Maximal Workload Prediction Models in the Clinical Cardio-pulmonary Effort Test

Fernando dos Santos Nogueira e Fernando Augusto Monteiro Sabóia Pompeu
Universidade Federal do Rio de Janeiro - UFRJ - Rio de Janeiro, RJ - Brazil

Objective

This study sought to derive generalized equations for predicting maximal workload for young men and women.

Methods

Direct ergospirometry (Aerosport® TEEM 100, USA) was used to determine $VO_{2máx}$ and the maximal work load (W_{max}) on the cycle ergometer test (Monark®, Brazil) of thirty men (25 ± 5 years, 75.0 ± 10.7 kg; 48.4 ± 8.8 $mL \cdot kg^{-1} \cdot min^{-1}$ and 243 ± 51 Watts) and thirty women (26 ± 5 years, 56.7 ± 5.9 kg, 39.8 ± 7.6 $mL \cdot kg^{-1} \cdot min^{-1}$ and 172 ± 37 Watts). Age and body mass were used as independent variables. For all statistic tests, a $p \leq 0.05$ significance level was adopted.

Results

In the multiple linear adjustment, the maximal workload was explained by age and body mass as 54% (r = 0.73) for men, and as 76% (r = 0.87) for women, with standard errors of 0.66 $W \cdot kg^{-1}$ and 25 Watts. The proposed equations were cross-validated using another sample with similar age and $VO_{2máx}$ characteristics comprised of fifteen men and fifteen women. The intraclass correlation between the predicted W_{max} values and those measures by ergospirometry were 0.70 and 0.69, with standard errors of 28.4 and 15.8 Watts, respectively, for men and women.

Conclusions

This study exhibits valid generalized equations for determining the maximal cycle ergonometer workload for men and women.

Key words

Oxygen consumption, physicial exertion, stress test, anaerobic threshold, ventilatory threshold.

Mailing Address: Fernando A. M. S. Pompeu • Av. Brigadeiro Trompowisky, 212 s/nº - Cidade Universitária – 29141-590 – Rio de Janeiro, RJ - Brazil
E-mail: cineantropo@oi.com.br
Received on 10/09/05 Accepted on 03/30/06

The term ergospirometry or spiroergometry was coined in 1929, suggested by Knipping & Brauer (see the comprehensive review by Hollmann & Prinz[1]). The primary metabolic measurement in this test is the aerobic capacity (VO_{2max}). Maximal aerobic capacity (VO_{2max}) is the highest oxygen capture that an individual can attain during physical work when breathing air at sea level[2]. This variable, according to the Fick principle, is determined by the cardiac output and the mixed arteriovenous difference of oxygen. The ergospirometric test, therefore, allows a valuable study of the integration between pulmonary, cardiovascular, and musculoskeletal systems[2,3], and in some cases is the only way to comprehend physiopathological mechanisms, such as in severe pulmonary vascular disease without direct hypertension, in the patent foramen ovale with left-right shunt development during exercise, in exertional dyspnea, and in exertional hypoxemia, among others[4]. Its application before invasive or high-cost procedures in large groups of patients with heart disease and lung disease has many advantages [3,4].

The maximal effort cycle ergometric protocol with 1-min load increments was first proposed by Wasserman et al[5], and later perfected by Buchfuhrer et al[6]. This protocol consists of continuous load increments added each minute in order to attain the maximal workload (W_{max}), characterized by objective criteria[7] as 10 ± 2 min. Therefore, prediction of Wmax from variables available before the beginning of the study for 10% increments W_{max} per minute is necessary. The equations normally used[8-12] are not very accurate, since they come from populations with anthropometric, cardiopulmonary, and biomechanical characteristics different from those of Brazilians. Valuable experimental assays and normative reviews published by groups of Brazilian researchers, however, have failed to present an alternative to these equations[13-16]. Because of this difficulty, this study aims to a) develop mathematical equations for predicting W_{max} in a continuous and escalating cycloergometer test with 10 ± 2 min duration, and b) test the external validity of the equations developed herein, confronting them with the validity of those derived for a foreign population.

Methods

The subjects of this study were 90 apparently healthy, non-smoking and non-athletic adult volunteers, 45 men and 45 women, women (Table 1). Subjects were randomly divided into two groups similar in age and body mass; the number of subjects was established according to Hopkins[17]. Thirty men and thirty women were randomly selected for the internal validity group (IV), and fifteen men and fifteen women for the external validity group (EV). Subjects were advised to abstain from extenuating physical activities and to maintain a mixed diet on the day prior to the test (> 5 METs). It was also recommended that they avoid ingestion of food and caffeine for three hours before the exercise. Prior to the test, the subjects filled out an informed consent form. The procedures adopted were approved by the local Ethics Committee for studies with human subjects.

Test protocol - A continuous and maximal escalating protocol was used[5], comprised of an initial resting period for six minutes with the patient sitting on the cycle ergometer (Monark®, Brazil), followed by a four-minute warm-up of pedaling without any workload, and later, by the escalating phase with a maximum duration between eight and twelve minutes[6]. Any test not interrupted because of fatigue during this period of time was excluded. Overload increments were determined for a constant pace in an empirical and individualized manner. These increments were maintained throughout the test (approx. 25 $W \cdot min^{-1}$). The pace was controled by means of an audiovisual metronome (approx. 74 $rev \cdot min^{-1}$).

Gas exchange and ventilatory variables were measured by a metabolic analyzer (Aerosport® TEEM 100, USA) in an open circuit and by a medium flow pneumotachometer (Hans Rudolph®, USA). These data were recorded every

Table 1 – Anthropometric characteristics and ergometric variables obtained in the maximal cycle ergometer test (mean ± SD)

Variables	Men IV (n = 30)	Men EV (n = 15)	*p*	Women IV (n = 30)	Women EV (n = 15)	*p*
Age (years)	25 ± 5	28 ± 7	0.12	26 ± 5	24 ± 5	0.35
Mass (kg)	75.0 ± 10.7	81.3 ± 10.0	0.06	56.7 ± 5.9	56.6 ± 6.8	0.92
Stature (cm)	176.9 ± 6.6	180.0 ± 8.3	0.19	161.7 ± 8.1	161.3 ± 8.1	0.89
VO_{2max} ($L \cdot min^{-1}$)	3.61 ± 0.71	4.03 ± 0.70	0.07	2.26 ± 0.71	2.03 ± 0.45	0.14
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	48.36 ± 8.80	50.07 ± 10.15	0.56	39.81 ± 7.64	35.91 ± 6.68	0.10
W_{max}	243 ± 51	289 ± 59	0.01	172 ± 37	163 ± 26	0.39
$W \cdot kg^{-1}_{max}$	3.29 ± 076	3.62 ± 0.97	0.21	3.02 ± 0.50	2.88 ± 0.32	0.33

Where: n = number of volunteers; IV = internal validity group; EV = external validity group; p = significance of the difference between the internal and external validity groups.

twenty seconds. Heart rate was monitored throughout the test by a cardiotachometer (Polar® Vantage NV, Finland).

Before each test, equipment was calibrated. The ergospirometer was calibrated in a closed circuit (AGA®, Brazil), furnishing a gas mixture containing 17.01% oxygen, 5.00% carbon dioxide, and balanced with nitrogen. Gas flow was calibrated using a three-liter syringe (Hans Rudolph®, USA) and the cycle ergometer by means of a 3 kg ballast.

Tests were considered maximal when at least three of the following criteria were observed[7]: plateau in VO_2 (increase $\leq$ 150 mL · min^{-1} or 2 mL · kg^{-1} · min^{-1}), HR_{max} $\geq$ 90% of predicted value for age (220 - age), Concept of Perceived Effort $\geq$ 18, RER (respiratory exchange rate) $\geq$ 1.15, and maximal voluntary fatigue with inability to maintain the preestablished rhythm. VO_{2max} was determined as the highest value found at the end of the test. In this study, the maximal workload was defined as that observed in VO_{2max}.

Statistical analysis - Statistical processing was done by means of the Statistical Package for the Social Sciences® package (SPSS, USA) version 13.0 and Microsoft Excel® for Windows XP® (USA). Descriptive statistics were used with means ± standard deviations (SD). For Group IV, stepwise multiple regression analysis was used to deduce mathematical models for prediction of maximal workload expressed in Watts (*W*). Eight equations[8-12] (Chart 1 and 2) for the same purpose (male and female genders) were analyzed by cross-validation with the subjects from Group IV. Values predicted for Group IV by means of foreign equations, and the values measured were confronted by analysis of variance with one factor and a *post-hoc* Tukey-HSD test. External validity of the equations derived in this investigation were tested by applying them to the EV group. Bland-Altman[19] and modified Bland-Altman[20] limits of agreement plots were used with the results measured and calculated by the predictive formulas. The degree of association between the values measured and those predicted was determined by the intraclass correlation coefficient (ICC)[21]. The error of prediction was also noted by means of the technical error of the measurement ($s = S.D._{dif} \div \sqrt{2}$) and the coefficient of variation (CV %). All statistical tests were performed at the $\leq$ 0.05 significance level.

Results

Characteristics of VO_{2max} and W_{max} of the volunteers are displayed on Table 1. The equation for prediction of maximal workload derived for the male group was:

Equation 1

$$W \cdot kg^{-1} = 6.413 - (0.0531 \cdot age) - (0.0242 \cdot weight)$$

$$R^2 = 0.54 \text{ and } SEE = 0.66 \text{ W} \cdot kg^{-1}$$

For the female group:

Equation 2

$$W_{máx} = -115.756 + (2.271 \cdot age) + (4.043 \cdot weight)$$

$$R^2 = 0.76 \text{ and } SEE = 25.03 \text{ W}$$

Where: R^2 = coefficient of determination and *SEE* = Standard Error of the Estimate

The prediction results using equations 1 and 2 derived in this study did not significantly differ from the results measured for the EV group (Fig. 1). A significant difference was detected for foreign equations between the values measured and those predicted, for both male and female groups (Fig. 1 and Chart 2).

Table 2 displays the results of the analysis performed with the foreign equations. Group IV had limits of agreement of 0.93 ± 95.0 W for the male group, and -20.5 ± 47.6 W for the female group (Fig. 2). These indexes for the EV group were 34.2 ± 86.0 W for the male group, and -4.14 ± 47.87 W for the female group (Fig. 3). There was a moderate association between the values measured and those predicted (ICC = 0.70 and 0.69), respectively, for men and women. The *SEE* for the male group was 28.42 W (CV = 10.45%), and for the female group, 15.78 W (CV = 9.55%).

Chart 1 – Characteristics of maximal workload prediction equations for incremental progressive cycle ergometer tests

Prediction equation	Subjects (n)		Age (years)	Characteristics	Variables
Jones et al[8]	Males Females	50 50	15-71	University students / General population	Age, stature, weight
Hsi et al[9]	Males Females	55 50	20-75	General population	Age, stature, weight
Neder et al[10]	Males Females	60 60	20-80	University population	Age, stature, weight
Ong et al[11]	Males Females	48 47	20-70	General population	Age, stature, weight
Wasserman et al[12]	Males Females	NR NR	NR	NR	Age, stature, weight

NR, not reported.

Chart 2 – Maximal workload prediction equations for the incremental cycloergometer test

Eq.	Reference	Equations	R^2	*SEE*
1	Jones et al (a)[8] 1M male 1F female	$kp \cdot m \cdot min^{-1} = -1909 - 288(G) + 20.4(H) - 8.7(I)$	0.74	216
2	Jones et al (b)[8] 2M male 2F female	$kp \cdot m \cdot min^{-1} = -1569 - 249(G) + 16.2(H) - 9.5(I) + 5.6(P)$	0.74	213
3	Hsi et al[9] 3M male 3F female	$W_{max} = -161 + 1.7(H) - 1.1(I) + 1.1(P)$ $W_{max} = -5 + 1.1(H) - 1.2(I)$	0.67 0.79	20 12
4	Neder et al[10] 4M male 4F female	$W_{max} = -45.4 + 1{,}36(H) - 1.78(I) + 0.65(P)$ $W_{max} = 28.1 + 0.96(H) - 1.19(I)$	0.67 0.72	25 14
5	Ong et al[11] 5M male 5F female	$W_{max} = 4.1394 - 0.3131(G) + 0.0076(H) - 0.0103(I) + 0.0058(P)$	0.74	NR
6	Wasserman et al[12] 6M male 6F female	$W_{max} = (VO_{2max} - VO_{2(OW)} \cdot 10^{-1})$	NR	NR

Equations 1 and 2 used the gender as a predictor (0 for males and 1 for females); equation 5 used the gender as a predictor (1 for males and 2 for females) and uses logarithmic transformation; for equation 6, VO_{2max} is predicted as $mL \cdot min^{-1} = (H - I) \cdot 20$ for sedentary men and 14 for sedentary women, and $VO_{2max(ow)}$ is $mL \cdot min^{-1} = 150 + 6(P)$; G, gender; H, stature (cm); I, age (years); P, weight (kg); NR, not reported.

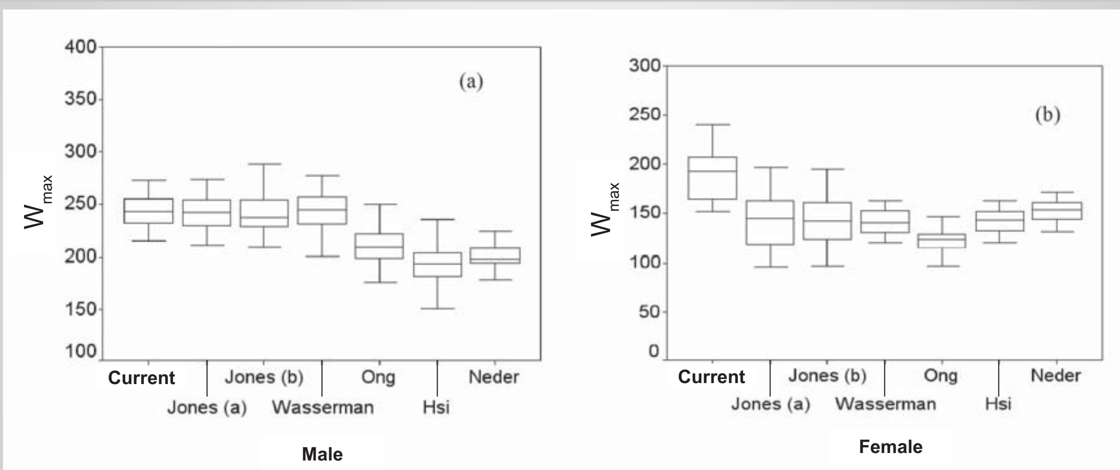

***Fig. 1** – Maximal capacity (W_{max}) measured and predicted by the current equation and by foreign equations, where (a) male group and (b) female group; * $p \leq 0.05$ between W_{max} measured (Table 1) and predicted (Table 2).*

Discussion

We recommend a 10% progression of the maximal workload per minute in the escalating, continuous and maximal protocol on the cycle ergometer for the detection of the anaerobic threshold and VO_{2max}. The test should be finalized by maximal effort criteria[6] after eight to twelve minutes[6]. Based on these requirements, different equations were presented for determining the W_{max}, normally using the anthropometric variables obtained at rest such as gender, age, weight, and stature. Despite the large number of prediction equations found in literature, none has proved to be well suited to the Brazilian population. It seems wise to expect a reasonable prediction capacity when the equation is applied to the population from which it was derived. The results of this study suggest a good external validity for the equations proposed herein when compared to equations coming from alien populations.

In rapid tests (< eight minutes), Buchfuhrer et al.,[6] observed a low VO_{2max} value. This was possibly due to limitations of muscular force. However, a reduction of VO_{2max} in longer (> sixteen minutes) tests would also be expected because of an increase in core temperature, dehydration, discomfort, or fatigue of ventilatory muscles[6]. Since longer tests require more time, do not furnish additional information, and do not produce maximal values, protocols with 10 ± 2 minutes duration are recommended.

Table 2 – Cross-validation for W_{max} on the cycle ergometer

Eq.	Reference	W_{max}predicted (Mean ± SD)	Limits of Agreement	*ICC*	*s*	*CV %*
1	Jones et al(a)[8] 1M male 1F female	242 ± 24 143 ± 29	1.0 ± 104.0 29.2 ± 72.4	0.13 0.37	37.69 26.14	15.52 16.56
2	Jones et al(b)[8] 2M male 2F female	242 ± 25 143 ± 27	1.0 ± 102.0 29.6 ± 70.6	0.18 0.38	36.81 25.46	15.18 16.16
3	Hsi et al[9] 3M male 3F female	195 ± 20 142 ± 11	48.4 ± 99.5 30.6 ± 71.6	0.17 0.10	35.91 25.82	16.40 16.43
4	Neder et al[10] 4M male 4F female	200 ± 16 153 ± 10	43.6 ± 97.2 19.8 ± 72.1	0.17 0.07	35.07 26.01	15.84 16.01
5	Ong et al[11] 5M male 5F female	212 ± 22 123 ± 13	31.6 ± 98.0 49.6 ± 68.5	0.23 0.19	35.29 24.73	15.52 16.75
6	Wasserman et al[12] 6M male 6F female	244 ± 16 141 ± 12	-0.8 ± 101.1 31.4 ± 61.5	0.09 0.01	36.79 27.27	15.10 17.40

W_{max} predicted = maximal workload predicted. ICC = interclass correlation coefficient. s = technical error of the measurement; and CV = coefficient of variation.

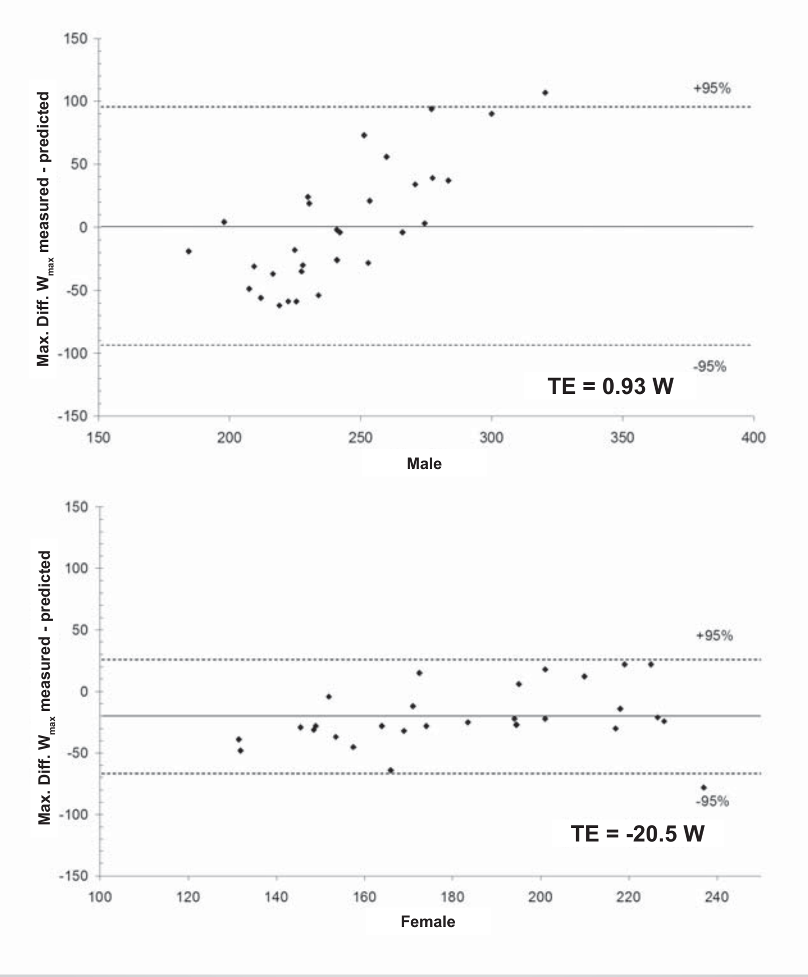

Fig. 2 *– Limits of agreement between values measured and predicted for maximal workload estimate in Group IV. Solid line is the total error (TE) from zero, with ± 95% (intermitent lines). Figure 3 follows the same format.*

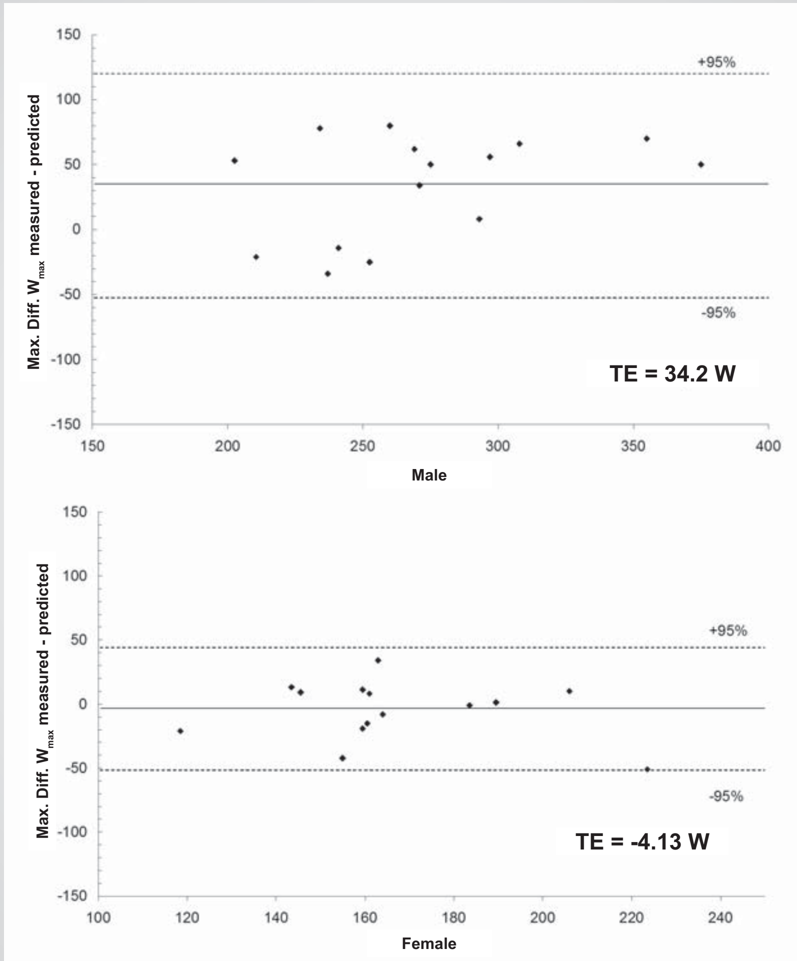

Fig. 3 *– Limits of agreement between values measured and predicted for maximal workload estimate in EV group.*

The precision of gas exchange and ventilatory measurements is essential for data to be reproduced, and quality control needs to be made by means of calibration, operation, and analysis performed by experienced technicians[15]. Tests in which these precautions are taken show a low variation in repeat measurements at the nearest timepoints[15,22-25]. Daily intrasubject variation, due to error and physiological fluctuations of oxygen consumption, minute ventilation, and heart rate, are[25] 3.8%, 8.0%, and 3.0%, respectively. Granja Filho et al[22], observed a 5.5% intrasubject variation for VO_{2max} in a study carried out recently. We conclude that this result is a fruit of our equipment for clinical use. Even with this greater inaccuracy, the ergospirometer adopted here was validated by another group[23] and is amply used in Brazilian laboratories because of its low cost. This difference in accuracy between measurements obtained with more sofisticated equipement and ours (3.8% versus 5.5%) may lead to a small error in the application of our formulas, which could not yet be determined.

Coefficients of determination for the prediction equations of this study were moderate for the male group ($R^2 = 0.54$) and high for the female group ($R^2 = 0.76$). We chose to express the maximal workload as W_{max} and $W \cdot kg^{-1}$, respectively, for women and men. This adjustment in the dependent variable was necessary in order to obtain a greater predictive power in the second case. This is probably due to the lower body adiposity in the male group[26,27]; therefore, a greater weight variation would imply a greater heterogeneity of lean body mass, and consequently, of muscular strength. These indexes are close to those of other studies[9-11]. Ong et al[11], sought to improve the predictive model of W_{max} using logarithmic transformation. The use of a nonlinear model was proposed in order to correct the influence of age in the decline of physical conditioning. The research performed by Ong et al[11], however, did not obtain more precise results than other studies[8-10].

The *SEE* indexes for the equations in this study were similar to those of other equations[8-10]. As a comparison, because of the difference in units recorded ($W \cdot kg^{-1}$,W , $kg \cdot m \cdot min^{-1}$), the *SEE* was divided by the average of the group studied in order to express the *SEE* in a porcentage of the mean (*SEE* %). Jones et al,[8] found 15% indexes for the male group and 26% indexes for the female group. On the other hand, Hsi et al,[9] and Neder et al,[10] found 14% and 17% values for the male group, and 12% and 13% values for the female group, respectively. In this study, these indices were 20% for the male group, and 14% for the female group. The indexes of *SEE*% for an indirect estimate of VO_{2max} in several field methods, such as the step test, submaximal cycle ergometer test, or walking/running on track test, represent 10% to 20% of the VO_{2max} measured[28].

No other author, among all those researched, performed a cross-validation study of his W^{max} prediction equations. We see on Table 2 that the intraclass correlation coefficients for external validity of the main equations analyzed in literature varied from ICC = 0.01 (6F) to ICC = 0.38 (2F). These indexes, as was expected, were lower than those found in the original assays and in the present study. Analyzing the proportion of possibly invalidated tests when these equations are used[8-12], there is a 40% to 64% loss of tests (Table 3). The equations we propose show 27% and 20% indexes for the male and female groups, respectively (Table 3).

Figures 4 and 5 present dispersion diagrams of the predicted values and the measured values for the equations with the lowest indexes of invalidated tests (1M and 1F). One can see that the inclination of the tendency line is near zero, suggesting an absence of covariance. Distortions such as these are common when the population validity of predictive models is considered[9,11].

Analysis of the limits of agreement reveals that there is a great variation between the equations. The total error (TE - the measured value minus the predicted value) varied considerably between the predictive models. A tendency to underestimate W_{max} when using the foreign models was noted. The present study, however, presented acceptable limits of agreement (Fig. 2). Some points showed considerable distancing as to the error in the male group. Nevertheless, for this analysis, one should consider the ± 2 min range previously recommended[6] and the index of invalidated tests shown on Table 3. For the female group, a small overestimation of the measured value was noted.

The predictive technique error suggested is close to the variation range recommended by Buchfuhrer et al[6]. We conclude, therefore, that the inference equations of W_{max} derived in this study for the escalating and continuous cycle ergometer protocols, with eight to twelve minutes duration, can be used with satisfactory external validity. We also conclude that the equations derived for alien populations that we studied did not show fully satisfactory results for the local population. For the future, a repetition of this assay for other age brackets and for the diverse patient groups that could not be included here is recommended.

Acknowledgements

The authors of this study express their gratitude to the Associação dos Amigos do Centro de Estudos e Aperfeiçoamento do Hospital dos Servidores do Estado do Rio de Janeiro, in the person of Dr. Aluysio S. Aderaldo Jr., for the significant contribution toward this study and to the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro - FAPERJ. We are also thankful for the valuable review by our colleagues, Verônica Salerno, Martha M. Sorenson, Ricardo Gancz, and Michelle Porto.

Table 3 – Stress tests invalidated* when applied to predictive equations.

		Invalidated Tests	
Prediction equation	**Subjects**	**Total**	**(%)**
Jones et al (a)[8]	Males Females	18 18	40 40
Jones et al (b)[8]	Males Females	19 18	42 40
Hsi et al[9]	Males Females	20 21	44 47
Neder et al[10]	Males Females	25 19	56 42
Ong et al[11]	Males Females	21 29	47 64
Wasserman et al[12]	Males Females	18 21	40 47
Equação atual	Males Females	04 03	27 20

**Tests invalidated when interruption occurred out of the 10 ± 2 minute range for n = 45 men and 45 women. For the current equation, the EV group was used (n = 15 men and n = 15 women).*

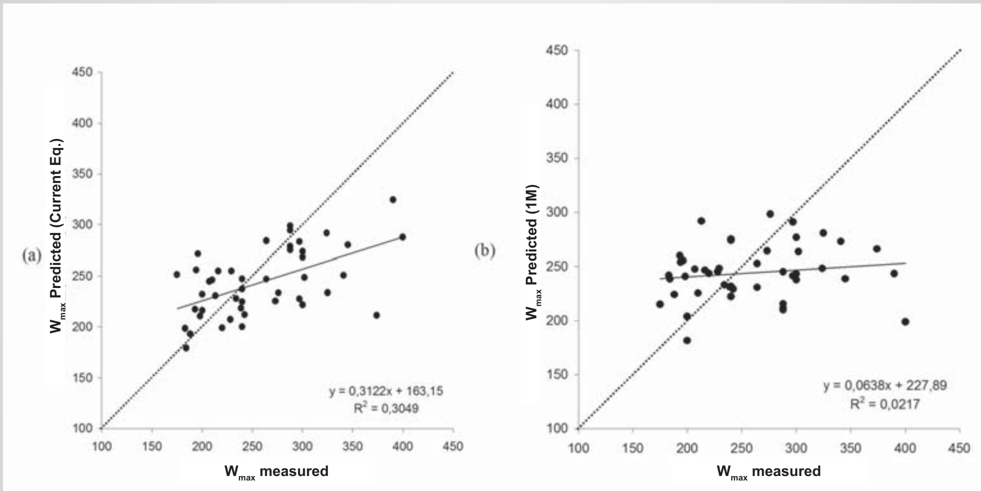

Fig. 4 *– Dispersion diagram between values measured and predicted by the proposed equation (a) and predicted by equation 1M (b) for the male group (n = 45, regression [——], identity line [·······]).*

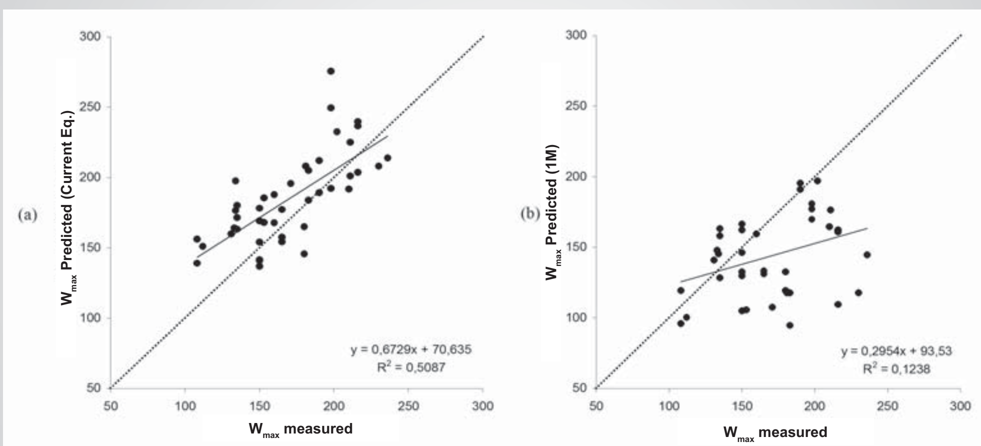

Fig. 5 *– Dispersion diagram between values measured and predicted by the proposed equation (a) and predicted by equation 1F (b) for the female group (n = 45, regression [——], identity line [·······]).*

Potencial Conflict of Interest

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

References

1. Hollmann W, Prinz JP. Ergospirometry and its history. Sports Méd. 1997; 23: 93-105.
2. Åstrand PO, Rodahl K, Dahl HA, Strømme SB. Evaluation of physical performance on the basis of tests. In: Textbook of Work Physiology. 4th ed. Champaign: Human Kinetics; 2003: 273-97.
3. Jones NL. Clinical exercise testing. 4th ed. Philadelphia: W.B. Saunders; 1997.
4. Wasserman K, Hansen JE, Sue DY, Whipp BJ, Casauri R. Principles of exercise testing and interpretation. 2th ed. Philadelphia: Lea & Febiger; 1994: 2-8.
5. Wasserman K, Whipp BJ, Koyal SN, Beaver WL. Anaerobic threshold and respiratory gas exchange during exercise. J Appl Physiol. 1973; 35: 236-43.
6. Buchfuhrer MJ, Hansen JE, Robinson DY, Sue DY, Wasserman K, Whipp BJ. Optimizing the exercise protocol for cardiopulmonary assessment. J Appl Physiol. 1983; 55: 1558-64.
7. Howley ET, Basset Jr. DR, Welch HG. Criteria for maximal oxygen uptake: review and commentary. Med Sci Sports Exerc. 1995; 27: 1292-301.
8. Jones NL, Makrides L, Hitchcock C, Chypchar T, Mccartney N. Normal standards for an incremental progressive cycle ergometer test. Am Rev Respir Dis. 1985; 131: 700-8.
9. Hsi WL, Lan C, Lai JS. Normal standards for cardiopulmonary responses to exercise using a cycle ergometer test. J Formos Med Assoc. 1998; 97: 315-22.
10. Neder JA, Nery LE, Castelo A, Andreoni S, Lerario MC, Sachs A, et al. Prediction of metabolic and cardiopulmonary responses to maximum cycle ergometry: a randomized study. Eur Respir J. 1999; 14: 1304-13.
11. Ong KC, Loo CM, Ong YY, Chan SP, Earnest A, Saw SM. Predictive values for cardiopulmonary exercise testing in sedentary chinese

adults. Respirology. 2002; 7: 225-31.

12. Wasserman K, Hansen JE, Sue DY, Whipp BJ. Protocols for exercise testing. In: Principles of exercise testing and interpretation. Philadelphia: Lea & Febiger; 1987: 58-71.

13. Guimarães GV, Bellotti G, Wajngarten M, et al. Exercício e insuficiência cardíaca. Estudo da relação da gravidade da doença com o limiar anaeróbio e o ponto de compensação respiratório. Arq Bras Cardiol. 1999; 73: 339-43.

14. Ribeiro JP. Limiares metabólicos e ventilatórios durante o exercício. Aspectos fisiológicos e metodológicos. Arq Bras Cardiol. 1995; 64: 171-81.

15. Guimarães JI, Stein R, Vilas-Boas F, et al. Normatização de técnicas e equipamentos para realização de exames em ergometria e ergoespirometria. Arq Bras Cardiol. 2003; 80: 458-64.

16. Yazbek Jr P, Carvalho RT, Sabag LMS. Batistella LR. Ergoespirometria: Teste de esforço cardiopulmonar, metodologia e interpretação. Arq Bras Cardiol. 1998; 71: 719-24.

17. Hopkins WG. A new view of statistics. Sportscience [online]. Available from: URL: http://sportsci.org/resourse/stats [Accessed 2005 Jan 5].

18. Malek MH, Berger DE, Housh TJ, Coburn JW, Beck TW. Validity of $VO_{2máx}$ equations for aerobically trained males and females. Med Sci Sports Exerc. 2004; 36: 1427-32.

19. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986; 2: 307-10.

20. Hall C, Figueroa A, Fernhall B, Kanaley JA. Energy expenditure of walking and running: comparison with prediction equations. Med Sci Sports Exerc. 2004; 36: 2128-34.

21. Bartko JJ. The intraclass correlation coefficient as a measure of reliability. Psych Reports. 1966; 19: 3-11.

22. Granja Filho PCN, Pompeu FAMS, Ribeiro AP. A acurácia da determinação do $VO_{2máx}$ e do limiar anaeróbio. Rev Bras Med Esporte. 2005; 11: 167-71.

23. Novitsky S, Degal KR, Chatr-Aryamontri B, Gubakov D, Katch VL. Validity of a new portable indirect calorimeter: the Aerosport TEEM 100. Eur J Appl Physiol. 1995, 70: 104/1-104/6.

24. Davies CTM, Tuxworth W, Young IM. Physiological effects of repeated exercise. Clin Sci. 1970; 39: 247-58.

25. Jones NL, Kane JW. Quality control of exercise test measurements. Med Sci Sports. 1979; 11: 368-72.

26. Pollock ML, Laughridge E, Coleman B, Linnerud AC, Jackson A. Prediction of body density in young and middle-aged women. J Appl Physiol. 1975; 38: 745-9.

27. Pollock ML, Hickman T, Kendrick Z, Jackson A, Linnerud AC, Dawson G. Prediction of body density in young and middle-aged men. J Appl Physiol. 1976; 40: 300-4.

28. Zwiren LD, Freedson PS, Ward A, Wilke S, Rippe JM. Estimation of $VO_{2máx}$: a comparative analysis of five exercise tests. Res Q Exerc Sports. 1991; 62: 73-8.