HEART RATE VARIABILITY AND BODY COMPOSITION AS VO_{2MAX} DETERMINANTS

VARIABILIDADE DA FREQUÊNCIA CARDÍACA E COMPOSIÇÃO CORPORAL COMO DETERMINANTES DO $VO_{2\text{MÁX}}$

VARIABILIDAD DE LA FRECUENCIA CARDIACA Y COMPOSICIÓN CORPORAL COMO DETERMINANTES DEL VO_{2MAX}

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ABSTRACT

Introduction: The maximum oxygen consumption (VO_{2max}) is the gold standard in the cardiorespiratory endurance assessment. Objective: This study aimed to develop a mathematical model that contains variables to determine the VO_{2max} of sedentary people. Methods: Twenty participants (10 men and 10 women) with a mean age of 19.8±1.77 years were included. For each participant, body composition (percentage of fat and muscle), heart rate variability (HRV) at rest (supine and standing), and VO_{2max} were evaluated through an indirect test on a cycloergometer. A multivariate linear regression model was developed from the data obtained, and the model assumptions were verified. Results: Using the data obtained, including percentage of fat (F), percentage of muscle (M), percentage of power at very low frequency (VLF), α-value of the detrended fluctuation analysis (DFAα1), heart rate (HR) in the resting standing position, and age of the participants, a model was established for men, which was expressed as VO_{2max} = 4.216 + (Age*0.153) + (F*0.110) - (M*0.053) - (VLF*0.649) - (DFAα1*2.441) - (HR*0.014), with $R^2 = 0.965$ and standard error = 0.146 L/min. For women, the model was expressed as VO_{2max} = 1.947 - (Age*0.047) + (F*0.024) + (M*0.054) + (VLF*1.949) - (DFAα1*0.424) - (HR*0.019), with $R^2 = 0.987$ and standard error = 0.077 L/min. Conclusion: The obtained model demonstrated the influence exerted by body composition, the autonomic nervous system, and age in the prediction of $VO_{2max.}$

Keywords: body composition; autonomic nervous system; oxygen consumption; linear models.

RESUMO

*Introdução: O consumo máximo de oxigênio ($VO_{2\text{máx}}$) é o padrão-ouro na avaliação da resistência cardiorrespiratória. Objetivo: Este estudo visou desenvolver um modelo matemático com as variáveis usadas na determinação do $VO_{2\text{máx}}$ em indivíduos sedentários. Método: Vinte indivíduos (10 homens e 10 mulheres) com média de idade 19,8±1,77 anos foram incluídos. Para cada participante, foram avaliados composição corporal (percentual de gordura e de músculo), variabilidade da frequência cardíaca (VFC) em repouso (em decúbito dorsal e em pé) e o $VO_{2\text{máx}}$, empregando-se o protocolo em cicloergômetro, método indireto. A partir dos dados obtidos, desenvolveu-se um modelo de regressão linear multivariado e os pressupostos do modelo foram verificados. Resultados: Usando os dados obtidos, incluindo percentual de gordura (G), porcentagem de músculos (M), porcentagem de energia em frequência muito baixa (FMB), valor de a da análise de flutuação sem tendências (DFAα1), frequência cardíaca (FC) em repouso na posição em pé e a idade dos participantes, estabeleceu-se um modelo para homens, expresso como: $VO_{2\text{máx}}$ = 4,216 + (Idade*0,153) + (G*0,110) - (M*0,053) - (FMB0,649*) - (DFAα1*2,441) - (FC*0,014) com R^2 = 0,965 e erro padrão = 0,146 L/min. Para as mulheres, o modelo foi expresso como: $VO_{2\text{máx}}$ = 1,947 - (Idade*0,047) + (G*0,024) + (M*0,054) + (FMB*1,949) - (DFAα1*0,424) - (FC*0,019) com R^2 = 0,987 e erro padrão de 0,077 L/min. Conclusão: O modelo desenvolvido demonstrou a influência exercida pela composição corporal, pelo sistema nervoso autônomo e pela idade na predição do $VO_{2\text{máx}}$.*

Descritores: *composição corporal; sistema nervoso autônomo; consumo de oxigênio; modelos lineares.*

RESUMEN

*Introducción: El consumo máximo de oxígeno (VO_{2max}) es el patrón áureo en la evaluación de la resistencia cardiorrespiratoria. Objetivo: Este estudio tuvo como objetivo desarrollar un modelo matemático con las variables que participan en la determinación del VO_{2max} en individuos sedentarios. Método: Veinte sujetos (10 hombres y 10 mujeres) con edad promedio de 19,8 ± 1,77 años se han incluido. Para cada participante, se evaluó la composición corporal (porcentaje de grasa y músculo), variabilidad de la frecuencia cardiaca (VFC) en reposo (decúbito supino y en pie) y VO_{2max} mediante un test indirecto en cicloergómetro. A partir de los datos obtenidos se desarrolló un modelo de regresión lineal multivariado y se comprobaron los supuestos del modelo. Resultados: Usando los datos obtenidos, incluyendo porcentaje de grasa (G), porcentaje de músculos (M), porcentaje de energía en frecuencia muy baja (FMB), valor de a del análisis de fluctuación sin tendencias (DFAα1), frecuencia cardiaca (FC) en reposo en la posición en pie y la edad de los participantes, se estableció un modelo para hombres que se expresa como VO_{2max} = 4,216 + (Edad*0,153) + (G*0,110) - (M*0,053) - (FMB*0,649) - (DFAα1*2,441) - (FC*0,014) con R^2 = 0,965 y error típico = 0,146 L/min. Para las mujeres el modelo se expresó como VO_{2max} = 1,947 - (Edad*0,047) + (G*0,024) + (M*0,054) + (FMB*1,949) - (DFAα1*0,424) - (FC*0,019) con R^2 = 0,987 y error típico de 0,077 L/min. Conclusión: El modelo desarrollado demostró la influencia ejercida por la composición corporal, el sistema nervioso autónomo y la edad en la predicción del VO_{2max}.*

Descriptores: *composición corporal; sistema nervioso autónomo; consumo de oxígeno; modelos lineales.*

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INTRODUCTION

For the determination of cardiorespiratory endurance, the gold standard has been maximum oxygen consumption (VO_{2max}), which corresponds to the maximum transport capacity and use of oxygen during high intensity exercise[1]. From a physiological point of view, VO_{2max} is determined by central conditions associated with the transport of atmospheric oxygen to the muscles (lung function, cardiac output, and blood volume), while the use of oxygen is determined peripherally by conditions such as muscular capillarity, diffusion capacity, and mitochondrial activity[2]. In addition, there is a significant genetic component of VO_{2max}[3].

From a central viewpoint, one of the main factors for the determination of VO_{2max} is cardiac output, which corresponds to the volume of blood ejected by the heart in one minute. This value can be increased by as much as six times in the case of high-intensity exercise in well-trained athletes[4]. Cardiac output exhibits rapid variation due to the action of the autonomic nervous system, and it can be greatly increased in the ventricular cavities, which has been observed in athletes[5].

To evaluate the action of the autonomic nervous system, Heart Rate Variability (HRV) has been used, which analyzes a time series (TS) of the variation in the duration of a beat with respect to the next. In addition, due to the use of digital signal processing systems, this TS can be analyzed by characteristics of its spectrum and by nonlinear methods[6]. Similarly, both HRV and heart rate (HR) at rest account for cardiovascular adaptations such as left ventricular hypertrophy and increased parasympathetic tone[7].

From a peripheral point of view, conditions exist at the muscular level itself that are related to VO_{2max} such as muscular capillarity and mitochondrial density[8]. This finding demonstrates the directly proportional relationship between VO_{2max} and muscle mass and an inversely proportional relationship to percentage of fat[9].

Given the significant role that VO_{2max} plays in predicting cardio-respiratory fitness and its limitations for direct evaluation in physically inactive people, the aim of this study is to contribute to the development of a mathematical model that determines the variables that are directly involved in predicting the VO_{2max} in sedentary people.

MATERIALS AND METHODS

After approval of the project by the ethics committee of the University of La Sabana, 20 volunteer subjects (10 men and 10 women) with a mean age of 19.8 ±1.77 were selected for convenience. The inclusion criteria consisted of a sedentary lifestyle, no history of cardiovascular disease, no musculoskeletal pathological conditions, and not taking any medications that affect the response of the autonomic nervous system. All participants signed an informed consent form. In addition, a specialist with the capacity to evaluate obtained biological signals was consulted, and those subjects whose signals were excessively contaminated and were impossible to clean were excluded. Participants were evaluated in the morning between 7 and 9 a.m. and were asked about quality of sleep the night before and the use of caffeine, alcohol, or cigarettes during the previous 24 hours; inclusion decisions were postponed for those who did not meet the established criteria.

Acquisition variables

Body composition was evaluated anthropometrically, and the measures included body weight (kg), height (cm) and six skin folds (triceps, suprailiac, subscapular, abdominal, thigh, and leg). To calculate the fat percentage, the Yuhasz[10] formula was used, and for muscle mass calculations, the Doupe et al.[11] formula was used. The perimeters, diameters, and folds were obtained by a standardized protocol applied by a certified expert of the International Society for the Advancement of Kinanthropometry (ISAK). In addition, waist circumference was measured midway between the seventh rib and the iliac spine[12]. The instruments used included a Harpenden® caliper, a Stanley® metric tape, a Berfer® pachymeter, a Faga® stadiometer, and an Omron® scale. HR was measured in subjects in the physiology laboratory of the Biomedical Campus of the University of La Sabana at an average temperature of 20°C without any influence from drafts, noise or lights, which can alter the response of the autonomic nervous system. For these measurements, a Polar RS800CX heart rate monitor was used for 10 minutes (five minutes in the supine position and five minutes in the standing position), which is enough time for signal analysis[13]. After warming up for five minutes, and after having established 75% of the maximum theoretical HR by the Tanaka et al.[14] formula the subjects performed an incremental test on the cycloergometer until they reached the established HR. At that point, the power was recorded, and this value was used to estimate VO_{2max} with the Astrand nomogram of the cycloergometer[15]. The general characteristics of the participants are described in Table 1.

Signal analysis

Analysis of HRV was performed using Kubios HRV software (University of Kuopio)[16]. The pre-processing phase of the HR signal consisted of removal of artifacts (RR interval variations greater than 0.45 sec with respect to the average) and filtering of the signal using a Smoothness priors high-pass filter with a Lambda of 500 and a cutoff frequency of 0.035 Hz[17]. From the noise-free tachogram obtained, the ST segment of the HRV was analyzed in the time domain, and the relevant parameters were calculated (average HR, standard deviation of the heart rate (STDHR), root mean square of the differences between successive RR intervals (RMSSD), and the number of successive RRs that differ by more than 50 ms divided by the total RR intervals (pNN50).

For analysis of the frequency domain, a Fast Fourier transform (FFT) and autoregressive (AR) analysis were used. To obtain an ST segment with equidistant samples, piecewise cubic spline interpolation was used at a rate of 4 Hz; then an FFT was applied to obtain the power spectral density (PSD) and power parameters (RMS and total percentage values) in the very low frequency (VLF, 0-0.04 Hz), low frequency (LF, 0.04 – 0.15 Hz), and high frequency (HF, 0.15 – 0.4 Hz) ranges. Subsequently, a 16th order AR model was implemented to obtain these same values in the VLF, LF, and HF ranges. For the nonlinear analysis, a Poincaré diagram was used to establish the SD1 and SD2 parameters, and detrended fluctuation analysis (DFA) was used to establish α1 and α2. The overall results of the HRV analysis are shown in Table 2.

Table 1. General characteristics of body composition and oxygen consumption.

	Men		Women		Difference
	$\overline{X}$	SD	$\overline{X}$	SD	
Age	19.50	1.08	20.10	2.28	p = 0.47
Weight (kg)	68.22	8.25	57.27	8.08	p < 0.01*
Height (cm)	177.90	8.62	161.10	3.63	p < 0.00*
% Fat	13.17	4.19	31.67	10.00	p < 0.00*
% Muscle	51.28	3.67	37.30	6.29	p < 0.00*
Waist circumference (cm)	83.70	7.87	78.74	6.18	p = 0.14
Power (W)	112.01	17.97	71.10	15.24	p < 0.00*
HR Test (beats/min)	147.85	4.57	145.30	4.30	p = 0.22
% max HR	76.07	2.24	74.94	2.04	p = 0.25
VO_{2max} (L/m)	2.57	0.45	2.23	0.39	p = 0.08
VO_{2max} (ml/kg/min)	37.88	6.09	39.70	9.27	p = 0.61

SD: Standard Deviation, HR: Heart rate, VO_{2max}: Maximum oxygen consumption, *Statistically significant difference.

Table 2. Variables used for analysis of Heart Rate Variability. Values in parentheses correspond to the standard deviation.

			Men	Women	Difference
Time domain	HR	Supine	69.2 ±(8.9)	76.8 ±(8.4)	p = 0.04*
		Standing	89.4 ±(9.0)	92.7 ±(5.6)	p = 0.40
	STDHR	Supine	6.4 ±(1.5)	6.8 ±(1.9)	p = 1.00
		Standing	7.2 ±(1.9)	7.2 ±(13)	p = 0.63
	RMSSD	Supine	89.5 ±(54.2)	82.9 ±(25.5)	p = 0.18
		Standing	21.9 ±(11.6)	22.8 ±(7.7)	p = 0.82
	pNN50	Supine	48.6 ±(22.5)	35.6 ±(18.1)	p = 0.17
		Standing	4.9 ±(4.9)	5.0 ±(5.6)	p = 0.96
Frequency Domain	%VLF	Supine	29.6 ±(15.9)	32.5 ±(14.5)	p = 0.68
		Standing	50.0 ±(21.8)	46.6 ±(18.3)	p = 0.71
	%LF	Supine	23.5 ±(7.0)	26.6 ±(8.9)	p = 0.41
		Standing	40.7 ±(18.1)	42.2 ±(16.8)	p = 0.85
	%HF	Supine	46.7 ±(17.9)	40.7 ±(18.6)	p = 0.47
		Standing	9.3 ±(6.1)	11.2 ±(4.2)	p = 0.42
	LF/HF	Supine	0.67 ±(0.59)	0.94 ±(0.82)	p = 0.41
		Standing	6.0 ±(3.6)	4.1 ±(2.0)	p = 0.16
Nonlinear analysis	SD1	Supine	63.4 ±(38.4)	44.6 ±(18.0)	p = 0.88
		Standing	16.6 ±(7.4)	16.1 ±(5.5)	p = 0.19
	SD2	Supine	100.2 ±(33.7)	88.2 ±(22.9)	p = 0.33
		Standing	78.8 ±(23.3)	70.6 ±(11.7)	p = 0.38
	DFAα1	Supine	0.78 ±(0.25)	0.78 ±(0.22)	p = 0.31
		Standing	1.56 ±(0.18)	1.49 ±(0.13)	p = 0.34
	DFAα2	Supine	0.89 ±(0.23)	0.23 ±(0.17)	p = 0.45
		Standing	0.90 ±(0.21)	0.90 ±(0.19)	p = 0.94

HR: Heart Rate; STDHR: Standard deviation of heart rate values; RMSSD: Root mean square of the differences between successive RR intervals; pNN50: Number of successive RR intervals that differ by more than 50 ms divided by total RR intervals; VLF: Very Low Frequency; LF: Low Frequency; HF: High Frequency; SD1 and SD2: Standard deviations of the Poincaré graph; DFA: Detrended fluctuation analysis.

Statistical analysis

Statistical analyses were performed with IBM SPSS Statistics 21. Initially, the means of the general parameters (age, weight, height, body composition, $VO_{2max,}$ and HR) of men and women were statistically compared with a two-tailed t-test for unpaired data. The level of statistical significance was set at a *p* value ≤ 0.05. Next, the Pearson correlation coefficients (*r*) were calculated between VO_{2max} and each of the variables including body composition, age, and HRV. An association was established according to the *r* value (no correlation r = 0.0, weak r = 0.1, medium r = 0.5, significant r = 0.75, very strong r = 0.9, and perfect r = 1) for further ordering using the association value[18]. From this ordering, the best predictors of the dependent variable (VO_{2max}) in men and women were recorded and used to implement a multivariate linear regression model, according to equation 1 below. In the development of this model, simple linear regression and stepwise regressions were performed to discriminate each of the predictors and eliminate collinearity.

Equation 1:

$$\boxed{VO_{2max} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_K X_K + \beta 1X1 + \varepsilon}$$

Where VO_{2max} is the value estimated by the Astrand nomogram, X_1, X_2… X_k are the independent variables, B_0 is the initial condition, β_1, β_2... β_k correspond to the coefficients of each of the variables, and ε is the residual or unpredictable value.

To determine the validity of the model, compliance with the assumptions was evaluated independently, including Homoscedasticity, (standardized residual error values vs. standardized predictions), Normality (behavior of probabilities), Non-collinearity (inflation factors of the variance), Linearity (correlations between independent variables and the dependent variable), and Independence (Durbin Watson model)[19].

RESULTS

The independent variables that showed a stronger association with the dependent variable (VO_{2max}) for men were age, HR at rest in a supine position, and DFAα1 in the nonlinear analysis. For women, the variables included percentage of muscle mass, percentage of fat, percentage of VLF in a supine position analyzed by the AR method, and HR value at rest with patient in a standing position (Table 3).

The model output showed an R^2 of 0.965 for men with a standard error of estimation of VO_{2max} of 0.146 L/min, while for women, the R^2 was 0.987 with a standard error of estimation of VO_{2max} of 0.077 L/min. The ANOVA for both men and women showed a linear relationship between the dependent variable and the independent variables, which was significant in men (p = 0.027) and women (p = 0.007). The Durbin Watson test for independence produced a value of 3.209 for men and 2.036 for women. The scatterplots of standardized predictions and standardized residuals (Figure 1A and 1B) did not show any pattern of association, which is consistent with homoscedasticity, while the normal probability graph (Figure 1C and 1D) showed a trend of aligned residues along the diagonal of the graph associated with normality.

Inflation factors of the variance in the model for men ranged from 1.494 to 5.676 and were higher for the DFAα1 variable. In the case of women, the values ranged from 1.493 to 3.145, and the percentage of muscle mass variable was higher.

Finally, the equation obtained for the prediction of VO_{2max} in men was:

Equation 2:

$$\boxed{\begin{aligned} VO_{2max} = {} & 4.216 + (age * 0.153) + (\%\,Fat * 0.110) - (\%\,Muscle * 0.053) \\ & - (\%\,VLF * 0.649) - DFA\alpha 1 * 2.441) - (Standing\ HR * 0.014) \end{aligned}}$$

Table 3. Correlation between the dependent variable (maximum oxygen consumption) and the independent variables used to develop the model.

		Age	% Fat	% Muscle	%VLF	DFAα1	Supine HR
Men n = 10	Correlation	0.423	0.162	0.076	-0.160	-0.362	-0.527
	p - value	0.112	0.328	0.417	0.330	0.152	0.059
Women n = 10	Correlation	0.212	-0.315	0.668	0.641	0.466	-0.723
	p - value	0.278	0.188	0.017*	0.023*	0.087	0.009*
All n = 20	Correlation	0.202	-0.465	0.609	0.206	0.136	-0.682
	p - value	0.394	0.039*	0.004*	0.384	0.569	0.009*

*Statistically significant difference.

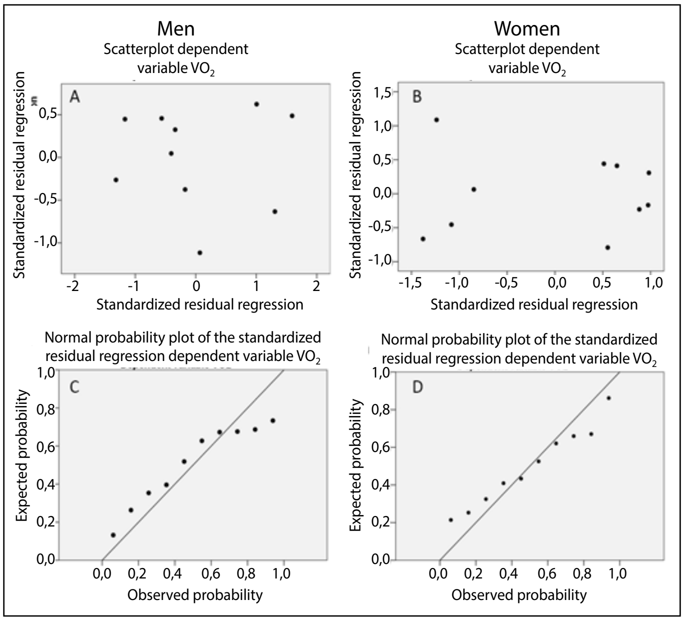

Figura 1. Figure A and B represent scatterplots of the residuals, while Figures C and D represent the probability of the residuals.

The equation for women was:

Equation 3:

$$VO_{2max} = 1.947 + (age * 0.047) + (\%\ Fat * 0.024) - (\%\ Muscle * 0.054) + (\%\ VLF * 1.949) - DFA\alpha 1 * 0.424) - (Standing\ HR * 0.019)$$

The results for the coefficients, standard error, significance, and inflation factors of the variance for men and women are shown in Table 4.

The results of the predicted values and actual values for each of the cases in men and women are shown in Table 5 and Figure 2.

Table 4. Characteristics of the constants developed for the model.

		Nonstandardized coefficients		Standardized coefficients	p - Value	Inflation Factor of the Variance
		B	Standard error.	Beta		
Men	constant	4.22	2.20	NA	0.15	NA
	Age	0.15	0.06	0.37	0.09*	1.80
	% Fat	0.11	0.02	1.02	0.01*	3.32
	% Muscle	-0.05	0.03	-0.43	0.16	4.61
	%VLF	-0.65	0.37	-0.23	0.18	1.49
	DFAα1	-2.44	0.46	-1.36	0.01*	5.68
	Standing HR	-0.01	0.01	-0.28	0.19	2.41
Women	(Constant)	1.95	0.72	NA	0.07	NA
	Age	-0.05	0.01	-0.28	0.04*	1.49
	% Fat	0.02	0.00	0.63	0.01*	2.54
	% Muscle	0.05	0.01	0.88	0.01*	3.14
	%VLF	1.95	0.28	0.73	0.01*	2.41
	DFAα1	-0.42	0.18	-0.26	0.09	2.54
	Standing HR	-0.02	0.00	-0.43	0.02*	1.86

NA: Not applicable. *statistically significant data ($p < 0.05$).

Table 5. Behavior of actual and predicted oxygen consumption values and their differences.

Number of cases		Actual VO_{2max}	Predicted VO_{2max}	Difference
Men	1	2.44	2.49	-0.05
	2	3.35	3.28	0.07
	3	2.44	2.60	-0.16
	4	2.47	2.42	0.05
	5	2.39	2.32	0.07
	6	3.06	3.15	-0.09
	7	3.11	3.02	0.09
	8	1.95	1.99	-0.04
	9	2.12	2.05	0.07
	10	2.40	2.39	0.01
Women	1	2.55	2.57	-0.02
	2	1.78	1.82	-0.04
	3	1.65	1.70	-0.05
	4	2.63	2.61	0.02
	5	2.59	2.60	-0.01
	6	2.46	2.43	0.03
	7	2.38	2.44	-0.06
	8	2.51	2.48	0.03
	9	1.84	1.76	0.08
	10	1.91	1.91	0.00

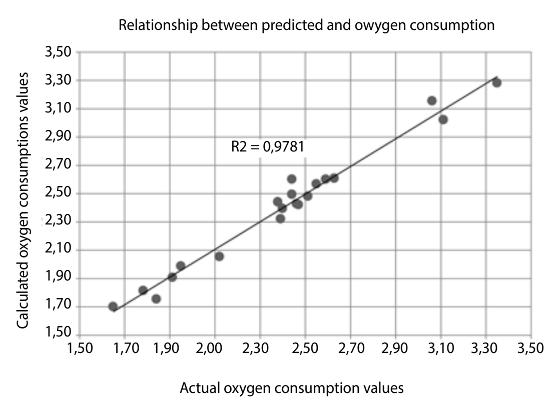

Figure 2. Correlation graph for data obtained in men and women through the Astrand test and calculated oxygen consumption from equations 2 and 3.

DISCUSSION

The fundamental hypothesis of the study is based on the ability to predict VO_{2max} from the variables body composition and HRV. The results obtained showed an inverse correlation between VO_{2max} and adipose tissue (r = -0.315) and a directly proportional relationship to muscle mass in women (r = 0.668). Similar results were found in previous studies, which demonstrated that adipose tissue exhibited an inverse relationship with the measured VO_{2max} (r = -0.40)[9] and, in turn, was proportional to muscle mass (r = 0.68)[20]; the latter was analyzed in patients with heart failure. Additional studies presented fat free mass (r = 0.87) as a fundamental determinant of VO_{2max}[21], which was not found in our case. Other widely used variables such as body weight and body mass index showed poor prediction of VO_{2max}, which was also shown in other studies[22].

Physiologically, the relationships found are valid, as skeletal muscle is considered the most active tissue from a metabolic point of view, in addition to being highly vascularized and rich in mitochondria[23], contrary to adipose tissue, which has poor metabolic activity.

Athletes and individuals highly trained in predominantly aerobic exercise have a decreased HR at rest as a result of both neural and anatomical adaptations[24]. For this reason, the HR at rest has been proposed as a predictor of VO_{2max}[25]. In this study, we showed that for men (r = -0.527) and women (r = -0.723), there is an inverse relationship between HR at rest in a standing position and VO_{2max}. With respect to HRV and prediction of VO_{2max}, some authors have stated that HRV can only explain up to 20.1% of the behavior of VO_{2max}[26]; however, our results demonstrated that variables such as percentage of power at VLF or DFA fluctuation analysis are highly associated with the prediction of VO_{2max}. These findings present new research opportunities, as the power at VLF is related to changes in the humoral system[27], while DFA fluctuations have been considered useful when analyzing the intrinsic behavior of a system[28]. Finally, the age of the participants influenced the final prediction model of VO_{2max}, with correlations of r = 0.423 in men and r = 0.212 in women, which has been considered in the development of other prediction models[29].

The Durbin Watson test for independence of variables showed, in the case of women, independence of the residuals, while in men, the residuals were autocorrelated. These finding are consistent because HRV is related to physical activity and body composition[30]. Changes in body composition can lead to changes in the autonomic response; thus, in obese patients, the percentage of fat is associated with a decrease in the behavior of LF (r = -0.43) and a lower RMSSD (r = -0.35)[31]. Similar results have been found in other studies in which adipose tissue has been shown to be related to the LF/HF (r = 0.56)[32].

Although many studies have shown changes in HRV in athletes and physically active people[33], few studies have linked these findings to the composition of muscle mass. Some authors have found that HRV in overweight patients is lower when it is associated with reduced muscle mass[34], while other authors have shown that anthropometric behavior contributes to changes in the HRV[35].

A small sample of individuals was used because this was considered a pilot study; the sample should be expanded to validate the equations.

CONCLUSION

The VO_{2max} responds physiologically to multiple variables; in this study, body composition (percentage of fat and percentage of muscle) was shown to be important for establishing VO_{2max}. Additionally, the behavior of the autonomic nervous system also contributes to the understanding of the physiological adaptations that accompany higher values of VO_{2max}. Our model showed that other important relationships exist between variables, such as the role of body composition in HRV. The joint analysis of body composition (percent of muscle mass and percent of fat), HR at rest, HRV (percent VLF and α coefficient of DFA), and age can explain the high percentage of VO_{2max} both in men and women.

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