Oxygen Uptake Kinetics and Delta Mechanical Efficiency Response of Men and Women at Different Exercise Intensities

EXERCISE AND SPORTS SCIENCES

ORIGINAL ARTICLE

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ABSTRACT

Introduction and objective: Delta efficiency (DE) and oxygen uptake kinetics ($K\dot{V}O_2$) are influenced by muscle metabolic parameters and oxygen transport. The aim of this study was to determine the difference in DE and $K\dot{V}O_2$ in three effort intensities in both genders. Methods: Fifty-six subjects (26 women) were submitted to a graded maximal exercise test (GXT) on cycle ergometer to determine the maximum oxygen uptake ($\dot{V}O_{2max}$), maximal power output (W_{max}), anaerobic threshold (AT) and respiratory compensation point (RCP). The AT and RCP were determined using the V-slope and $\dot{V}_E$ / $\dot{V}$ $\dot{V}O_2$ methods; the RCP using the relationship $\dot{V}O_2$ versus $_E$ both by two investigators. The DE and $K\dot{V}O_2$ have been considered as a slope between $\dot{V}O_2$ versus Watts and $\dot{V}O_2$ versus time (s), respectively, from the beginning of test until AT (S_1), from AT to RCP (S_2) and from RCP to $\dot{V}O_{2max}$ (S_3), determined by linear regression analysis. Results: Regarding DE, significant differences were observed between S_1 *versus* S_2 ($p = 0.001$), S_1 versus S_3 ($p = 0.001$) and S_2 versus S_3 ($p = 0.006$). There was no significant difference ($p = 0.060$) or interaction ($p = 0.062$) between men and women. For $K\dot{V}O_2$, significant differences were observed between S_1 versus S_3 ($p = 0.001$) and S_2 versus S_3 ($p = 0.001$) in both genders. Significant differences ($p = 0.001$) and interaction ($p = 0.006$) were observed between men and women, in the last parameter. Conclusions: DE decreases with increasing intensity of power output, but there are no differences when comparing men and women. On the other hand, women present faster $K\dot{V}O_2$ than men.

KeyWords: ergospirometry, effort test, $\dot{V}O_2$ e $\dot{V}O_{2max}$ slow component.

INTRODUCTION

The ergospirometric test with graded loads until the individual's capacity threshold, performed to measure the maximum oxygen uptake ($\dot{V}O_{2max}$)(1), anaerobic threshold (AT)(1-3), maximum power output (W_{max}) and mechanical efficiency(4) is a common practice in laboratories of exercise physiology(2,5). The analysis of these variables becomes more important during the performance of physical exercises of long duration, since the mechanical efficiency is one of the main parameters observed in endurance events(6). The mechanical efficiency reflects the amount of potential chemical energy stored in the muscle converted into mechanical work. This efficiency is usually estimated from the oxygen consumption(4,7). In the evaluation of this parameter, the cycle ergometer is preferable, since it presents readings of the physical power closer to the real value(1,4).

The maintenance of the physical exercise depends on a suitable supply of oxygen to the active muscles(6). The availability of oxygen to the muscle tissue during exercise can be measured through the delta mechanical efficiency (EMr), which corresponds to the quotient between the variation of the energy cost and the variation of the power generated(4,7,8). In the high intensity exercises the EMr may interfere in the capacity to move high loads of work with predominance of oxidative metabolism, observing extra oxygen consumption(7,8). These observations are not commonly performed with women(8-11) and the reasons why are unclear, such as: effects of the menstrual cycle and hormone oscillations on the mechanical efficiency. Lower indices of hemoglobin and hematocrit observed in women can also contribute to the development of anemia(12), increasing the levels of 2,3 diphospholicerate (2,3-DPG) and hence, decreasing the oxygen affinity with hemoglobin(13,14). The intensification of the Bohr effect means a greater swerve of the oxyhemoglobin dissociation curve to the right(13,14), and can result in low indices of inclination of the $\dot{V}O_2 \cdot$ time $^{-1}$ ratio and fast kinetics of the oxygen consumption.

Recently, a technique to determine the kinetics of the oxygen consumption ($K\dot{V}O_2$) through an increment protocol based on the $\dot{V}O_2 \cdot$ time $^{-1}$ ratio was proposed by Boone et al.(9); however, only the male subjects were evaluated. Considering that the behavior of the $\dot{V}O_2 \cdot$ time $^{-1}$ ratio can provide important information on the velocity of oxygen offer to the active tissues in sport events as well as clinical practice, and that in women such mechanism needs to be better elucidated, the aim of the present retrospective investigation was to analyse the K $\dot{V}O_2$ response and observe the difference in the EMr between men and women in different metabolic levels during an incremental test on cycle ergometer.

METHODS

Subjects

The present investigation was composed of 56 volunteers, physical education students where 30 were male (25 ± 1 year; 74.3 ± 2.1kg) and 26 were female (27 ± 1 year; 57.4 ± 1.1kg), apparently healthy, non-smokers and non-athletes. The volunteers were recommended to abstain from extenuating physical activities (>5 METs) and alcohol ingestion 24h prior to the test, besides keeping mixed diet in the 48h preceding the exertion. Additionally, they were asked to abstain from food containing caffeine in the three hours prior to the exertion. Each subject was informed on the risks associated with the adopted procedures. A clarified consent form was read and signed. All procedures were approved by the Local Ethics Committee for Experiments with Humans (Rio de Janeiro, CEP/ HSE 000.021/99). This study was carried out according to the Declaration of Helsinki.

Ergometric protocol

A graded maximal and continuous exercise protocol (GxT)[3] in mechanical cycle erogmeter (Monark®, São Paulo, SP, Brazil) for determination of the maximal aerobic power ($\dot{V}O_{2max}$), maximum power output (W_{max}), anaerobic threshold (AT) and respiratory compensation point (RCP) was used. The seat height was adjusted for each subject, in a way that the knee kept an angle close to total extension (approximately 175º). Maximum power output was previously estimated for each individual in order to enable increment of 10% of the maximum load at every minute[15]. The GxT protocol consisted of initial rest for six minutes seated on the seat of the cycle ergometer, followed by four-minute warm-up pedaling with no load and subsequently by the graded phase (approximately 25 W • min^{-1}). The maximum exercise duration was 10 ± 2min. The subjects kept steady cadence during the exam (aprox. 1.23Hz), controlled by an audiovisual metronome (Wittner Junior Plast 826, Isny/Allgäu, Germany).

The minute ventilation ($\dot{V}_E$) and the expired fraction of oxygen and carbon dioxide were continuously measured through open circuit indirect calorimetry (TEEM 100® Total Metabolic Analysis System, Aerosport®, Ann Arbor, MI., USA)[16]. The subjects used a nose clip and a medium flow pneumotachometer (Hans Rudolph Inc®, Kansas City, MO, USA). The oxygen consumption per minute ($\dot{V}O_2$) and the carbon dioxide excretion per minute ($\dot{V}O_2$) were presented at every 20 seconds. The heart rate (HR) was continuously monitored during the test through telemetry (Vantage NV®, Polar Electro Oy®, Kempele, Finland) and the perceived exertion concept (PEC), on the Borg scale fro m six to 20, was collected at the end of the each stage.

Controls and calibrations

The metabolic analyser and the cycle ergometer were calibrated before each test. The ergospirometer was calibrated in closed circuit through a certified gas mixture containing 17.01% of oxygen; 5.00% of carbon dioxide and balanced with nitrogen (AGA®, Rio de Janeiro, RJ, Brazil). The flow was calibrated using a 3-liter air syringe (Hans Rudolph Inc.®, Kansas City, MO, USA). At the end of each test, measurement of the oxygen and carbon dioxide percentage fractions in the gas mixture applied for calibration was performed. The maximum error admitted was of indices between 16.16 and 17.86% for FO_2 and 4.75 and 5.25% for FCO_2. The cycle ergometer was calibrated through a 3kg ballast.

The tests were considered mximal when at least three of the following criteria were observed[17]: a) plateau on $\dot{V}O_2$ (increase ≤ 150ml • min^{-1} or 2ml • Kg^{-1} • min^{-1}); b) respiratory exchanges ratio (RER) ≥ 1.15; c) 90% of HR_{max} expected for age (220 – age); d) perceived exertion concept ≥ 19 (6-20); e) maximum voluntary fatigue with incapacity of keeping pre-established rhythm. The $\dot{V}O_{2max}$ was determined as being the highest value found at the end of the test.

Data analysis

Two methods were used to detect the AT by visual inspection: the ventilatory equivalent method (EqV)[18] and the simplified V-slope (V-slope)[19].

The EqV was characterized as the moment in which increase in the ventilatory equivalent for oxygen uptake occurs ($\dot{V}_E$ / $\dot{V}O_2$) with o concomitant increase in the ventilatory equivalent for excretion of the carbon dioxide ($\dot{V}_E$ / $\dot{V}O_2$).

The simplified V-slope method was analysed on a chart of Cartesian coordinates, having the oxygen consumption per minute ($\dot{V}O_2$) on the abscises axis and the excretion of carbon dioxide per minute ($\dot{V}O_2$) on the ordinates and the moment at which the points surpassed the line parallel to the bisection of the straight angle was observed.

PCR analysis[20]: on the Cartesian coordinates chart, having the $\dot{V}O_2$ on the abscises axis and the $\dot{V}_E$ on the ordinates axis, the intersection of two straight lines segments below and above this point was observed. The $\dot{V}_E$ linearly increases with the $\dot{V}O_2$ below this point, but above it, the $\dot{V}_E$ it increases more rapidly.

Each individual had the two methods of AT determination and the PCR identification method visually analysed by two experienced investigators.

STATISTICAL ANALYSIS

Statistical treatment was performed through the Statistical Package for the Social Sciences® (SPSS® Inc., Chicago, IL, USA), SigmaPlot® (Systat® Software Inc, Chicago IL, USA) and Microsoft Excel® for Windows® (Microsoft®, Redmond, WA, USA) applications. Descriptive statistics through mean ± mean standard error (MSE) was applied. The mean of the results obtained by the two evaluators from the EqV and V-slope methods was considered as the AT[21]. The mean of the two investigators was also used the PCR.

Delta mechanical efficiency (EMr) was determined at three different intensities: from the beginning of the test to the AT (S_1); from the AT to the PCR (S_2) and from the PCR to the $\dot{V}O_{2max}$ (S_3)[22]. The EMr was considered as the angle coefficient of the $\dot{V}O_2$ *versus* wok load (W) ratio determined by linear regression analysis. The angle coefficient of the $\dot{V}O_2$ versus time ratio (in seconds) was also determined in order to measure the K $\dot{V}O_2$[9].

Shapiro Wilk test was used to verify the normal distribution of the data; when normal distribution was not observed, a logarithmic transformation was carried out. Two-way ANOVA and Tukey-HSD post-hoc test were applied to determine whether there were significant differences between the angle coefficients in each metabolic level and between genders. The significance level adopted was $p \leq 0.05$.

RESULTS

The AT, PCR, $\dot{V}O_{2max}$ and RER results were presented in table 1. Significant differences were observed in the three metabolic levels (S_1, S_2 and S_3) both in men and women.

$\dot{V}O_2 \cdot W^{-1}$ ratio– progressive increase of S_1 to S_2 and of S_2 to S_3 was observed (table 2; figure 1). Significant differences were observed between S_1 versus S_2 ($p = 0.001$); between S_1 *versus* S_3 ($p = 0.001$) and between S_2 versus S_3 ($p = 0.006$) in both genders (table 2; figure 1). Significant differences have not been observed between men versus women ($p = 0.060$) or significant interaction ($p = 0.062$) intensity versus gender (table 2). This result showed the decrease in EMr with the increase in exertion intensity regardless of gender.

Table 1. Ergometric variables obtained in the maximal I test in cycle ergometer.

	Male			Female		
	VO_2 (L • min^{-1})	Watts	RER	VO_2 (L • min^{-1})	Watts	RER
AT	1.64 (0.06)[a]	148 (6)[a]	0.87 (0.02)	1.10 (0.05)	87 (4)	0,86 (0.01)
PCR	2.79 (0.11)[*‡a]	237 (10)[*‡a]	0.99 (0.01)*‡	1.63 (0.07)*‡	141 (5)*‡	0,99 (0.02)*‡
VO_{2max}	3.84 (0.14)[*a]	297(10)* [a]	1.11 (0.02)*	2.26 (0.09)*	183 (7)*	1.09 (0.02)*

Mean ± (MSE). Anaerobic threshold (AT); respiratory compensation point (RCP); maximum aerobic power ($VO2_{max}$). [a] Significant difference between men and women; *Significant difference for the variables at the AT intensity ($p \leq 0.05$); ‡ Significant difference for the variables at maximal exertion ($p \leq 0.05$).

Table 2. Parameters of the delta mechanical efficiency (mL • min-1 • W-1) during the graded maximal exercise test (GxT).

	Male			Female		
	S_1	S_2	S_3	S_1	S_2	S_3
Inclination	8.30 (0.24)	11.27 (0.36)[a]	12,12 (0.66)[b,c]	8.57 (0.37)	9.16 (0.50)[a]	11.61 (0.77)[b,c]
Intercept	305.17 (34.83)	20.24 (75.07)	263,35 (199.66)	331.03 (21.82)	243.98 (39.61)	- 42.80 (134.33)
ESE	141 (8)	187 (13)	202 (14)	90 (5)	97 (8)	131 (10)
r^2	0.85 (0.01)	0.74 (0.03)	0.64 (0.03)	0.83 (0.02)	0.74 (0.04)	0.64 (0.05)

Mean ± MSE (mean standard error); ESE = estimation standard error; VO_2 (mL. min-1) versus W: beginning of the test until AT (S_1); AT until PCR (S2); PCR until $VO2_{max}$ (S_3). [a] Significant differences between S_1 versus S_2 ($p = 0.001$), bSignificant differences between S_1 versus S_3 ($p = 0.001$) and c Significant differences between S_2 versus S_3 ($p = 0.006$) in both genders for the angle coefficient.

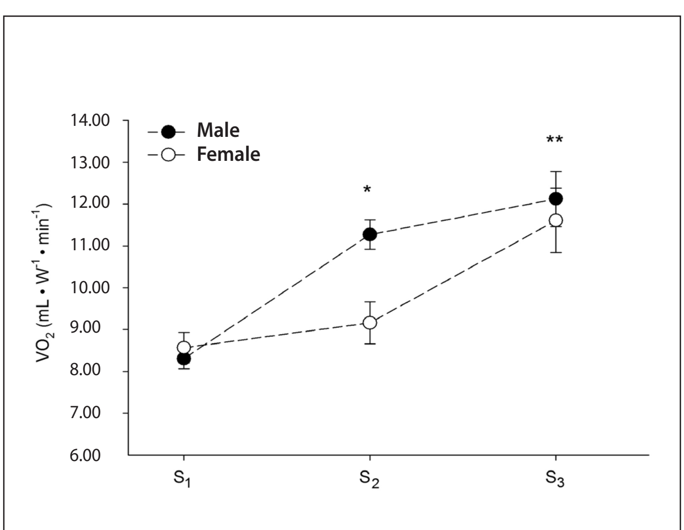

Figure 1. Angle coefficient of the VO_2 (mL.min-1) versus W ratio: beginning of the test until AT (S_1); AT until PCR (S_2); PCR until VO_{2max} (S_3). *Significant difference between S_1 versus S_2 ($p = 0.001$); ** Significant difference between S_3 versus S_2 ($p = 0.006$).

$\dot{V}O_2$ kinetics– significant differences were observed between S_1 *versus* S_3 ($p = 0.001$) and between S_2 *versus* S_3 ($p = 0.001$) in both genders (table 3; figure 2). Significant difference has not been observed between S_1 *versus* S_2 ($p = 0.753$). Significant differences ($p = 0.001$) were observed between men *versus* women (table 3; figure 2) and significant interaction ($p = 0.001$) between intensity *versus* gender (table 2; figure 2). Significantly faster $K\dot{V}O_2$ was observed in the female gender compared to the male one, regardless of the exertion intensity.

Table 3. Indices for the VO_2 (mL.min-1) versus time (s) ratio during the graded maximum exercise test (GxT).

	Male			Female		
	S_1	S_2	S_3	S_1	S_2	S_3
Inclination	3.94 (0.20)	5.98 (0.32)	6.58 (0.42)[a]	2.64 (0.13)	3.00 (0.15)	4.08 (0.25)[a,b]
Intercept	369.30 (29.03)	-173.00 (75.47)	-244.40 (203.38)	378.10 (21.87)	237.00 (33.20)	-227.27 (127.30)
ESE	127 (6)	152 (10)	176 (12)	82 (5)	87 (7)	103 (7)
r^2	0.88 (0.01)	0.83 (0.02)	0.74 (0.03)	0.86 (0.02)	0.80 (0.03)	0.78 (0.03)

Mean ± (MSE); ESE= estimation standard error; VO_2 (mL. min-1) versus time: beginning of the test until AT (S_1); AT until PCR (S_2); PCR until VO_{2max} (S_3). [a] Significant difference between S_1 versus S_3 ($p = 0.001$); bSignificant difference between S_2 versus S_3 ($p = 0.001$) in both genders for the angle coefficient.

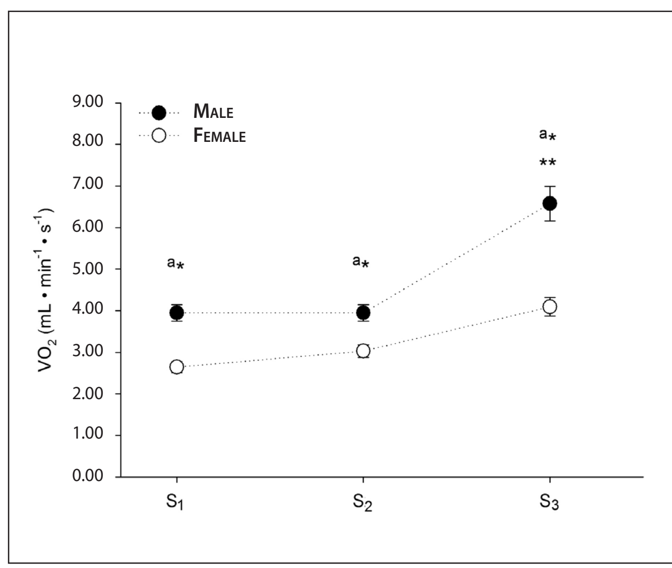

Figura 2. Angle coefficient of the VO_2 versus time ratio: beginning of the test until AT (S_1); AT until PCR (S_2); PCR until VO_{2max} (S_3). aSignificant difference between men versus women ($p = 0.001$). *Significant difference between S_1 versus S_3 ($p = 0.001$); **Significant difference between S_2 versus S_3 ($p = 0.001$).

DISCUSSION

The present investigation considered that the determination of the $\dot{V}O_2$ kinetics in increment protocols from a method based on the $\dot{V}O_2 \cdot$ time^{-1} ratio needs to be better elucidated in female subjects. Until the present study, the $K\dot{V}O_2$ response in tests with increments at every minute had not been investigated in women. Therefore, the effect of the increase of the intensity over $K\dot{V}O_2$ response in men and women during an increment test was assessed. The EMr during the exercise with increments at every minute for women and men was also observed.

The recruiting pattern of the type II muscle fibers, predominantly glycolytic, may be pointed as explanation for the reduction in delta mechanical efficiency as well as the increase of the $\dot{V}O_2$ slow component at intensities from the AT[7,8,10,22-26]. Bonne et al.[25] showed progressive increase of amplitude of the electromyographic activity, demonstrated by the integrated EMG (iEMG) in maximum exertion tests performed in cycle ergometer. The RMS has been applied to study the increase of the total myoelectrical activity in maximum exertion tests in cycle ergometer and can be applied as an indicator of recruiting of motor units of high excitement threshold[25-27]. In the present study, the hypothesis of high glycolytic metabolism as well as high RER (table 1) observed in the high work loads was corroborated.

Although neither significant difference ($p = 0.060$) nor interaction ($p = 0.062$) has been observed between genders, a phenomenon of different magnitude of EMΔ (table 2) was observed. Increase of 2.97 $mL \cdot W^{-1} \cdot min^{-1}$ between S_2-S_1 (S_2-S_1) in men and only 0.60 ± 0.51 ($mL \cdot W^{-1} \cdot min^{-1}$) in women was observed. These results suggest an important phase in which there seems to be greater recruiting of type II fibers after the AT[22-27]. Bell and Ferguson[28] showed in young women, high correlations of the type I myosin heavy chain in 60 and 75 revolutions per minute in cycle ergometer ($r = 0.80$ and $r = 0.84$, respectively), when confronted with the mechanical efficiency. These cadences were similar to the ones applied in the present investigation. The differences between genders seem to fundamentally occur due to the body size and composition. Although the composition of the muscle fibers is similar in both genders[7,28], the volume of each fiber seems to be greater in men.

Boone et al.[9] found mean values of inclination of 4.09$mL \cdot W^{-1} \cdot s^{-1}$ for the $K\dot{V}O_2$.in male physical education students submitted to progressive tests (increments of $25W^{-1}$). These values were similar to the ones observed in the men evaluated in the present investigation at the AT intensity (table 3). This same variable presented values of 2.64 $mL \cdot W^{-1} \cdot s^{-1}$ in women, indicating fast oxygen supply to the active tissues. The slow component of the oxygen consumption in men of 2.03 ± 0.22 $mL \cdot W^{-1} \cdot s^{-1}$ determined by the $\dot{V}O_2 \cdot time^{-1}$ ratio and the low value in women 0.36 ± 0.14 ($Ml \cdot W^{-1} \cdot s^{-1}$) between S_2-S_1 presented similar behavior to the delta efficiency (table 2; figure 1). Unfortunately, Boone et L.[9] did not determine the $\dot{V}O_2 \cdot time^{-1}$ ratio at the intensities above the AT justifying additional complexities due to the slow $\dot{V}O_2$ kinetics. The present investigation was the first one to analyse the $\dot{V}O_2 \cdot time^{-1}$ ratio in women according to our searches in the ISI and Medline databases, which makes it difficult to compare it with other studies. The decomposition of a progressive test in distinct metabolic levels (S_1, S_2 and S_3) made it possible to analyse and identify in a progressive test the moment where the slow $\dot{V}O_2$ component became more significant.

During the increment test, the hemodynamic alterations, especially the increase in the intramuscular flow, increase in 2,3-DPG, body temperature and decrease of pH caused by the increase of intensity[3,5] have potential effect on the oxygen release of the hemoglobin of the active musculature[14]. These factors may cause a swerve to the right of the oxyhemoglobin dissociation curve which indicates oxygen release to meet the higher energetic demand of the skeletal muscles in contraction. The 2,3-DPG seems to present an important reducing role in the oxygen affinity to the hemoglobin[13,14]. Sexually mature women present lower hemoglobin concentrations than the men and frequently present anemia due to their menstrual bleeding[12]. This phenomenon may explain the low values of $\dot{V}O_2 \cdot time^{-1}$ inclination found in the women in the present study (table 2), indicating that oxygen is rapidly provided to fulfill the metabolic demands and hence indicating a compensation mechanism in women.

It is essential that the measurements of the gas and ventilatory exchanges are accurate so that the data are reproduced, and the quality of the measurements should be controlled through the calibration, operation as well as analysis procedures by experienced technicians[29]. Tests which are carefully carried out present low variation in the repeated measurements in close moments[1,15]. The daily intra individual variation, due to the error and physiological fluctuations of the $\dot{V}O_2$, $\dot{V}_E$, and HR, are[30], respectively, 3.8%, 8.0% and 3.0%. Granja Filho et al.[1] observed an intra-individual variation index of 5.5% for the $\dot{V}O_{2max}$. Nogueira and Pompeu[21] and Magrani and Pompeu[31] observed satisfactory indices for the measurements analysed in equipment used in this study. There are differences in the measures obtained by this equipment when they are compared with the ones derived from more sophisticated equipments (3.8% versus 5.5%), the ergospirometer here adopted was validated by another group[16] and is widely applied in Brazilian laboratories.

Considering that the $K\dot{V}O_2$ determination in increment protocols fro ma method based on the $\dot{V}O_2 \cdot time^{-1}$ ratio needed to be better investigated in female subjects, it was concluded that the delta mechanical efficiency decreases with the increment of work intensity, when the angle coefficient of the $\dot{V}O_2 \cdot W^{-1}$ ratio is analysed at different metabolic levels; however, there are no differences when both genders are compared. On the other hand, women present faster $K\dot{V}O_2$ in comparison to men.

ACKNOWLEDGEMENTS

The authors of this study express their gratitude to the Association of Friends of the Center of Studies and Improvement of the Hospital of State Servants of Rio de Janeiro, in the name of Dr. Aluysio S. Aderaldo Jr. for the significant contribution for the performance of this investigation and to colleague Gilberto Sabóia Pompeu Neto. This study received grant from the Coordination for the Improvement of Higher Education Personnel (CAPES), Carlos Chagas Filho Foundation of Support to Research of Rio de Janeiro State (FAPERJ) and National Board of Scientific and Technological Development (MCT/CNPq).

All authors have declared there is not any potential conflict of interests concerning this article.

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