = 0.72) and 80% VO_{2max} (p = 0.13); or for equation 01F at 40%VO_{2max} (p = 0.06), 60% VO_{2max} (p = 0.15) and 80% VO_{2max} (p = 0.70). In order to improve VO_{2max} prediction for the male group, another equation was derived to be applied at peak exercise:

Equation 02M

VO_{2max} = 0.518 + (0.01016 x $Watt_{max}$) + (0.01482 x Body Mass) - (0.0292 x Age)

$R^2 = 0.71$ and $SEE = 0.40\ l{\cdot}min^{-1}$

No significant difference was found between the maximum values measured and predicted in group EV when equation 02M was used.

In the second study, submaximal values of VO_2 and of the load obtained in SWT_{sub} were 1.55 (±0.46) $l{\cdot}min^{-1}$ and

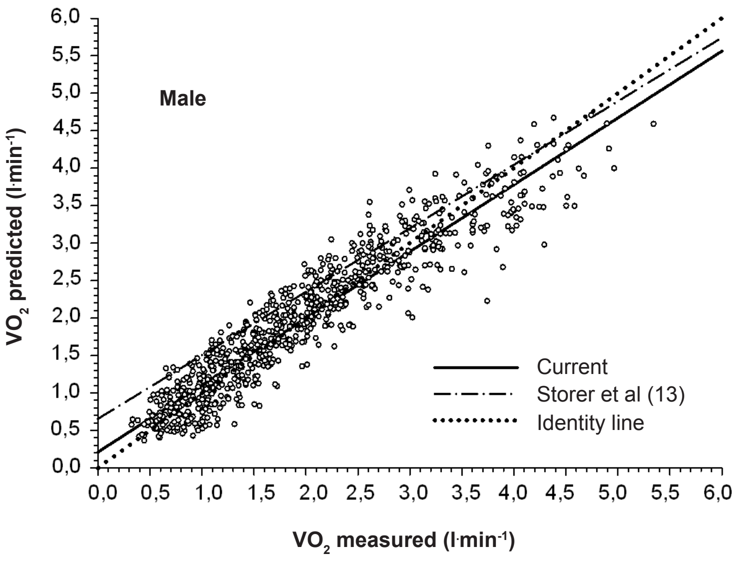

Figure 1 - Scatter plot of the male group EV with VO_2 values measured and predicted by equations 01M and 03M - Study 1.

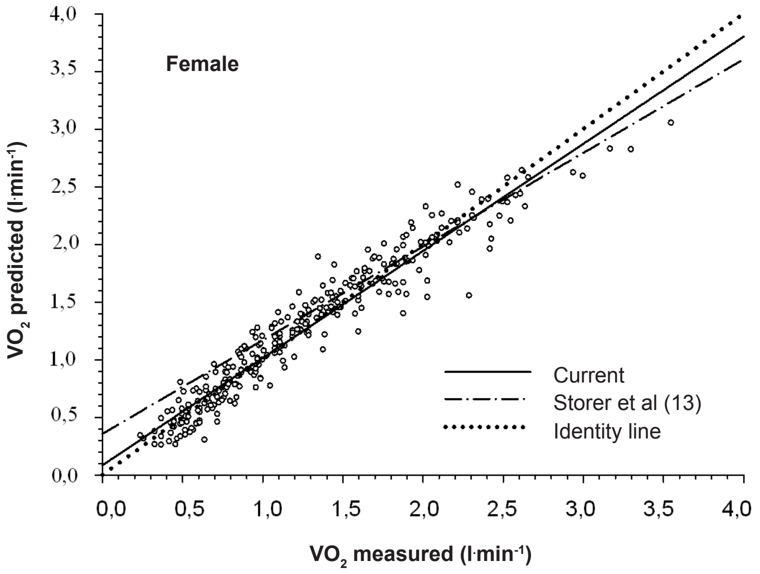

Figure 2 - *Scatter plot of the female group EV with VO_2 values measured and predicted by equations 01F and 03F - Study 1.*

100 (±19) watts for men, and 0.93 (±0.35) $l \cdot min^{-1}$ and 70 (±21) watts for women. Submaximal VO_2 values predicted by all models were not significantly different from the values measured (Table 1). The maximum oxygen uptake value (VO_{2max}) obtained in GXT was 3.09 (±0.99) and 1.49 (±0.13) $l \cdot min^{-1}$ for men and women, respectively. For the female group, there were no significant differences between VO_{2max} values predicted and measured by GXT. For the male group, VO_{2max} values measured by GXT were statistically different from the values predicted by 07M-NV ($p = 0.04$, CV = 35.31%, $s = 0.90$ $l.min^{-1}$, $r^2 = 0.46$) and by 07M-NW ($p = 0.03$, CV= 39.3%, $s = 1.01$ $l.min^{-1}$, $r^2 = 0.25$) when Siconolfi et al's correction[23] was applied to Åstrand-Ryhming nomogram[16]. VO_{2max} and W_{max} obtained in SWT_{max} were 3.12 (±0.73) $l \cdot min^{-1}$ and 215 (±46) watts for men, and 1.63 (±0.14) $l \cdot min^{-1}$ and 139 (±22) watts for women. For the female group, no significant difference was found between VO_{2max} values predicted and measured in SWT_{max}. For the male group, in turn, VO_{2max} values obtained in SWT_{max} were statistically different from the values predicted by 07M-NV ($p = 0.01$) and by 07M-NW ($p = 0.01$), when the Siconolfi et al's correction[23] was applied to Åstrand-Ryhming nomogram[16]. The male group also showed VO_{2max} values statistically different from those predicted by equation 08M ($p = 0.02$). Results from the analysis carried out by using VO_{2max} predictive methods compared to values measured in SWT_{max} are shown in Table 1.

Discussion

Despite the large number of VO_2 prediction equations, very few of them are not specific for a determinate population. The high correlation and moderate standard error of the estimate found in the present study showed that VO_2 can be predicted with satisfactory accuracy by using body mass, age, and workload as independent variables.

Quality control of measurements by means of calibration procedures and operation of equipment by experienced technicians[24] is fundamental for respiratory and gas exchange parameters to be accurately reproduced. In tests where these procedures are adopted, there is low variation in measurements repeated a short time apart[24,25]. The ergospirometer used in this study was validated by another group[26]. The quality of measurements taken by our equipment, in turn, was determined by means of the intraclass correlation coefficient for test and retest measurements of the respiratory and gas exchanges, which were 0.91 for EV; 0.95 for VO_2 and 0.93 for VO_2. These results were obtained at loads between 15 and 340 watts in the cycle ergometer. The difference in the accuracy of the measurements obtained with equipments more sophisticated than the one we used (3.8%[27] *versus* 5.5%) may lead to a small error in the application of our equations, but this error could not be determined.

The results obtained by cross-validation of equations 01M and 01F (study 1) showed an accurate VO_2 prediction. When equations 01M and 03M were used to predict VO_{2max}, a significant difference was observed between values measured and predicted. Unlike the results found for the male group, equations 01F and 03F were accurate for VO_{2max} prediction in the female group. This result can be explained by the fact that men are more aggressive during peak exercise, which leads to an increased aerobic component and activation of fast muscle fibers, consequently increasing power production and changing the linear $VO_{2/watt}$ ratio[28]. In order to improve VO_{2max} prediction for the male group, equation 02M was proposed, which proved to be superior to equation 03M.

Malek et al[29] analyzed the external validity of Storer et al's equations[15] for VO_{2max} prediction in aerobically trained

Table 1 - Cross-validation for VO_2 in the cycle ergometer - Study 2

Equation	Predicted VO_2 ($l \cdot min^{-1}$) (Mean ± SD)	Limits of agreement	s	r	CV
Submaximal effort					
Present study					
01M	1.46 ± 0.25	0.09 ± 0.27	0.19	0.87	12.71
01F	0.94 ± 0.18	- 0.01 ± 0.30	0.22	0.50	23.10
ACSM[8] r					
04M	1.67 ± 0.25	-0.12 ± 0.28	0.20	0.85	12.18
04F	1.21 ± 0.19	-0.29 ± 0.33	0.23	0.39	12.68
ACSM[8] a					
05M	1.51 ± 0.25	0.04 ± 0.29	0.20	0.82	13.37
05F	1.08 ± 0.23	-0.15 ± 0.37	0.26	0.24	26.16
Neder et al[14]					
08M	1.48 ± 0.21	0.06 ± 0.66	0.23	0.08	16.43
08F	1.15 ± 0.23	-0.22 ± 0.77	0.16	0.14	17.00
Maximal effort					
Present study					
01M	2.73 ± 0.55	0.39 ± 0.33	0.23	0.90	7.96
01F	1.66 ± 0.29	- 0.07 ± 0.29	0.20	0.22	11.42
02M	3.22 ± 0.57	-0.10 ± 0.33	0.23	0.90	7.30
ACSM[8] r					
04M	2.94 ± 0.54	0.19 ± 0.34	0.24	0.90	7.83
04F	1.98 ± 0.28	-0.35 ± 0.29	0.21	0.17	11.40
ACSM[8] a					
05M	2.92 ± 0.58	0.21 ± 0.32	0.23	0.90	7.61
05F	1.93 ± 0.29	-0.30 ± 0.31	0.22	0.00	12.28
Åstrand-Ryhming[16]					
06M-NW	3.14 ± 0.49	-0.02 ± 0.66	0.47	0.45	14.88
06F-NW	2.14 ± 0.31	-0.51 ± 0.42	0.30	0.72	15.89
06M-NV	3.15 ± 0.91	-0.03 ± 0.42	0.30	0.89	9.48
06F-NV	1.83 ± 0.24	-0.20 ± 0.13	0.09	0.90	5.26
Siconolfi et al[23]					
07M-NW	2.09 ± 0.17*	1.03 ± 0.66	0.46	0.52	17.82
07F-NW	1.83 ± 0.15	-0.20 ± 0.26	0.19	0.68	10.82
07M-NV	2.10 ± 0.28*	1.03 ± 0.48	0.34	0.92	12.99
07F-NV	1.73 ± 0.05	-0.10 ± 0.11	0.08	0.68	4.69
Neder et al[14]					
08M	2.76 ± 0.52*	0.36 ± 0.69	0.25	0.89	9.23
08F	1.92 ± 0.24	-0.29 ± 0.56	0.20	0.84	12.99

*M - male; F - female; ACSM[8] r - current equation; ACSM[8] a - old equation; s - technical error of the measurement; r - correlation coefficient between values measured and predicted; CV - coefficient of variation; * significant difference ($p \leq 0.05$) for the value measured; VO_2 and workload measured in submaximal rectangular exercise test (SWT).*

individuals, and showed that these had the lower standard error of the estimate (SEE) among the equations they analyzed. The SEE found by Malek et al[29] was 0.32 and 0.27 l·min^{-1} for men and women, respectively, whereas in the original study, Storer et al[15] found SEE of 0.20 and 0.13 l·min^{-1} for men and women, respectively. In the present study, the SEE found for these equations were 0.41 and 0.15 l·min^{-1}, for men and women, respectively. These values were close to those found for equations 01F and 02M derived here.

The results obtained in study 2 demonstrated accuracy in the prediction of VO$_2$ values by equations 01M, 01F and 02M. Equations 01M and 01F proved to be as good as ACSM's[8] and Neder et al[14] (04M, 04F, 05M, 05F, 08M and 08F) for the prediction of submaximal values (Table 1). In an attempt to analyze the applicability of equations 01M, 01F and 02M in different protocols, two maximal tests were performed, one graded (GTX) and another by using square wave (SWT$_{max}$). In both protocols, equations 01M, 01F and 02M predicted VO$_{2max}$ accurately. Equation 02M, however, was superior for it showed a lower coefficient of variation and total error (TE= - 0.10 l·min^{-1}), in comparison to equation 01M (TE= 0.39 L·min^{-1}). Maximum values obtained in GXT and in SWT$_{max}$ were only different from the values predicted by Åstrand-Ryhming nomogram[16] when using the workload (NW) and VO$_2$ (NV), when corrected by equation 07M. Siconolfi et al[23] derived equations (07M and 07F) that modify VO$_{2max}$ values obtained by the original method of Åstrand-Ryhming nomogram[16]. We noticed that equation 07M worsens the original prediction made by Åstrand-Ryhming method[16], producing a total error of 1.03 l·min^{-1}. The high workload increments in 1-minute-duration stages and the plateau criterion of 250 ml.min^{-1} and RER $\geq$ 1.00 at peak exercise may have caused VO$_{2max}$ to be underestimated in Siconolfi et al's study[23]. There was also a significant difference between the VO$_{2max}$ values measured and predicted when equation 08M was applied[14]. This method, which was developed for the Brazilian population, did not prove accurate in predicting the VO$_{2max}$ of active subjects in SWT.

Analysis of limits of agreement showed a trend to overestimate VO$_{2max}$ when the Åstrand-Ryhming nomogram[16] was used in the female group (Table 1). Zwiren et al[30] analyzed the external validity of Åstrand-Ryhming nomogram[16] in women aged between 30 and 39 years with VO$_{2max}$ of 2.4 ($\pm$ 0.45) l·min^{-1} and concluded that the Åstrand-Ryhming method[16] overestimated VO$_{2max}$ by 20%. When Åstrand-Ryhming nomogram[16] was used to infer this parameter in the male group, the values predicted were not significantly different from those measured. On the other hand, Table 1 shows that 06M-NW and 06M-NV had higher coefficients of variation, typical measure error, and lower correlation in comparison to the male equations 01M and 02M. Davies et al[31] studied a male group aged 22 ($\pm$ 2) years with higher VO$_{2max}$ (50.7 ml.kg^{-1}.min^{-1}) and found a confidence interval (CI = 95%) of -0.96 ($\pm$0.47) l.min^{-1} (HR = 120<140 bpm) and -0.64 ($\pm$0.39) l.min^{-1} (HR = 140<180), as predicted by the workload, by using Åstrand-Ryhming nomogram. For Davies et al[31], this method has a CV of 15% for estimates using VO$_2$ and of 21% using the load.

Recent studies showed that the relationship between oxygen uptake and workload is linear up to the intensity of 50% to 60%VO$_{2max}$. After this point, the function becomes exponential[32]. We analyzed this relationship by using the single-phase or two-phase linear model. In the latter, it is understood that there is a linear function up to the transition point, from which VO$_2$ starts to increase in exponential function. For the male group, the linear model showed R^2 = 0.88, SEE = 0.34 and mean square errors (*MSE)* = 0.12. When the two-phase model was used, the values obtained were adjustment of R^2 = 0.80, SEE = 0.34 and MSE = 0.11. These results were quite similar and suggest that the two-phase model was not superior.

In conclusion, the models derived in the present study proved to be accurate in predicting submaximum and maximum VO$_2$ in young Brazilian adults. Based on study 1, equation 01M did not prove to be valid at maximal intensities. The other equations (01F and 02M) may be used with satisfactory external validity at peak exercise. VO$_{2max}$ prediction significantly improved for the male group when equation 02M was used. The equations derived by Storer et al[15] did not show a higher accuracy in predicting VO$_{2max}$. In study 2, the equations derived were valid both for submaximal and maximal intensities. The equation proposed by Siconolfi et al[23] (07M) to correct Åstrand-Ryhming method[16], and Neder et al's equations[14] for men did not show a satisfactory result for the local population. We also concluded that the equations derived in this study showed satisfactory external validity in protocols with or without steady state.

Limitations

Factors such as variation in the mechanical efficiency at a given workload, medication or alcohol intake, heat, hypobaric environments and individuals with diseases or body mass and age different from those of the subjects of this study may increase prediction error. Thus, this study does not present a form of replacing, with the same accuracy, direct VO$_2$ measurement. Other equations for other age ranges and different patient groups should be further derived.

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