

## Indirect estimation of $\text{VO}_2\text{max}$ in athletes by ACSM's equation: valid or not?

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### Abstract

**Aim:** The purpose of this study was to assess the indirect calculation of  $\text{VO}_2\text{max}$  using ACSM's equation for Bruce protocol in athletes of different sports and to compare with the directly measured; secondly to develop regression models predicting  $\text{VO}_2\text{max}$  in athletes.

**Methods:** Fifty five male athletes of national and international level (mean age  $28.3 \pm 5.6$  yrs) performed graded exercise test with direct measurement of  $\text{VO}_2$  through ergospirometric device. Moreover, 3 equations were used for the indirect calculation of  $\text{VO}_2\text{max}$ : a)  $\text{VO}_2\text{max} = (0.2 \cdot \text{Speed}) + (0.9 \cdot \text{Speed} \cdot \text{Grade}) + 3.5$  (ACSM running equation), b) regression analysis model using *enter* method and c) *stepwise* method based on the measured data of  $\text{VO}_2$ . Age, BMI, speed, grade and exercise time were used as independent variables.

**Results:** Regression analysis using *enter* method yielded the equation ( $R=.64$ , standard error of estimation [SEE] = 6.11):  $\text{VO}_2\text{max} (\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 58.443 - (0.215 \cdot \text{age}) - (0.632 \cdot \text{BMI}) - (68.639 \cdot \text{grade}) + (1.579 \cdot \text{time})$  while *stepwise* method ( $R = .61$ , SEE = 6.18) led to:  $\text{VO}_2\text{max} (\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 33.971 - (0.291 \cdot \text{age}) + (1.481 \cdot \text{time})$ . The calculated values of  $\text{VO}_2\text{max}$  from these regression models did not differ significantly from the measured  $\text{VO}_2\text{max}$  ( $p>.05$ ). On the contrary,  $\text{VO}_2\text{max}$  calculated from the ACSM's running equation was significantly higher from the actually measured value by 14.6% ( $p <.05$ ).

**Conclusions:** In conclusion, it seems that ACSM's equation is not capable of accurately predicting  $\text{VO}_2\text{max}$  in athletes aged 18-37 years using Bruce protocol. Only the regression models were correlated moderately with the actually measured values of  $\text{VO}_2\text{max}$ . Hippokratia 2013, 17, 2: 136-140

**Keywords:**  $\text{VO}_2\text{max}$  prediction, running equation, metabolic equivalent, exercise testing, cardiorespiratory fitness

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### Introduction

Maximal oxygen consumption ( $\text{VO}_2\text{max}$ ) is defined as the ability to transport and consume oxygen during exhausted work and is related to cardiorespiratory fitness<sup>1</sup>. The American College of Sports Medicine (ACSM) has published several metabolic equations for the indirect estimation of  $\text{VO}_2\text{max}$  while walking, running, and stepping as well as for leg and arm ergometers<sup>2</sup>.

In the laboratory setting, the most accurate way to assess  $\text{VO}_2\text{max}$  is undoubtedly via applying a maximal graded exercise test (GXT) performed to volitional exhaustion on a motorized treadmill or cycle ergometer while expired air is analyzed continuously by gas analyzers<sup>3,4</sup>. However, equipment costs and staff training limit direct measurement mainly to research and few clinical settings<sup>5</sup>. Thus, the need for an accurate prediction of the  $\text{VO}_2$  with the use of various equations is considered necessary. The equations can be performed according to: work information (speed, grade, work rate, step rate) or following calculations of appropriate work.

There are several exercise treadmill protocols for the prediction of  $\text{VO}_2\text{max}$ . Current evidence suggests that in order to elicit the  $\text{VO}_2\text{max}$  of apparently healthy indi-

viduals, continuous treadmill tests should generally last between 5 and 26 minutes. This is dependent on the basis that short tests are preceded and that treadmill grades do not exceed 15%<sup>6</sup>. The running equation of ACSM is only valid with steady state exercise and is designed for speeds greater than 5.0 mph ( $134 \text{ m}\cdot\text{min}^{-1}$ )<sup>2</sup>.

In the literature, the majority of studies have developed several regression models for the prediction of  $\text{VO}_2\text{max}$  based on a variety of maximal treadmill exercise tests<sup>2,7,8</sup>. Additionally, the indirect estimation of multiple equivalents (METs) in the majority of the commercially available software of exercise test units is calculated from the ACSM running equation and it is applied in many cardiovascular centers and sports medicine labs even when using interval protocols on the treadmill. The degree of error in estimating aerobic capacity in the stress test setting is not well characterized and from our knowledge there is no study examining the accuracy of the ACSM running equation using the Bruce protocol in a specific population such as athletes although it is still widely used. The introduction of ventilatory expired gas analysis into traditional stress test procedures led to the direct measurement of  $\text{VO}_2$ . Despite this, estimating than

directly measuring  $\text{VO}_2$  remains a very common clinical standard in many stress-testing laboratories assessing exercise-trained subjects for cardiovascular screening. Thus, the aim of this study was to evaluate the accuracy of the indirect  $\text{VO}_2$ max measurement using the ACSM's running equation for the Bruce protocol in athletes of different sports in comparison with the directly estimated. Additionally, a secondary goal was the prediction of  $\text{VO}_2$ max using models of regression analysis.

## Materials and Methods

### Subjects

Study participants included 55 male athletes of different sports (soccer,  $n=15$ ; basketball,  $n=13$ ; cycling,  $n=7$ ; volleyball,  $n=7$ ; body-building,  $n=4$ ; weightlifting,  $n=3$ ; wrestling,  $n=3$  and tae-kwon do,  $n=3$ ). The physical and anthropometric characteristics of the subjects are listed in Table I. All subjects had a minimum of 3 training sessions per week and they were competing at national and international level. Before the study, subjects provided informed consent for their participation. The study protocol was in agreement with the guidelines of the Ethics Committee of the Aristotle University of Thessaloniki.

### Pretesting Procedures

All subjects underwent a noninvasive cardiovascular screening, before exercise testing, in accordance with the recommended standards<sup>9</sup>. The height was measured to the nearest 0.5 cm using a stadiometer (KDS, Kyoto, Japan) and the weight to the nearest 0.1 kg on a medical-scale grade (Seca, Hamburg, Germany). All subjects were asked to avoid drinking any caffeinated and alcoholic beverages or using any ergogenic aids at least two days before the experimental session.

### $\text{VO}_2$ max direct measurements

All participants performed a maximal exercise test using a Trackmaster treadmill. For the purpose of the study the treadmill was calibrated in order to ensure the accuracy of grade and speed. Subjects exercised to exhaustion using Bruce protocol. All athletes did not use the handrails. The electrocardiogram was monitored continuously during the test (CH-2000, Cambridge Heart Co., USA). The  $\text{VO}_2$ max was measured via an ergospirometric device based on breath-by-breath gas analyzing system (Ultima Series, MedGraphics, USA). Prior to testing, a pneumotachograph was calibrated using a 3.0 L-syringe at various flow rates. Thereafter, oxygen and carbon dioxide analyzers were calibrated with known gas mixture according to the specifications of the manufacturer. The following exercise test criteria were used for the achievement of  $\text{VO}_2$ max:

1. Leveling off (plateau) of oxygen uptake with an increase of work rate<sup>10</sup>.
2. Respiratory exchange ratio ( $\text{VCO}_2/\text{VO}_2$ ) greater than 1.10<sup>11</sup>.
3. Achievement of 90% of the age-adjusted estimate of maximal heart rate<sup>12</sup>.

In addition, the following parameters were recorded from the cardiorespiratory exercise test: the duration of the test, the maximal value of  $\text{METs}_{\text{max}}$  both by the ergospirometer and the exercise testing software unit using the Bruce protocol, the maximal pulmonary ventilation ( $\text{VE}_{\text{max}}$ ), the maximal heart rate ( $\text{HR}_{\text{max}}$ ), and the respiratory exchange ratio (RER).

### $\text{VO}_2$ max indirect calculations

We hypothesized that other equations except from the ACSM's metabolic equation might be accurate for the prediction of  $\text{VO}_2$ max. Thus, overall the  $\text{VO}_2$ max was calculated based on the following metabolic calculations:

1. ACSM equation:  $\text{VO}_2\text{max} = (0.2 \cdot S) + (0.9 \cdot S \cdot G) + 3.5$  (equation A)<sup>2</sup>

S: speed; G: grade

2.  $\text{VO}_2$ max was estimated using regression models using enter (equation B) and stepwise (equation C) methods.

Additionally, using the ACSM equation, the subjects had to complete at least one minute of each stage in order to be awarded with the full estimated metabolic equivalents value.

### Statistical analyses

Statistical analyses were performed using the PASW statistics for Windows version 18 (SPSS Inc., Chicago, Illinois, USA). All data were expressed as mean values and standard deviation (SD). Age, BMI, speed, grade and exercise time were served as independent variables in multiple linear regression analysis, using both *enter* and *stepwise* methods to predict measured  $\text{VO}_2$ max. *Enter* is a method in which all predictors are forced into the model simultaneously. This method relies on good theoretical reasons for including the chosen predictors, but the experimenter makes no decision about the order in which variables entered. In the *stepwise* method, decisions about the order in which predictors are entered into the model are based on a purely mathematical criterion. The computer then searches for the predictor that best predicts the outcome variable by selecting the predictor that has the highest simple correlation with the outcome. If this predictor significantly improves the ability of the model to predict the outcome, then this predictor is retained in the model and the computer searches for a second predictor. The criterion used for selecting this second predictor is that it is the variable that has the largest semi-partial correlation with the outcome<sup>13</sup>. Changes of variables within groups were evaluated by the Student's *t*-test for paired data. For the estimation of the relationship between the measured and predicted values of  $\text{VO}_2$ max, as calculated from the three equations, Pearson correlation was used. Level of significance was set at  $p < .05$ .

## Results

Athletes' physical characteristics are reported in Table 1. The cardiorespiratory data during rest and maximal exercise test are presented in Table 2.

All the subjects ultimately completed at least one minute of the fifth stage ensuring that they reached a running

**Table 1:** Physical and anthropometric data of athletes (mean  $\pm$  SD).

	mean $\pm$ SD
Age (years)	28.3 $\pm$ 5.6
Training experience (years)	15.0 $\pm$ 10.1
Height (cm)	181.0 $\pm$ 0.1
Weight (kg)	81.1 $\pm$ 10.5
Body Mass Index (kg·m <sup>-2</sup> )	24.7 $\pm$ 2.9

SD: standard deviation.

**Table 2:** Cardiorespiratory data at rest and maximal exercise test (mean  $\pm$  SD).

	Resting	Maximal Exercise
HR (beats·min <sup>-1</sup> )	69.7 $\pm$ 7.0	183.5 $\pm$ 12.7
VO <sub>2</sub> (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	6.0 $\pm$ 2.2	46.1 $\pm$ 7.6
VE (l·min <sup>-1</sup> )	13.6 $\pm$ 4.0	120.3 $\pm$ 21.4
RER	0.85 $\pm$ 0.1	1.21 $\pm$ 0.14
METS <sup>a</sup>	1.7 $\pm$ 0.62	13.1 $\pm$ 2.2
METS <sup>b</sup>	-	17.6 $\pm$ 1.2
Time (min)	-	14.1 $\pm$ 1.3

METS<sup>a</sup>: Actually measured values of METS as calculated from the ergospirometry, METS<sup>b</sup>: Indirect estimation of METS as calculated from the CH-2000 stress test unit on Bruce protocol according to the equation METs = [(0.1 · speed m·min<sup>-1</sup>) + (1.8 · speed m·min<sup>-1</sup> · fraction grade) + 3.5 ml·kg<sup>-1</sup>·min<sup>-1</sup>] / 3.5<sup>2</sup>, SD: standard deviation.

**Table 3:** Multiple regressions analyses results for predicting VO<sub>2</sub>max (ml·kg<sup>-1</sup>·min<sup>-1</sup>).

	Enter				Stepwise			
	$\beta$	<i>t</i> -value	<i>b</i> -weight	p	$\beta$	<i>t</i> -value	<i>b</i> -weight	p
Constant	58.44	2.32	-	.024	33.97	3.10	-	.003
Age	-0.215	-2.63	-0.36	.011	-0.291	-4.12	-0.48	.000
BMI	-0.632	-1.79	-0.24	.080	-	-	-	-
Grade	-68.639	0.69	-0.07	.687	-	-	-	-
Exercise time	1.579	0.13	0.26	.132	1.481	2.08	0.24	.043

**Table 4:** Differences between measured and predicted values of VO<sub>2</sub>max (mean  $\pm$  SD).

VO <sub>2</sub> max	mean $\pm$ SD (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	df (%)	<i>p</i>
Measured VO <sub>2</sub> max	46.09 $\pm$ 7.63	-	-
A	52.83 $\pm$ 2.81*	14.6	.000
B	46.08 $\pm$ 4.87	0.02	.994
C	46.08 $\pm$ 4.63	0.02	.995

\**p*<.05 vs measured VO<sub>2</sub>max, A=ACSM's running equation<sup>2</sup>, B= Regression equation (*enter* method), C= Regression equation (*stepwise* method), SD: standard deviation.

speed at the end of the test since the running economy might be different between fast walking and running.

Multiple linear regression analysis using the *enter* method yielded the following prediction equation (B):

VO<sub>2</sub>max (ml·kg<sup>-1</sup>·min<sup>-1</sup>) = 58.443 - (0.215 · age) - (0.632 · BMI) - (68.639 · grade) + (1.579 · time) (*R* =.64, SEE = 6.11). The model was statistically significant (*p*<.05) explaining 40.7% (*R*<sup>2</sup>=.407) of the variance of measured VO<sub>2</sub>max. According to standardized  $\beta$ -weights (Table 3), age explained the largest amount of variance of VO<sub>2</sub>max.

*Stepwise* regression analysis generated the following equation (C): VO<sub>2</sub>max (ml·kg<sup>-1</sup>·min<sup>-1</sup>) = 33.971 - (0.291 · age) + (1.481 · time) (*R*=.61, SEE=6.18). Both age and exercise time, as predictor variables for VO<sub>2</sub>max, were statistically significant (*p*<.05) explaining the 36.8% (*R*<sup>2</sup>=.368) of the variance of VO<sub>2</sub>max. The unstandardized coefficients, *t* statistics, and *beta* coefficients for each independent variable are shown in Table III. There were no collinearities in both models of regression analysis since the values of the variance inflation factor (VIF) and the tolerance (1/VIF) for all the predictors in both methods were <4 and >0.2, respectively.

The differences between the values of VO<sub>2</sub>max, as they were calculated from the metabolic equations, are demonstrated in Table 4. Specifically, the calculated value of VO<sub>2</sub>max based on equation A was significantly higher compared to the actually measured VO<sub>2</sub>max by 14.6% (*p*<.05). Thus, the equation A was poorly, but nevertheless

significantly correlated with the measured VO<sub>2</sub>max, while *enter* and *stepwise* regression equations were moderately correlated with the measured VO<sub>2</sub>max. Particularly, the correlation coefficients between the actually measured and the equation-based predicted values of VO<sub>2</sub>max were 0.27 (*p*=0.043) for equation A and 0.64 (*p*<0.001) and 0.61 (*p*<0.001) for equations B and C, respectively.

## Discussion

The main finding of the study was that the ACSM's running equation overestimates the VO<sub>2</sub>max values when assessed in athletic population. On the contrary, the regression-based equations were significantly correlated with the actually measured VO<sub>2</sub>max.

Measurement of VO<sub>2</sub>max has ubiquitous outcomes in many fields of exercise science<sup>14,15</sup>. Thus, an increase of VO<sub>2</sub>max is the most important demonstration for a training

effect<sup>14</sup>. In clinical settings,  $\text{VO}_2\text{max}$  has also become the gold standard measure of cardiovascular fitness and exercise capacity<sup>16</sup>. Low cardiorespiratory fitness is a powerful and independent predictor of cardiac mortality in patients with chronic heart failure or hemodialysis patients<sup>17-19</sup>. On the contrary, an improvement of aerobic capacity following exercise training is associated with a lower risk of morbidity and mortality in these patients<sup>20,21</sup>.

In a previous study, Foster et al<sup>22</sup>, had suggested that individual characteristics may present significant impact on the estimation of  $\text{VO}_2$ . Even though the ACSM's equation was developed using highly fit male subjects or based on estimates<sup>23,24</sup>, our data suggest that its use for predicting  $\text{VO}_2\text{max}$  in a group of athletes aged 18-37 yrs participating in various sport disciplines leads to inaccurate results. Particularly, ACSM's running equation overestimates the  $\text{VO}_2\text{max}$  values by 14.6% when assessed in athletes. Also, other studies have criticized the use of the ACSM's equation in adults<sup>25</sup>. This overestimation of the ACSM's equation in predicting  $\text{VO}_2\text{max}$  is most likely due, in part to its intended use for estimation during steady state exercise, which makes it inappropriate for use with graded stress testing of any age group<sup>5,26</sup>. Furthermore, many studies have shown that trained and elite athletes exhibit better running economy than untrained and amateur or recreational athletes, respectively<sup>27</sup>. These differences in running economy and energy expenditure have been attributed to several biomechanical, metabolic and neuromuscular factors such as metabolic adaptations of the muscular cell, the ability of the muscles to store and release elastic energy and more efficient mechanics such as improved running technique, leading to less expended energy on braking forces and minimized vertical oscillation<sup>28</sup>.

Physical activity levels may be an independent predictor of  $\text{VO}_2\text{max}$  in healthy adults, following sex and age in order of significance<sup>7</sup>. In absence of specific physical activity recordings in our study and comparisons between sex, the age was found to be a significant predictor of  $\text{VO}_2\text{max}$  in both *enter* and *stepwise* regression equations. In the present study, the age factor was more effective than BMI, grade and exercise time using the *enter* method and more effective than exercise time when using *stepwise* method, while BMI, speed and grade were excluded from this model analysis. Peterson et al<sup>5</sup>, observed a 0.20 increase in  $R^2$  when adding gender, age, BMI and activity levels to a model that originally included just the "traditional" test variables of treadmill: grade and speed.

Age is considered to be an important variable when estimating  $\text{VO}_2\text{max}$  across a wide chronological range<sup>14</sup>. George et al<sup>29</sup> used a maximal graded exercise test to predict  $\text{VO}_2\text{max}$  in 18-65 aged adults and they concluded that the age seems to be more effective at predicting  $\text{VO}_2\text{max}$  than gender and BMI, but not as effective as treadmill speed and grade.

Peterson et al<sup>14</sup>, also reported that there was a lack of significance for the exercise time as a predictor of  $\text{VO}_2\text{max}$ , due to the used Pieper protocol, suggesting that

protocols utilizing large metabolic increments such as the Bruce protocol would make test duration a significant predictor of  $\text{VO}_2\text{max}$ . This observation is confirmed by our results using *stepwise* regression equation. Nevertheless, exercise time was not a strong predictor of  $\text{VO}_2\text{max}$  when using *enter* method in regression analysis.

The most common maximal GXT for the treadmill still remains the Bruce protocol that provides excellent accuracy and a standardized testing procedure for all participants<sup>7</sup>. The Bruce protocol has advantages and disadvantages and probably is not appropriate for predicting  $\text{VO}_2\text{max}$  in all populations due to the abrupt increase in exercise intensities which make it difficult for many individuals to complete<sup>28</sup>. Bruce et al<sup>7,8</sup>, studied inherent physiologic differences between healthy, sedentary and diseased populations. In each population, a unique relationship of work load with  $\text{VO}_2$  existed. On the other hand, the Bruce protocol requires all participants to advance from one stage to the next at the same speed and grade making it comparable between participants based on the same exercise intensity requirements. Also, total exercise time can be used by clinicians as a measured variable to accurately classify participants according to cardiorespiratory fitness or cardiovascular risk<sup>1</sup>.

The limitations of the study mainly concern the size of the sample since a small number of athletes from eight different sport disciplines were recruited. Thus, it would have been advantageous to have included a randomly matched cohort of athletes from many different sports in order to quantify the  $\text{VO}_2\text{max}$  discrepancy under the also known limitation of the aggressive nature in workload adjustment of the Bruce protocol. Furthermore, the training characteristics might differ between the athletes' sport clubs in terms of frequency and intensity of the training load even in the same sport.

## Conclusions

Our results indicated that the widely used ACSM's running equation performing the Bruce protocol in many sport centers is not accurately predicting  $\text{VO}_2\text{max}$  in athletes aged 18 - 37 years. Thus, it is verified that direct measurement of  $\text{VO}_2\text{max}$  in athletes should be preferred instead. Cardiopulmonary exercise testing is the only way to directly measure  $\text{VO}_2$ , but despite this, the estimation of exercise capacity based on equations will undoubtedly continue mainly due to cost effectiveness issues. In case of indirect estimation of maximal aerobic capacity, regression models in specific populations of different age and physical fitness with standard treadmill velocities and grades would be most efficient in predicting  $\text{VO}_2\text{max}$ . Further studies are encouraged to develop and examine precise regression models that accurately estimate  $\text{VO}_2\text{max}$ .

## Conflicts of interest

None declared.

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