The VO_{2max} plateau is not associated with the anaerobic capacity in physically active subjects

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Abstract

The present study aimed to verify if the incidence of plateau is associated with anaerobic capacity. Therefore, nine physically active male (age: 23 ± 4 yr; body mass: 72.4 ± 8.2 kg; height: 176.4 ± 6.8 cm; VO_2max: 41.3 ± 5.7 ml.kg^{-1}.min^{-1}) participated in the present study. The subjects in a cycle ergometer the following tests: a) maximum incremental test to determination of VO_2max; b) six submaximal tests for determination of supra maximum demand of O_2; c) supra maximum test for maximum accumulated oxygen deficit (MAOD) determination. The plateau was identified when the difference in the VO_2 in the last two stages of incremental test was $\leq$ 2.1 ml.kg^{-1}.min^{-1}. It was observed an inverse correlation, although no significant, between MAOD and VO_2 plateau ($r = -0{,}61$; $p > 0{,}05$). Thus, it appears that anaerobic capacity is not a decisive factor for determining the incidence of VO_2 plateau in physically active individuals.

KEY WORDS: MAOD; Oxygen deficit; Stabilization of oxygen uptake; Incremental test; Supra maximum test.

Introduction

Traditionally, maximum oxygen consumption (VO_2max) has been used to represent the maximum aerobic capacity[1-2]. Presently, VO_2max is used as an indicator of cardiorespiratory fitness[3-8], running performance predictor[6-8], to evaluate training related adaptations in healthy individuals[9] and in patients with coronary arterial disease[10], detraining[11-12], mortality predictor[13] and to evaluate sleeping disorder[14]. Thereby, VO_2max identification is important to evaluate the fitness levels in athletes as well as in high-risk groups. VO_2max is measured via incremental tests (TI), usually performed to voluntary exhaustion. Although several variables have been considered in order to establish maximum effort[2], the main characterization of VO_2max is through stabilization in oxygen consumption (VO_2) during the final stages of TI. This VO_2 characterization during the final stages of TI has been termed VO_2 plateau[2]. Theoretically, plateau refers to a stabilization or small increases ($\leq$ 2.1 ml.kg^{-1}.min^{-1}) of VO_2, even if loads are incremented in the final stages of TI[2]. However, some tests are interrupted before reaching VO_2max. In this case, the value obtained is termed as peak oxygen consumption (VO_2peak)[15]. It has been suggested that plateau incidence may be related to athlete's training state, in which athletes with higher physical condition could tolerate higher levels of pain and fatigue and higher motivation to support higher loads in the final test[16-17], and that the higher intensities could be related to increases in energy supply by the anaerobic metabolism[1].

Provided the relevance to establish VO_2max parameters, previous studies used one additional test to confirm if VO_2 value, obtained in a traditional TI protocol, could be considered as maximum[18-19]. The confirmation test is performed until fatigue with constant loads and intensities near to the VO_2max. For instance, SNELL et al.[19] performed the confirmation test with two intensities (95% and 105% of the maximum power in TI) and, in both conditions, it were not observed significant differences between VO_2 in the verification test and the VO_2max achieved in TI, even in the absence of plateau. This result suggest that the maximum aerobic power can be achieved during TI, even if there is no plateau in VO_2.

Previous studies with trained individuals have suggested that VO_2 plateau may be related to the anaerobic metabolism[1]. During high-intensities exercises, the ATP resynthesizes occurs predominantly via anaerobic metabolism, which seems to justify, in the final stages of the incremental test, an increase in exercise intensity even with no modifications VO_2 (stabilization). In a recent study, Gordon et al.[1] showed a negative correlation between ΔVO_2 and maximum accumulated oxygen deficit (MAOD) in highly trained cyclists. These results indicate that individuals with higher anaerobic capacity have higher incidence of plateau. Given that MAOD is elevated in both aerobic and anaerobic trained individuals as compared with physical active ones[20], it seems plausible to suggest a lower incidence of VO_2 plateau in physical active and non-athletes individuals. However, to the present moment no study analyzed the relationship between anaerobic capacity and the VO_2 plateau in individuals with low levels of physical condition.

Thus, the present study aimed to verify the relationship between anaerobic capacity measured via MAOD and the incidence of VO_2 plateau in physical activity individuals. The hypothesis was that there would be positive correlations between MAOD and VO_2 plateau.

Method

Subjects

Nine male subjects participated in the present study 23 ± 4 years, 72.4 ± 8.2 kg e 176.4 ± 6.8 cm). They were physically active, healthy and had previous experience with exhaustion exercise. All participated in recreational sports and activities (running, soccer and tennis), however, none were engaged in competitive activities. All subjects were informed about the aims, procedures and possible risks associated with the present study and gave their informed consent prior to enrolment in the study. All subjects were free from pharmacological treatments, neuromuscular or cardiovascular disease and were non-smokers. The present study was approved by the commit of ethical research of the School of Physical Education and Sport of the University of Sao Paulo.

Experimental design

All subjects were submitted to four experimental sessions, with at least 72 h of interval between sessions. In the first session, subjects performed an incremental test to voluntary exhaustion in a cycle ergometer to measure VO_2max and its respective VO_2max power (WVO_2max). In the following sessions (i.e., second and third) subjects were submitted to six tests with constant loads (3 tests per session) with intensities below VO_2max. Sessions as well as sub-VO_2max tests order was randomized between subjects. Tests were performed in a controlled environment with constant room temperature (20-24 °C) and with two hours of interval from the last meal. Subjects were instructed not to performed strenuous physical exercises and not to consume alcohol 48 hours before data collection. In order to avoid any possible effect of ergogenic[21] and circadian cycle[22], all tests were performed in the same period of the day and subjects were instructed to not consume caffeine 48 hours before tests.

Anthropometric measures

Body mass and height were measured via an electronic scale (Filizola, model ID 1500, São Paulo, Brazil) and a wood stadiometer, respectively.

Incremental test

Incremental test was performed in an electromagnetic cycle ergometer for lower limbs (Godart-Holland, Lannoy). Immediately before test, subjects remained seated on the cycle ergometer for five minutes to determine baseline VO_2 (VO_2LB). The VO_2LB refers to rest VO_2, which was determined from the arithmetic mean of VO_2 during the final 30 seconds of the rest. Three minutes after warm-up, with the inertial resistance from the equipment, subjects cycled with a cadence of 60 rpm and increments of intensity of 30 $W.min^{-1}$. Test was interrupted when cadence was lower than 50 rpm. Throughout test, exchange gas and heart rate (HR) were measured breath-by-breath and beat-by-beat, respectively. VO_2 was measured continuously via a portable gas analyzer (K4b2

Cosmed, Rome, Italy), whereas the HR was assessed by heart rate monitor (Polar, Kempele, Finland). Maximum heart rate (HRmax) was established as the higher values obtained in the final test. VO_2max was determined according to at least three of the five criterion: increases in VO_2 lower than 2.1 $ml.kg^{-1}.min^{-1}$ regardless of increases in exercise intensity; subjects' voluntary exhaustion; respiratory exchange ratio higher than 1.10; blood lactate concentration after test higher than 8.0 $mmol.l^{-1}$; maximum heart rate predicted by age (220-age)[2]. VO_2 plateau was determined when the difference in oxygen consumption during the last 30 seconds in the last two final stages was ≤ 2.1 $ml.kg^{-1}.min^{-1}$. WVO_2max was established as the maximum power at VO_2max value.

Test with constants loads

The cycle ergometer, saddle height, pedal pace, warm-up, interruption criterion and VO_2 measurement in the exercises with constants loads were the same as in the progressive test until exhaustion. Subjects exercised for ten minutes, or until voluntary exhaustion, in six tests with intensities below the WVO_2max: 40, 50, 60, 70, 80 and 90% of WVO_2max and one above WVO_2max (110 WVO_2max). The rest interval between tests was approximately ten minutes, or until subjects return to VO_2LB values. Mean VO_2 values during the last minute of the test was used to represent the VO_2 in these tests.

Calculations

The arithmetic mean of VO_2 during the last 30 seconds in the sub-WVO_2max exercises was plotted with its respective intensities in order to develop individuals' linear regression equations. The angular coefficients produced by these equations were used to estimate the oxygen demand (VO_2DEM) in the supra-WVO_2max exercise (equation described below). The trapezium method was used to calculate VO_2 area in respect to the duration time of supra-WVO2max exercise. After that, accumulated VO_2 (VO_2ACUM), that is, the area under the curve of VO_2-time, was determine from the VO_2LB[10]. The MAOD was established as the VO_2DEM minus VO_2ACUM.

$$VO_2DEM = [(b*110/60).t]$$

Where VO_2DEM is the estimated O_2 demand during supra-WVO_2max exercise; 110 is the intensity of the supra-WVO_2max exercise; *b* is the angular coefficient in $1.min^{-1}$ obtained from the linear regression in the VO_2-intensities in the sub-WVO_2max tests; *t* is the total duration time of exercise expressed in seconds.

Statistical analyses

All analyses were performed with the SPSS software (version 13.0, Chicago, USA). Data normality was verified by Shapiro-Wilk test and all presented normal distribution. Data are reported as means and standard deviation (SD). The correlation coefficient between ΔVO_2 and MAOD was determined with Pearson linear correlation. VO_2max and the 90% VO_2 of the WVO_2max values were compared by a paired T test. The unpaired T test was used for between-group comparisons (plateau vs. non-plateau) for all the dependent variables (VO_2max, MAOD, peak power, peak heart rate, respiratory exchange ratio [R], peak blood lactate concentration, ventilatory threshold of VO_2, and % of ventilatory threshold of VO_2 related to VO_2peak). The level of significance adopted was 5% ($p < 0.05$).

Results

Variables related to the progressive test are presented in TABLE 1. It was not observed significant differences between VO_2max and VO_2peak obtained at 90% of WVO_2max ($p > 0.05$).

The between-group comparisons revealed no significant differences for the dependent variables: maximum oxygen consumption (VO_2max), peak power, peak heart rate, respiratory exchange ratio, peak blood lactate concentration, VO_2 at the ventilatory threshold and % of the VO_2 of the ventilatory threshold in respect to VO_2max (TABLE 2).

TABLE 1 - Variables obtained during the progressive test (n = 9).

VO_2max ($l.min^{-1}$)	3.0 ± 0.5
VO_2max ($ml.kg^{-1}.min^{-1}$)	41.3 ± 5.7
Respiratory Exchange ratio (R)	1.29 ± 0.09
Maximum power (Watts)	247 ± 39
Total duration time (min)	8 ± 1
Maximum heart rate (bpm)	180 ± 9
[La^-] peak ($mmol.l^{-1}$)	10.3 ± 1.4

Values are presented as mean ± standard-deviation. VO_2max: maximum oxygen consumption; [La-]peak: peak blood lactate concentration.

TABLE 2 - Between-group comparisons (plateau vs. non-plateau) for the progressive test variables.

	Grupo platô	**Grupo sem platô**
VO_2max ($ml.kg^{-1}.min^{-1}$)	41.9 (3.9)	40.6 (8.7)
Peak power (W)	264 (39)	225 (30)
W_{VT}	180 (36.7)	172.5 (28.7)
VO_2VT	31.0 (2.1)	34.1 (5.5)
VT (%VO_2max)	74.6 (8.2)	84.7 (5.7)
R	1.28 (0.11)	1.32 (0.03)
Peak lactate ($mmol.l^{-1}$)	10.8 (0.9)	10.1 (1.8)
Peak heart rate (bpm)	180 (6)	178 (14)

VO_2max: maximum oxygen consumption; W_{VT}: power ventilator threshold; VO_2VT: oxygen consumption at ventilatory threshold; VT: ventilatory threshold; R: respiratory exchange ratio.

Five out of nine subjects presented VO_2 plateau (55% of the subjects). The correlation analysis in these subjects (FIGURE 1, left panel) showed a non-significant inverse correlation between Δ VO_2 and MAOD (r = -0.61, p = 0.270). Similar non-significant result was observed when pooling data from all subjects (r = 0.28; p = 0.464).

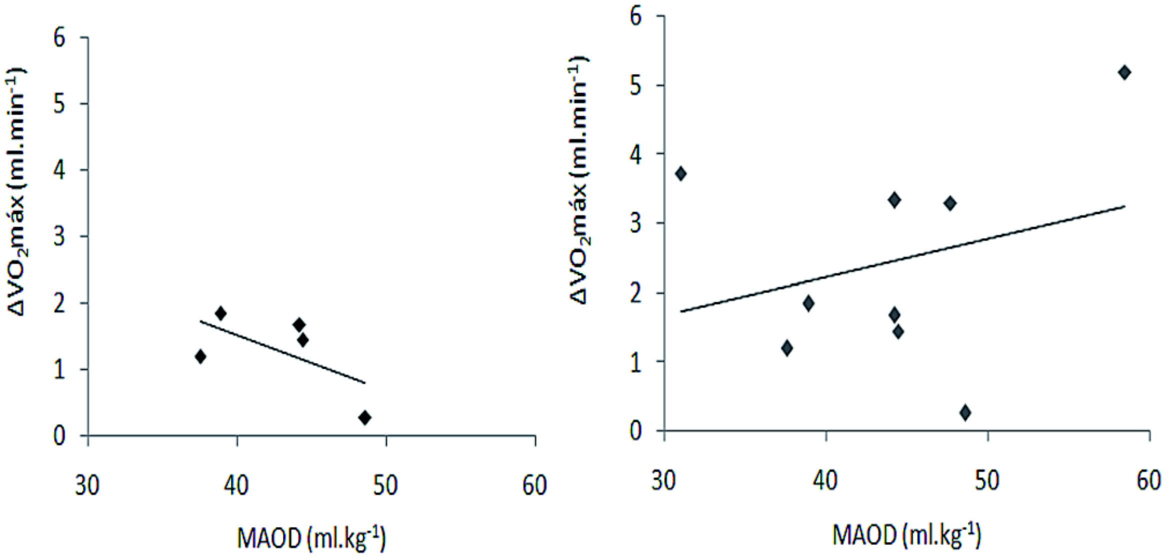

FIGURE 1 - Coefficient correlation between rate of increase in oxygen consumption (ΔVO_2max) and maximum accumulated oxygen deficit (MAOD).

The left panel refers to subjects that presented plateau, whereas the right panel represent all subjects (plateau and non-plateau).

Discussion

The aim of the present study was to verify the relationship between anaerobic capacity and VO_2 plateau incidence in physically active subjects. Our hypothesis was that MAOD would be positively associated with VO_2 plateau. However, the results from the present study showed that VO_2 plateau incidence does not seems to be associated with the anaerobic capacity in physically active subjects.

The VO_2max has been utilized to assess the maximum aerobic power[1-2]. The presence of plateau is considered a key criterion to determine if the value obtained during the test can be considered as maximum[19]. However, not all subjects are capable to achieve plateaus state. Previous studies demonstrated a high heterogeneity of plateau incidence between 12 to 59%[1, 18, 23-26]. Studies in highly trained athletes showed similar or even lower percentage of plateau incidence as in the present study. Lucia et al.[25] reported a plateau incidence of 47% in elite professional cyclists, whereas Doherty[21] showed a plateau incidence of 25% and 39% for men and women, respectively in Olympic athletes runners of medium and long distance. In the present study, five out of nine subjects presented plateau. These results are similar to Gordon et al.[1] that observed plateau presence in four out of nine (44.4%) highly training cyclists.

In the present study, we observed a non-significant correlation between MAOD and ΔVO_2, which do not corroborate with the above-mentioned study[1], given that it was observed a significant negative correlation between variables ($r = -0.77$, $p = 0.008$) in highly trained cyclists that presented plateau ($VO_2max = 59.3 \pm 4.8$ $ml.kg^{-1}.min^{-1}$). This result suggest that, in physically active subjects, others variables seems to affect the plateau incidence, in addition to the anaerobic capacity. It has been suggested that the plateau incidence is associated with the individual capacity to support high levels of fatigue and its resistance to pain[16]. However, highly trained athletes, which are familiarized with high levels of effort and pain sensation during training session and/or competitions, did not show higher incidence of plateau[21, 25], strengthening the idea of other intervening variables. Petot et al.[17] have suggested that the incapacity to reach plateau in incremental test is due to the incapacity to support the high power levels demanded during the test final stages. In their study, an incremental test was performed to verify the VO_2max. For the subjects that presented plateau or for those that the secondary criterion was achieved, even in the absence of plateau, a new test was performed. Test started similarly to the incremental test, with increases in load in a time function. When subjects achieved its VO_2max, determined in the first test, the power was reduced until the subject was able to maintain the VO_2 values previously determined. Using this protocol, 100% of subjects were able to reach plateau. Another study that corroborate with the present results is the Rivera-Brown et al.[23] where the incidence of plateau in pre-pubertal boys was 33% and, it was not observed any relationship between anaerobic power and plateau incidence. This results seems reinforce that other variables may be relevant to plateau incidence, as children's shown lower anaerobic capacity levels, thus, it would be expected a reduced incidence of plateau.

Additionally, results from the present study demonstrated that VO_2 peak at 90% of WVO_2max was not significant different from VO_2max. That is, the VO_2 values obtained during the final TI can be considered as maximum, even for those subjects that did not reach plateau. Indeed, exercise performed within this level of effort (~90% of WVO_2max) usually achieve the VO_2max values[27]. Furthermore, peak heart rate, R and blood lactate concentrations reached elevated values, confirming that the values observed can be considered as maximum for all subjects[2]. It was also demonstrated that individuals with higher levels of maximum aerobic power did not present a higher incidence of plateau. Altogether, these results suggests that when physically active subjects reach the first load correspondent to VO_2max they interrupt the exercise.

Importantly, the present study has some limitations. First, only nine subjects were evaluated, which could have been insufficient to observe significant correlations between variables. Especially in the sub-analysis, in which it was considered only the subjects that presented plateau ($n = 5$). In this analysis we observed a negative correlation, however, it was not statistical significant. In order to observe significant correlations with small sample sizes it is necessary values nears of one (+1 or -1), which increase the chance for type II error (observe non-significant correlations between variables, when in fact there is significant correlations)[28]. Limitations related to the use of MAOD to determine the anaerobic capacity should be highlighted, an impossibility to directly measure the variable, due to a lack of gold-standard method to determine the anaerobic capacity; the use of VO_2 to estimate the energetic metabolism that is measured as the whole-body, not being possible to account for the demand imposed by the musculoskeletal system during the exercise task; the contribution of the anaerobic lactic system on intensities above the anaerobic threshold are not excluded of the calculations and the slow component of VO_2 during the higher intensities may overestimate the O_2 demand. Despite these limitations, the MAOD has been considered as a decent method to estimate the anaerobic capacity[6, 29-30].

In short, it was observed non-significant correlations between plateau and anaerobic capacity, suggesting that the plateau incidence it is not related only with the anaerobic capacity in physically active subjects. Altogether, these results indicate that for subjects with this level of training, the anaerobic capacity it is not the main predominant factor to plateau incidence.

Resumo

O platô do VO_2max está associado à capacidade anaeróbia em indivíduos fisicamente ativos

O presente estudo teve como objetivo verificar se a incidência do platô está relacionada com a capacidade anaeróbia. Para tanto, nove indivíduos fisicamente ativos (idade: 23 ± 4 anos; massa corporal: 72,4 ± 8,2 kg; estatura: 176,4 ± 6,8 cm; VO_2max: 41,3 ± 5,7 $ml.kg^{-1}.min^{-1}$) participaram do presente estudo. Eles foram submetidos aos seguintes testes, realizados em cicloergômetro: a) um teste incremental máximo para a determinação do VO_2max; b) seis testes submáximos para determinar a demanda supramáxima de O_2; c) um teste supramáximo para a determinação do déficit máximo acumulado de oxigênio (MAOD). O platô foi caracterizado quando a diferença do VO_2 entre os dois últimos estágios do teste incremental foi $\leq$ 2,1 $ml.kg^{-1}.min^{-1}$. Foi observada uma correlação inversa, porém não significante, entre e o MAOD e o platô do VO_2 ($r = -0{,}61$; $p > 0{,}05$). Dessa forma, parece que a capacidade anaeróbia não é fator decisivo para determinar a incidência de platô no VO_2 em indivíduos fisicamente ativos.

Palavras-chave: MAOD; Estabilização do consumo de oxigênio; Déficit de oxigênio; Teste incremental; Teste supramáximo.

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