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RESEARCH ARTICLE

Investigating the validity of allometrically designed equations to estimate VO_2max in Iranian boys

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ABSTRACT

Background: Cardiac respiratory system plays an important role in individuals' health, promotion of patients' life quality, and professional athletes' performance. It is of great importance to measure it for exchange of inhaled gases during sports stress tests as an efficient method to study the physiological efficacy of cardiac respiratory system and understand the active skeletal muscle metabolism in work measurement. Regarding the problems of measuring inhaled gases in sports maximal tests, using safe and simple methods with good validity in estimating the individuals' cardiac respiratory preparedness becomes appropriate. **Aims and Objectives:** In this research, we aim to evaluate individual's aerobic power with allometric equations through a simple mathematical formula. **Materials and Methods:** A total of 72 healthy youth boys with mean age (13.95 ± 1.84) years and weight (51.64 ± 13.15 kg) were divided into two groups of normal maturity (33 person) and non-normal (39 person) and participated in the maximal protocol of aerobics voluntarily. The practical capacity was measured directly by analyzer gas. Then, using regression analysis and harmonic graph of Bland Altman, we obtained the relationship between VO_2max from the standard method (direct measurement) and estimated (design allometric equations). **Results:** Iranian-specific allometric equations ($VO_2max = 0.15 \times \text{lean body mass}^{0.8}$, $R = 0.73$, SEE = 0.57) and ($VO_2max = 0.97 \times \text{body surface area}^{1.89}$, $R = 0.72$, SEE = 0.58) were designed with greater validity and neutrality of maturity. **Conclusions:** We can with use of this allometric equations, the amount of youth boys' aerobic power, preparation and assessed without any sports test.

KEY WORDS: Maturity; Allometric Equations; VO_2max; Boys

INTRODUCTION

In recent years, there has been great attention to measure physiological factors using anthropometry factors. Some researchers investigated the relationship between weight and maximum consumed oxygen and proposed some equations to calculate VO_2max based on weight and allometry equations.[1]

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Cardiorespiratory preparation is a physical preparation factor playing a role in long-term activity performance. In these activities, aerobic path provides greater contribution of the required energy. The maximum energy consumed is a suitable criterion to measure capacity and ability of cardiorespiratory system.[2] Theoretically, VO_2max is a point where oxygen cost of active myofibrils under certain work reaches the intracellular physiometabolic leveling in establishing balance between oxygen volume required to oxidation metabolism and VO_2 consumed in mitochondrial chemical reactions so that increasing work intensity does not raise consumption oxygen of active myofibrils.[3-5]

Scientific evidence confirms precise measurement of consumed oxygen during maximal aerobic sports test which is dependent on individual's maximal effort, and it is possible for individual not to participate in such sports protocol eagerly and show their great ability or some patients with cardiovascular and respiratory failures, hypertension, renal failure, and diabetes experiencing specific limitation are not safe to choose and execute increasing maximal tests and possibly suffer damages.[6]

To evaluate the maximum consumption of oxygen, there are two methods of direct (laboratory) and indirect (field). Using devices specific for direct evaluating maximum oxygen consumed is not possible due to expensive devices, inability to displace the devices, and unfamiliarity of instructors to work with them. Therefore, researchers have set out to develop other methods to facilitate the evaluation of performance in different body organs and transfer the evaluation of athletes' performance from laboratory to sports fields. One of these methods is using mathematical equations and their applications in body organs. Based on this, researchers investigate physiological indexes through allometry equations. Allometry is a suitable way to express the relationship between variable (physiological, anatomical, or thermal) with a unit of body size (weight) through mathematical relationship.[7] The allometry analysis or calibration is explained with this equation ($Y = aM^b$) in which y is a variable related to weight, b is the allometry power, and a is constant. The power b is the main factor because it represents the intensity and relation direction with body weight. If Y increases directly with body weight, b = 1, and if body mass does not have any effect on y, b = 0, the variable is independent of weight. If b is >1, it means that the increase of variable is greater than weight increase. If Y decreases for body weight increase, b becomes negative.[8-10]

Therefore, access to physiological efficient index without any need of maximal tests and with consideration of anthropometric intervention factors which can show valid and exact evaluation of cardiovascular system performance becomes of great importance. In this research, we tried to evaluate the validity of designed allometry equations to estimate the VO_2max for Iranian teen boys using direct method of assessing inhaled gases to design the allometry equations for Iranian boys and provide the optimal allometry formula in estimating VO_2max in this age range.

MATERIALS AND METHODS

This applied research is of analytical type of correlation. First, four schools of Hamedan city were randomly chosen and 72 11–17-year-old boys were participated in the research with written consent under the supervision of the Ethics Committee of Medical Science University of Hamedan. The individuals' parents were first became familiarized with the aim and procedure of the project. The Physical Activity Readiness Questionnaire health questionnaire of medical sports association of America was filled, and anthropometric characteristics and body mass index (BMI) percentage[11,12] using centers for disease control and prevention and fat content of sum of two subcutaneous layers of brachial triceps and subscapular of boys were obtained according to Slatter's equations.[13,14]

Ergometry intensity of each individual was recorded in terms of %heart rate (HR) reserve during implementation of graded exercise test (GXT) from Karvonen's formula.[15] Rating of perceived exertion was recorded, too.[16] To determine lean body mass (LBM), James' method was used and individuals' BMI was calculated.[17,18] Body surface area (BSA) was obtained with Haycock formula, and weight and height were obtained from the formula.[19] To assess the maturity, Mirwald's maturity offset formula was used to determine the maturity type of individuals.[20] Age, height, weight and sitting height, and foot length were measured and inserted in the formula which gave 33 individuals in normal maturity and 39 in non-normal maturity.

GXT protocol was implemented on treadmill according to BABA's 1996 method,[21] for 10 min, as designed for children, and increased in terms of exercise time, speed, and slope in which the individual continued to run beyond his lactate threshold, on the treadmill equipped with gas analyzer system (manufactured in Germany). The test was completed when (a) respiratory exchange ratio (RER) gain was >1.1 according to changes of VCO_2/VO_2 on screen, (b) the HR of >185, and (c) the announcement of exhaustive case.[22,23] In this protocol, for the first four stages of ergometry, 15 s and in the next stages 5–7 min were taken and the whole protocol lasted 10 min.[21,24] To determine VO_2max in the direct method of analyzer gas, the mean of every 10 s of measuring VO_2 and VCO_2 was recorded and physiological information in final 20 s of ergometry was used to determine the practical capacity.

The individual's HR was measured in each second by telemetry polar model T_{34} manufactured in Germany to the end of GXT protocol and store. The estimation of aerobic capacity using allometry equations of $y = am^b$ was determined.[7] All cardiorespiratory variables were taken after 2–3 h from light lunch and avoidance of pastries and coffee using light shoe and dress at 4–6 pm on treadmill. GXT test in physiology laboratory of Bu-Ali Sina University was carried out at 19–21° centigrade and relative humidity of 39–43 at 1860 m sea level.

To do statistical analysis, the normality of distribution of VO_2max values of individuals was specified with Shapiro–Wilk in normal maturity and non-normal maturity. Then, using the regression, the effect of normal and non-normal maturity on designed allometry equations was determined using scales of anthropometrical characteristics. The information of descriptive statistics was based on mean ± standard deviation. The significance level $P \leq 0.05$ was taken for statistical hypotheses.

RESULTS

Using the off maturity formula of Mirwald, 72 11–17-year-old boys were divided into 33 of normal maturity and 39 of non-normal maturity. Physiological and anthropometrical characteristics of the healthy boys are presented in Table 1. Regarding the mean sports, HR (199.8 ± 4.6) in minutes, percentage of reserved HR (94.68 ± 3.81) beats per minute, work pressure perceived (18.6 ± 0.9), and RER (VCO_2/VO_2: 1.26 ± 0.08), it can be said that the individuals have done maximal physical effort in the implementation of the protocol GXT in BABA method and the mean value of relative peak oxygen consumption (37.12 ± 10 $mil.min^{-1}.kg^{-1}$) could indicate the actual maximum cardiovascular performance and can be used to assess boys' aerobic capacity in ergometry.

To design allometric equations for Iranian boys, regression analysis and logarithmic conversion of equation $y=ax^b$ to Log (y) = Log (a) +bLog (x) were used. The equations obtained are seen in Table 2. Regarding Table 3 and Figure 1, we can say that allometric equations are valid enough to assess the efficiency of boys' respiratory cardiac system (R = 0.65–0.73, P = 0.000, SEE = 0.57–0.63).

Table 1: Anthropometric and physiological characteristics during increasing ergometry in adolescent boy

Variables	Mean	SD	SEM
Weight (kg)	51.64	13.15	1.55
Age (year)	13.95	1.8	0.21
$RPE_{(20)}$	18.6	0.9	0.1
% Body fat	20.7	10.3	1.2
LBM (kg)	43.31	9.3	1.1
BSA (m^2)	1.51	0.25	0.03
% BMI	40.7	2.55	3
$HR_{exercise}$ (bp/min)	199.8	4.6	0.55
% HRR	94.7	3.8	0.45
RER: VCO_2/VO_2	1.26	0.08	0.009
VO_2max (1 min^{-1})	1.96	0.83	0.1
VO_2max (mil min^{-1} kg^{-1})	37.12	10	1.18

SD: Standard deviation, SEM: Standard error of mean, RPE: Rating of perceived exertion, BMI: Body mass index, HR: Heart rate, HRR: Heart rate reserve, RER: Respiratory exchange ratio, LBM: Lean body mass, BSA: Body surface area

As seen in Figure 2 and the harmonic Bland-Altman graph, there is a good agreement between direct method of gas analyzer and allometry equation to assess individuals' aerobic capacity and the results are similar. Using allometric equation $VO_2max = 0.15 \times LBM^{0.80}$ with correlation of R = 0.73 with direct method of gas analyzer, we can estimate the cardiac respiratory preparation level of boys with a simple calculation. As seen in Table 4, there is a significant relationship between VO_2max from designed allometric equations and direct method in both normal and non-normal maturity groups, and the maturity does not have any effect on VO_2max from three allometric equations. Researchers can use these allometric equations in maturity age of boys, while it is certain that prematurity and late maturity do not affect results.

DISCUSSION

In the present research, to investigate the cardiac respiratory preparation level of boys without the need to modern equipment and exhaustive tests, allometric equations were used. With the intervention of body weight, BSA, and LBM, new allometry equations were presented for Iranian boys to obtain the cardiac respiratory preparation level

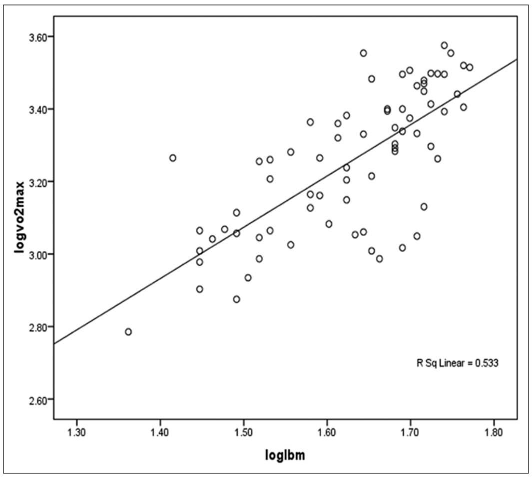

Figure 1: The dispersion graph of relationship between lean body mass and VO_2 and allometric optimal equation in boys

Table 2: Design of allometric equations to determine cardiac respiratory preparation level of boys

Characteristic of anthropometric	*P*	SEE	R^2	R	Allometric equations
Weight (kg)	0	0.15	0.43	0.66	$VO_2max=0.37\times m^{0.41}$
BSA (m^2)	0	0.14	0.52	0.72	$VO_2max=0.97\times BSA^{1.89}$
LBM (kg)	0	0.13	0.53	0.73	$VO_2max=0.15\times LBM^{0.80}$

VO_2max is absolute and the units of weight and LBM are kg and BSA m^2. LBM: Lean body mass, BSA: Body surface area of boys *in vitro* with a simple method and good validity (R = 0.65–0.73). Regarding the allometric equations, it can be said that parallel with increase of body weight in growth process, cardiovascular, respiratory, and muscular systems grow but not in the same rate. It is evident that growth of body muscles is greater than that of heart and lung tissues and the lung and heart system capacity must increase during the growth period to supply oxygen to each weight kilogram, and this increases the oxygen delivery from lungs to skeletal muscles, blood volume, and its elements.

Due to the dependence of VO_2max on the performance of these three systems, the capacity increase increases organism in consuming oxygen during maximal sports activities and increases the practical capacity of individual. As noted, weight plays a great role in aerobics capacity and weight and mass are important in allometric equations, and design of these equations can estimate the cardiac respiratory preparation of individuals accurately. As seen in Table 3, the greatest correlation in allometric equations belongs to the one with LBM parameter ($VO_2max = 0.15 \times LBM^{0.80}$).

Table 3: Correlation between VO_2max from designed allometric equations and gas analyzer direct method

Allometric equation	R	R^2	SEE	*P*
VO_2 max=0.37×$m^{0.41}$	0.65	0.42	0.63	0
VO_2 max=0.97×$BSA^{1.89}$	0.72	0.51	0.58	0
VO_2 max=0.15×$LBM^{0.80}$	0.73	0.53	0.57	0

LBM: Lean body mass, BSA: Body surface area

There has not been any study about allometric equations in Iran, for assessment of cardiac respiratory preparation level in direct method to compare the results. The nearest study is the validity of allometry equations for measuring VO_2max in 12–16-year-old girl students of Mashhad city, with correlation R = 0.72 in Bruce's estimated test and equation $VO_2max = 1.94 \times m^{0.75}$.[25] Furthermore, in Erfani's study in 2012 on youth girls, the relationship of two Beunen and Milano' selected allometry equations with Bruce's test and indirect method was reported R = −0.70 and R = 0.22 which were lower than this study (R = 0.65–0.73), and this is due to the use of indirect method of assessing cardiacrespiratory preparation with allometric estimation formulae for non-Iranian individuals.[26]

Numerous studies have attempted to estimate physiological variables with anthropometric variables such as weight or height using allometric equations. Nhantumbo in 2012 studied the youths' aerobics performance using allometry equation and one-mile walking test in a rural area of Mozambique and proposed different allometry coefficients to assess girls' and boys' aerobics preparation.[27]

In another research, Chamari *et al*., in 2005, measured professional and young soccer athletes' aerobics power using allometry scale. The results showed that maximal and submaximal VO_2 increases proportion with allometry powers of 0.72 and 0.60.[28] Weibel *et al*. studied 34 species of mammals at the range of 7 g–500 kg concluding that allometry coefficient to assess VO_2max was 0.872 for all species.[8] Eisenmann and Pivarnic studied the relationship between VO_2max of young marathon running men and

Table 4: Correlation between VO_2max from designed allometric equations and direct method in normal and non-normal maturity groups of boys

Allometric equations designed (L min^{-1})	Total		Normal maturity			Abnormal maturity		
	R	Significance	R	Significance	SEE	R	Significance	SEE
VO_2max=0.15.$LBM^{0.80}$	0.73	0	0.74	0	0.56	0.69	0	0.61
VO_2max=0.97.$BSA^{1.89}$	0.72	0	0.73	0	0.64	0.68	0	0.55
VO_2max=0.37.$LBM^{0.41}$	0.65	0	0.64	0	0.71	0.63	0	0.59

LBM: Lean body mass, BSA: Body surface area

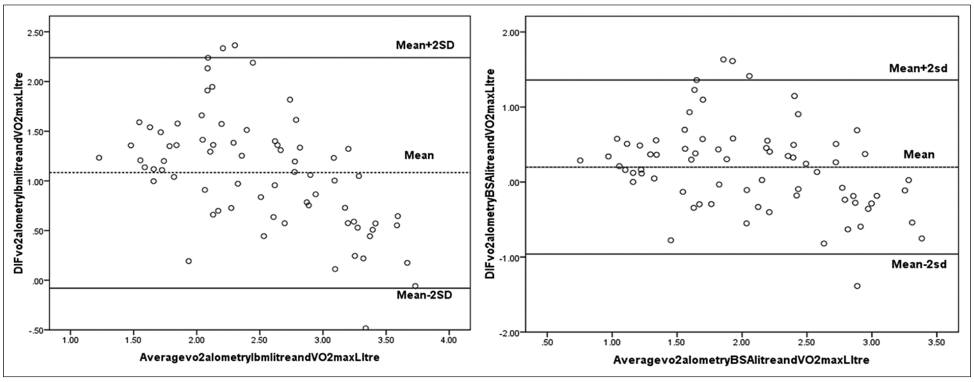

Figure 2: (a and b) Harmonic Bland–Altman graph to assess aerobics capacity in the direct method and gas analyzer

women from allometry scale. In this research, the value of allometry coefficient in boys and girls was 0.81 and 0.61, respectively.[29] Beunen *et al*. studied 73 8–16-year-old non-athletic boys longitudinally showing that the interpersonal allometry coefficient in most age groups was 0.75 as obtained with the direct method of respiratory gases.[9]

CONCLUSION

The results showed that VO_2max is a suitable variable to assess respiratory-cardiac preparation which can be obtained by allometric estimation equations. We could estimate the assessment index of youth boys' cardiac respiratory system without complex modern equipment at acceptable validity of $R = 0.65–0.73$, the most important of which was $VO_2max = 0.15 \times LBM^{0.80}$ at correlation $R = 0.73$. The most important point was that maturity did not have any effect on allometry equations which could help the researchers to estimate the efficacy of cardiac respiratory system before sport program intervention.

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