



Identification of the lactate threshold and the blood glucose threshold in resistance exercise

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ABSTRACT

The purpose of this study was to verify the possibility of identifying the blood glucose threshold (GT) as well as to compare and correlate the GT with the lactate threshold (LT) during resistance exercises. Twelve healthy male volunteers aged 24.4 ± 1.2 years and adapted to resistance training were submitted to an incremental resistance exercise with graded intensities according to their maximal workload (kg) performed for 1 repetition (1RM) on both leg press (LP) and bench press (BP). The intensities applied for each 1 min stage were of 10%, 20%, 25%, 30%, 35%, 40%, 50%, 60%, 70%, 80% and 90% of 1RM, respectively, or until volitional exhaustion. Blood lactate and glucose measurements were done each 2 min rest between each stage (YSI 2300 S). The blood lactate and glucose responses were similar for both exercises. No differences were verified for the relative intensity (% 1RM) at which the inflection point of blood lactate and glucose curves were observed respectively for LP ($36.6 \pm 1.4\%$ and $32.9 \pm 1.5\%$) and BP ($31.2 \pm 1.2\%$ and $31.2 \pm 1.8\%$) ($p > 0.05$). Additionally, a high correlation was verified between LT and GT identified both on LP ($r = 0.80$) and SR ($r = 0.73$) ($p < 0.05$). It was concluded that it is possible to identify the LT and GT on resistance exercises. However, additional studies should investigate the meaning of these thresholds and their validity for exercise evaluation and training prescription.

INTRODUCTION

The blood lactate response to exercise has been used in the identification of aerobic aptitude parameters such as the lactate threshold (LT); the individual anaerobic threshold; the minimum lactate and the lactate maximal steady phase. These parameters may be used as reference for prescription and control of physical training intensities. Moreover, different protocols of evaluation have been used, especially in running^(1,2), cycling⁽³⁾ and swimming⁽⁴⁾. Nonetheless, some authors have proposed the identification of the lactate threshold also during incremented resistance exercises⁽⁵⁻⁶⁾.

Besides the blood lactate response, initial studies about the glycemia response to incremental exercise in runners⁽⁷⁻¹⁰⁾ suggested the blood glucose threshold identification (GT) as an alternative to evaluate the aerobic capacity. Further studies also showed evidence of the similarity between the lactate responses and glycemia during incremental exercises, confirming hence, an identification of a GT in running^(9,11), swimming^(4,12), and cycle ergometer⁽¹³⁻¹⁴⁾. Besides

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that, the application of these thresholds in the evaluation and prescription of exercises for diabetic patients has also been suggested⁽¹⁵⁾. Nonetheless, the comparison between the blood lactate threshold and the glycemia during resisted exercises, as well as the possibility of identification of a blood glucose threshold in this kind of exercise, have not been analyzed yet.

Resistance exercises programs have been recommended not only for improvement of functional aptitude of athletes and healthy sedentary individuals, but also as a non-medicated treatment of some pathologies, once they have shown to be efficient in the improvement of metabolic, neuromuscular and cardiovascular functions, as well as of the body composition of special populations⁽¹⁶⁻¹⁹⁾. Thus, it is relevant that individualized methods of functional evaluation in resistance exercises are investigated.

The aims of the present study were to analyze the possibility of identification of the blood glucose threshold, as well as to compare and correlate the intensities of the blood glucose and lactate thresholds in incremented resistance exercises.

METHODS

Participants' selection

The methods used in the present study were approved by the Ethics in Human Research Committee of the São Carlos Federal University. Twelve young male volunteers, with age, total body weight and mean height (\pm standard error) of 24.4 ± 1.2 years, 81.1 ± 3.7 Kg and 177.3 ± 1.9 cm, respectively, were selected after answering an anamnesis about their health history and physical activity aptitude. In order to be included in the study, each participant should be adapted to exercises with weight for at least two years; not use any kind of drug; besides not present osteoligament problems or any other health problem that could limit his participation in the effort tests proposed in this methodology. Methodological details, including the inclusion criteria, were also presented in the informed consent form about the risks and benefits of the study's procedures. The participants were submitted to two exercise sessions at distinct days, being one test for maximal load determination (1RM)⁽²⁰⁾ in the studied exercises, and two incremental tests in resistance exercises performed at the same day, respectively, in the Leg Press 45° (LP) and Straight Supine (SS).

Choice and description of the performed exercises

The Leg Press and Straight Supine exercises were selected due to their characteristics and applicability to the study and to the chosen population.

The Leg Press 45° is a multi articular exercise which involves coordinated action of muscular groups of the lower limbs. The starting point for the movement was seated position with torso at 45° inclination in relation to the ground horizontal line; extended knees and feet touching the weight platform. In the movement cycle, the

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knees and the hip performed a 90° flexion in eccentric contraction of the involved muscles, returning in concentric contraction afterwards.

The Straight Supine presents biarticular characteristic, involving coordinated action of scapular waist muscles and elbow. The exercise is performed in open chain for upper limbs, and the movement performance consisted of removing the bar from its stand with hands at a distance sufficient so that at the moment that the bar touched the dorso, the elbow would make a 90° angle in flexion; all that from the laid initial position with back leaned against the supine seat, and feet on the ground. During the movement cycle the contractions of the muscles involved were eccentric in the flexion and concentric in the elbow extension. During the entire movement cycle the volunteers were oriented to avoid the isometric component, keeping the dynamic characteristics of both exercises at all times.

Determination of the lactate and blood glucose thresholds

The LT and GT determination occurred through visual observation of the lactate curve and glycemia, respectively, by two independent and experienced evaluators. The intensity in which the linear nature was lost with a sudden and exponential increase of the lactataemia curve was considered as being the LT. The intensity in which the glycemia curve presented the lowest point was considered for the GT, and it was independently determined from the blood lactate response.

Experimental protocol of increasing loads

The following standardization adapted from Barros *et al.*⁽⁶⁾ was used in order to perform the increasing load protocol: a) it was performed one to two days after the 1RM load determination of the LP and SS exercises; b) the exercises were tested at the same day, with an interval of at least twenty minutes between them, being the following order: LP and SS; c) the loads division was determined as follows: 10, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90% of 1RM. This load division was followed for the two exercises; d) the cycle of each repetition was of approximately three seconds. The duration of each stage was of one minute, with a total of 20 repetitions per stage and interval of two minutes between stages for the load increase and blood samples collection for later lactate and blood glucose measurement. The rhythm of each stage was controlled by verbal commands, and the test end was determined by the inability of performing the movement within the correct mechanics previously established, by the inability to perform the number of complete repetitions in the referred time for the stage or even by the volunteer's will despite the given verbal stimulation.

Blood collections and analyses

The blood collections were initially taken from the earlobe by puncture, after aseptic measure with alcohol and use of disposable gloves and materials. All blood samples were collected during the first minute of recovery after the end of each stage being satisfactorily completed. 25 ml of blood was then collected in heparinized and calibrated glass capillars and later placed in Eppendorf tubes containing 50 ml of NaF 1%. All blood samples were stored at -20°C for later analysis. The lactate and blood glucose concentrations were measured through a electro-enzymatic lactate and glucose analyzer (YSI 2300L – Yellow Springs Instruments – Ohio – USA). Such technique has been used and recommended in the usual literature for studies which use the glycemia response in the diagnosis evaluation^(21,22). The lactataemia and glycemia values were expressed in mmol.l⁻¹ and mg.dl⁻¹, respectively.

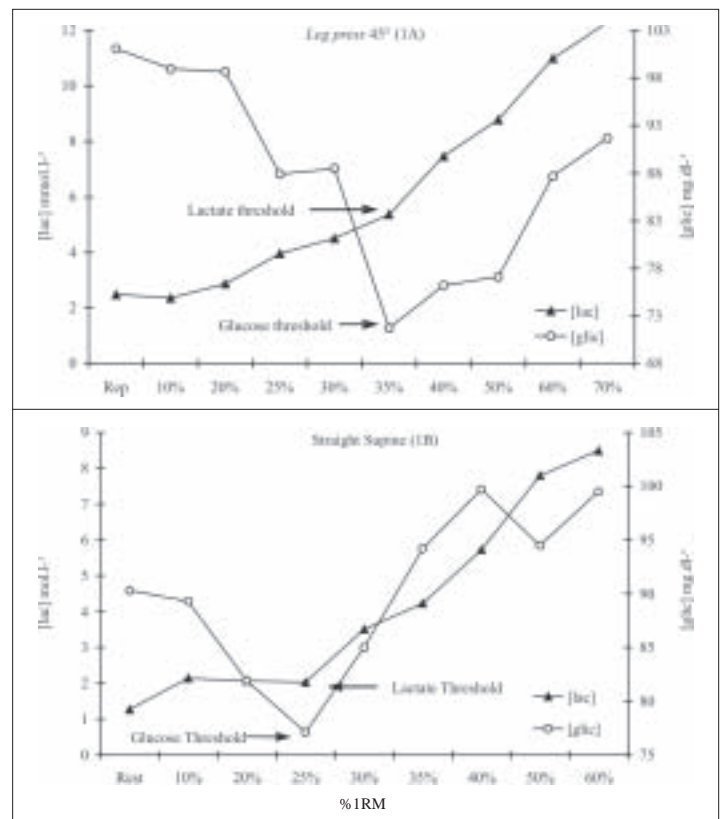
Statistical treatment

The data statistical treatment was conducted through descriptive analysis of all variables in which the values were expressed in

mean ± standard error (X ± EP). Student-t test for paired samples was used in order to compare LT and GT values identified in the studied exercises. The comparisons between the values relative to the percentage of 1RM found in the lactate and blood glucose thresholds in both exercises were performed using the ANOVA One-way test, with complementation of the Tukey-Kraemer test in order to state the possible differences found. The existing linear correlation between two variables was verified through the Spearman coefficient between the absolute values in which the LT and GT were observed in the incremental tests in the LP and SS. All the statistical treatment was performed by the GraphPad Instat 2.01 software. The significance index adopted was of 5% with a trustworthiness degree of 95%.

RESULTS

The blood lactate and glycemia responses during the incremental tests used in this study enabled the identification of the lactate threshold (LT) and the glycemic threshold (GT) as well (figures 1A and 1B). The behavior of the blood lactate and glycemia mean values are presented in figure 2 for both used exercises.



Figures 1 – Blood lactate ([lac]) and glycemia ([glic]) behavior during identification of the lactate and glycemic thresholds in the Leg Press 45° (A) and Straight Supine (B) exercises for a volunteer

Significant statistical differences (F = 83,57; p < 0,0001) were found for the lactate (LP: 115,9 ± 13,2 Kg; SS: 29,9 ± 2,4 Kg) and glycemic thresholds (LP: 132,8 ± 15,5 Kg; SS: 30,3 ± 3,4 Kg) when expressed in absolute loads. Nevertheless, when the thresholds values were expressed for the relative load (% of 1RM) no significant differences were observed (p > 0,05) for the relative loads to the lactate (LP: 32,9 ± 1,4% and SS: 31,2 ± 1,2%) and glycemic thresholds (LP: 36,6 ± 1,5% and SS: 31,2 ± 1,8%).

Table 1 presents the summary of the main results concerning the absolute (kg) and relative loads (%1RM) corresponding to the LT and GT identified by the two studied methods, as well as the blood lactate and glucose concentration at the moments corre-

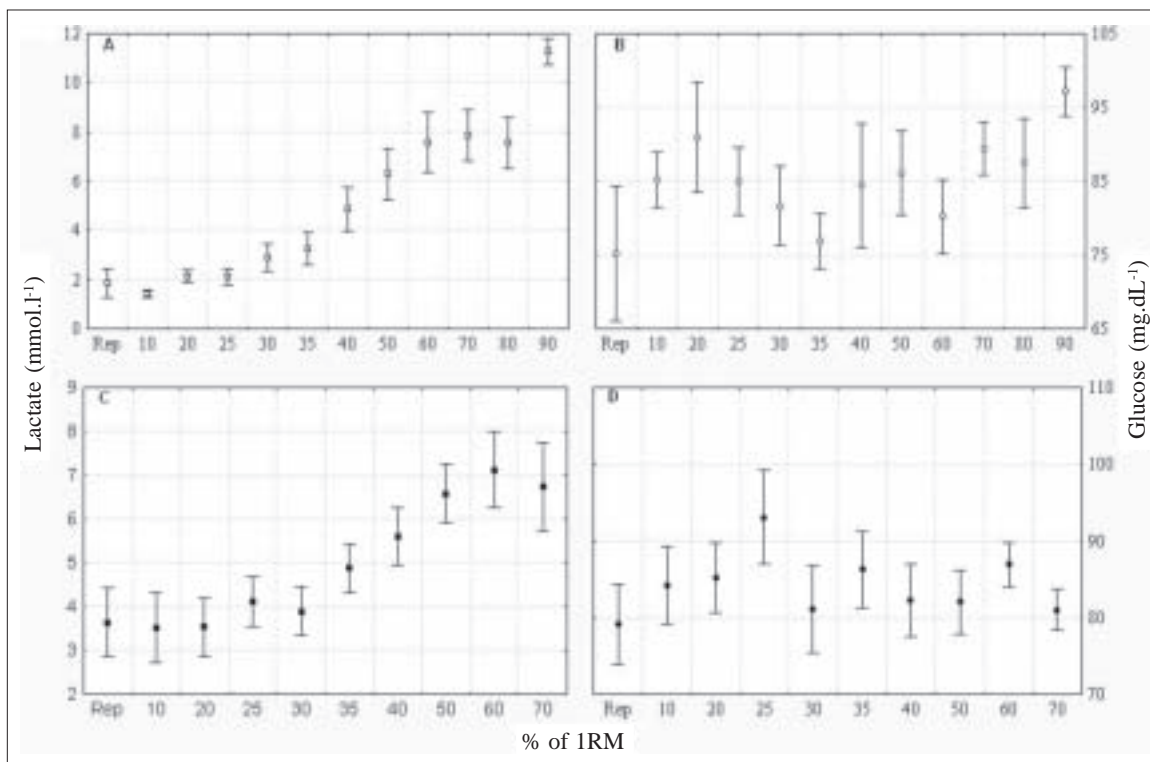


Figure 2 – Mean values of the blood lactate (*[lac]*) and glycemia (*[glic]*) behavior during the Leg Press 45 (**A** and **C**) and Straight Supine (**B** and **D**) exercises, respectively

TABLE 1
Mean results (\pm SE) corresponding to absolute load (Kg), relative load (%1RM), lactate and glycemia concentration in the referred studied thresholds (n = 12)

	Absolute load (kg)	Relative load (%1RM)	Lactate (mmol.l ⁻¹)	Glycemia (mg.dl ⁻¹)
LP[LT]	115,9 \pm 13,3 ^{a,b}	32,9 \pm 1,4	2,7 \pm 0,3	65,7 \pm 3,3
LP[GT]	132,8 \pm 15,5 ^{c,d}	36,6 \pm 1,5		
SS[LT]	29,9 \pm 2,4	31,2 \pm 1,2	3,8 \pm 0,5	66,5 \pm 3,1
SS[GT]	30,3 \pm 3,4	31,2 \pm 1,8		

LP – Leg Press 45°, SS – Straight Supine, [LT] – lactate threshold, [GT] – glycemic threshold, a = p < 0,0001 between LP[LT] vs. SS[LT], b = p < 0,0001 between LP[LT] vs. SS[GT], c = p < 0,0001 between LP[GT] vs SS[LT] and d = p < 0,0001 between LP[GT] vs. SS[GT].

sponding to the LT and GT, respectively. However, statistically significant differences were not evidenced (p > 0,05) for both parameters (e.g. blood lactate and glucose) between LP vs. SS. Significant correlation was observed between GT and LT both in the exercise performed at the LP (r = 0,80; p < 0,001) and at the SS (r = 0,73; p < 0,006;) when the Spearman correlation coefficient was applied.

DISCUSSION

The present study investigated the possibility of identifying the lactate threshold (LT) as well as the glycemic threshold (GT) in resisted exercises. Our results showed that both the LT and the GT could be identified during the incremental exercises protocol applied in the LP and SS exercises. The lactate and glycemic thresholds, both in the LP and SS, occurred in intensities between 31 and 36% of 1RM, what is according to previous studies which investigated the LT occurrence in resisted exercises⁽⁵⁻⁶⁾.

Barros *et al.*⁽⁵⁾ and Azevedo *et al.*⁽⁶⁾, investigated the behavior of the blood lactate in three distinct resisted exercises, using similar experimental procedure to the present investigation, and observed that the LT occurred in intensities between 28% and 31% of 1RM, not being found statistic differences between the relative intensities (% 1RM) corresponding to the thresholds identified for each exercise, in both studies. Nonetheless, the glycemic responses

and the possibility of identification of the glycemic threshold during incremental resisted exercises were not investigated by these authors. As far as we know, the present study was the first one to investigate the glycemia response during incremental resisted exercises.

During the incremental tests used in our methodology, the glycemia progressively decreased until an intensity that agreed with the LT, presenting hence from that intensity on, a remarkable increase. Such behavior was similar to the ones described by other authors during non-resisted incremental exercises performed in running^(8,11) and swimming^(5,12) and in dynamic exercises of increasing loads performed in cycle ergometer⁽¹³⁾. Moreover, it has been shown that the GT may be identified even when the incremental tests are performed after lactic acidosis induction (minimum lactate tests) in running⁽⁹⁻¹⁰⁾, cycle ergometer⁽¹³⁾ and swimming⁽⁴⁾, both in athletes⁽⁹⁻¹⁰⁾ and non-athletes⁽¹¹⁾.

During exercise, an increase of the phosphorylation of the proteins related to the glucose pick up by the skeletal muscle is experienced, resulting in greater quantity of GLUT4 translocated to the cellular membrane with consequent increase in the glucose pick up by the active muscle⁽²³⁾. In the present study, this sequence of events could also explain the initial decreasing behavior of the glycemic curve up to some intensities (e.g. LT and/or GT) from which the glycemia returns to increase. The glycemia increase in supra-threshold intensities may have occurred due to a greater adrenergic activity inducing hepatic glycogenolysis, as well as by a greater glucogenic activity by the glucanone, once several authors⁽²⁴⁻²⁷⁾ have suggested that these control mechanisms occur during high intensity exercises, being able to explain the glycemic response similar to the blood lactate response in supra-threshold intensities in the present study.

According to Rose and Richter⁽²³⁾ during intense exercise inhibition of the hexokinase enzyme occurs, limiting the glucose inflow and the phosphorylation in the myocyte cytosol. In addition, according to Shalin⁽²⁸⁾, the glucosephosphatase and phosphofructokinase enzymes control the degradation of glycogen and glucose, and their actions are inhibited due to the intramuscular pH decrease. Such evidences could suggest that in the present study a lower utilization and capacitation of glucose have occurred when the ex-

ercise reaches supra-threshold intensities, contributing to the increase of the glycemia and GT observation, especially in the LP.

Another possible mechanism that would explain the glycemia increase during exercise in supra-threshold intensities is the interleucin-6 activity (IL-6), which plays an important role in the hepatic gluconeogenesis increase⁽²⁹⁻³⁰⁾; however, the exercise intensity effect in these responses is not elucidated yet.

In the present study variables that could explain the glycemic behavior were not measured, such as the hyperglycemic hormones responses. Nevertheless, making use of incremental tests in resistance exercises, even with stages of only 1 min of duration and 2 min of pause between them, glycemic behavior similar to the one mentioned in previous studies was observed, allowing hence, the GT identification.

The absolute values (kg) concerning the thresholds (LT and GT) were different between the LP and SS exercises (table 1). The fact that the LT and GT values observed in the LP were higher than in the SS was already expected due to the greater muscular mass involved in the LP. Despite of that, when they were represented by the relative load, no differences were identified between SS and LP for the 1RM percentage in which the lactate and blood glucose thresholds were observed (table 1). These results reinforce the idea that, even for specific muscular groups worked in a non-cyclic isolated manner, (body building), the relative intensity in which the glycolytic activity starts to significantly supplement the ATP resynthesis, seems to be relatively constant between the different kinds of neuromuscular demand. The exponential response of the blood lactate in intensities above 30% of 1RM corroborates other authors who showed that in intensities above 30% of 1RM the anaerobic metabolism starts to participate more significantly⁽³¹⁻³²⁾. Moreover, it is possible that a greater number of motor units recruited in intensities above 30% of 1RM results in greater effect of the resisted non-cyclic contractions, causing relative occlusion; smaller oxygen offer and consequent accumulation of blood lactate. In addition to that, it has been demonstrated that in intensities above the anaerobic threshold, the increase of the number of motor units recruited itself, which has been confirmed by electromyographic registers of greater breadth⁽³³⁾, would explain the blood lactate accumulation above 30% of 1RM observed in the present study.

The blood lactate concentrations in which the LT was observed in the LP exercise in the present study were similar to the values previously observed by Barros *et al.*⁽⁵⁾. The blood lactate concentration in which the LT was observed in the SS exercise differed from the lactate concentrations observed by other authors investigating the LT in resisted exercises⁽⁵⁻⁶⁾. Nonetheless, these authors used different exercises such as straight screw; vertical pulling and flexor board. Moreover, the incremental tests for the SS in the present study were preceded by incremental tests in LP, which were performed 20 minutes before the SS tests.

The incremental tests performance in LP only twenty minutes before the incremental test performance in SS could explain the higher concentrations of blood lactate observed both in resting (pre-exercise) and in the intensities corresponding to the LT during the test in the SS in relation to the LP. Such procedure could even explain the higher concentrations of lactate at the moment of the LT in SS in relation to the studies by Barros *et al.*⁽⁵⁾ and Azevedo *et al.*⁽⁶⁾. Thus, one of the main limitations of the present study was the LP incremental tests application on the same day, with interval of only twenty minutes between LP and SS. Such procedure could also explain the inconsistency of the glycemia mean behavior during LP incremental tests in relation to SS (figures 2B and 2D).

The exercise previously performed in the LP does not seem to alter the identification of the LT in subsequent incremental test in SS (figures 1A and 1B, respectively). Nevertheless, it is possible that the previous performance of high intensity exercise involving large muscular groups (e.g. LP) may interfere in the glycemia re-

sponse and identification of the GT in subsequent exercise involving smaller muscular groups (e.g. SS).

It has been shown that the exercise performed by specific muscular group (e.g. exercise with one leg) interferes in the glucose pick up in a non-exercised muscle (control leg)⁽³⁴⁾. Moreover, it is known that the resisted exercise promotes an increase in the glycemic control⁽¹⁶⁻¹⁷⁾; however, the biomolecular aspects involved in the increase of the glucose pick up during and after exercise performance (mediated or not by the insulin sensibility increase), and which can last up to 48 hours after exercise, are not clear yet. Therefore, we suggest that for future studies investigating the glycemia behavior in resisted exercises, no more than one session of incremental resisted exercises is performed on the same day, as occurred in the present study.

Several neuroendocrine and metabolic mechanisms may influence the glycemic behavior during exercise, consequently the GT identification. According to Schwartz *et al.*⁽³⁵⁾, exercises performed in sub-threshold intensities result in low adrenergic activity. We believe that it is possible that this kind of response also occurs in resisted exercises, especially when performed in low intensities and when the involved muscular mass is smaller, as the SS exercise. Thus, during the SS performance in the present study, the activity of hyperglycemic hormones may have been smaller when compared to the LP. Such event would result in smaller hepatic production of glucose in relation to its pick up rate by the active muscles during the SS, once this pick up rate could be still increased due to the exercise previously performed (LP), making the observation of a blood glucose threshold in the SS difficult.

Despite the limitations discussed above, it was possible to identify the lactate and glycemic thresholds during the incremental resisted exercises performance, with a high correlation between them (table 1 and figures 1A and 1B). The results suggest new possibilities for evaluation, prescription and control of the training loads in resisted exercises for the improvement of performance, health, and consequently of people's life quality. It is possible that training in intensities relative to the LT and GT result in improvement in the neuromuscular, metabolic and cardiovascular functions of the practitioners (such as $\dot{V}O_{2max}$ improvement or intensity associated to it). Nevertheless, further investigation about the validity and meaning of these thresholds for different populations (sedentary, athletes, cardiopatic, diabetic and so on) should be conducted.

We concluded that, for the participants of the present study, the blood lactate and glycemia responses allowed the identification of the lactate and glycemic thresholds during incremental resisted exercises. Moreover, the intensities relative to these thresholds did not differ from each other besides being highly correlated.

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