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IDENTIFICATION OF THE ANAEROBIC THRESHOLD IN SEDENTARY AND PHYSICALLY ACTIVE INDIVIDUALS WITH TYPE 2 DIABETES

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ABSTRACT

Objective: To compare anaerobic threshold (AT) intensities determined from blood lactate, blood glucose and ventilatory responses among sedentary (SD) and physically active (AD) type-2 diabetics and active non-diabetics (AND), and to correlate metabolic, hemodynamic and body composition variables with the AT. Method: The SD (n= 9, 56.7 ± 11.9 years), AD (n= 9, 50.6 ± 12.7 years) and AND (n= 10, 48.1 ± 10.8 years) groups performed a cycle ergometer test with increases of 15 watts every three minutes until exhaustion. Heart rate, arterial pressure, perceived exertion, blood lactate, blood glucose and ventilatory variables were measured during the last 20 seconds of each incremental stage, to determine the lactate, ventilatory and glucose thresholds. Results: The AT intensities identified by the different methods did not differ from each other (p> 0.05). However, the absolute intensities were lower for SD than for the active groups (p< 0.05). No differences in intensity were found between the groups in relation to maximum oxygen consumption (%VO_2 peak) and maximum power (%Ppeak) at which the AT was observed. There was a significant correlation between AT and percentage fat (r= -0.52), and there was a trend towards correlation between AT and ambulatory blood glucose (r= -0.33). The hemodynamic variables did not show any correlations with AT. Conclusion: The AT was identified by means of the techniques studied, among type 2 diabetics and non-diabetics. Despite the differences between the groups with regard to absolute intensities (Watts), diabetes did not appear to influence the relative intensities at which the AT was observed. The AT presented a correlation with body composition and a trend towards correlation with ambulatory blood glucose, thus suggesting that the AT is an important parameter in clinical assessments for such patients.

Key words: anaerobic threshold; methods; type 2 diabetics; sedentary individuals; physically active individuals.

INTRODUCTION

Indicators of aerobic fitness such as maximum oxygen uptake (VO_2max)[1] and anaerobic threshold (AT)[2] have often been used for functional evaluations in different populations. Because AT shows high correlations with aerobic performance,[3] it stands out in the field of functional evaluation, being especially applied to athletes such as cyclists[4], swimmers[5], and runners[6], as well as to physically active individuals[7], and, to a lesser degree, to individuals with pathologies such as type 2 diabetes.

Blood lactate[6,4], ventilatory[9], and blood glucose[5,7,10] responses have been used in the identification of AT during incremental tests. The *individual glucose threshold* (IGT)[11], attempts at identifying the AT stemming from glucose response, and is the one which has been less studied concerning lactate and ventilatory thresholds. It has been suggested that IGT delimits the intensity of exercise that represents a balance between tissue glucose capture and release to the bloodstream, not differing from the intensity of exercise immediately previous to the increase of lactate and ventilation[12,13].

Knowing the intensity corresponding to the IGT may be relevant to the prescription of exercise intensities for diabetics. The few studies on this subject have focused on athletes and physically active, non-athlete individuals[7]. For diabetics, nevertheless, the AT determination has been made only based on parameters such as lactate and ventilation[8]. Thus, given the possibility of applying IGT for type 2 diabetics, it is important to analyze the similarity between lactate, ventilation and glucose responses and its validity for the identification of the AT in those patients, who represent 90-95% of the cases of diabetes[14].

Type 2 diabetes is one of the main causes of death and functional incapacity in several countries[14]. Aerobic and resistance exercises have been recommended in the treatment of diabetes[14], but there is the need of further investigations on the intensities that optimize the effects of the exercise in controlling patients' glucose levels.

AT identification through IGT techniques is interesting, because it seems to delimit, at least with healthy individuals, domains of intensity with a predominance of blood glucose capture and production[7]. However, aspects such as the level of functional fitness, training state, presence or absence of other risk factors such as obesity and hypertension, can modify both the absolute and relative intensities of AT ocurrence[12,15]. Thus, the objectives of the present study were: 1) to identify and compare AT as determined by blood lactate, ventilation, and glucose responses in sedentary and physically active type 2 diabetics, as well as in non-diabetics physically active individuals and 2) correlate metabolic, hemodynamic and of body composition variables with the AT identified in this sample.

MATERIALS AND METHODS

Sample

After the approval from the Commitee for Ethics in Research (Comitê de Ética em Pesquisa) (Normative Opinion 101/2005) from Universidade Católica de Brasília and the signature of the terms of free agreement for participation form, 28 individuals of both sexes took part in the study. The sample was divided into three groups, with nine participants, who were sedentary, and diagnosed with type 2 diabetes (SD), nine physically active type 2 diabetics, (AD)[16] and 10 physically active participants who did not have that disease (AND)[16] who engaged in resistance exercises complemented by aerobic exercises twice to four times a week. By the time the study was carried out, type 2 participants were compensated by medical and nutritional treatment, based on hypoglycemic agents and/or on a balanced diet.

Procedures

Tests were carried out at the Laboratory of Exercise Physiology of Universidade Católica de Brasília, in the morning and after fasting. Participants were submitted to heart tests, including an electrocardiogram (ECG) at rest with systolic and diastolic blood pressure checks (SBP, DBP) (*Microlife, England*), as well as an anthropometrical evaluation with estimates of relative fat (%fat) by means of predictive equations[17,18], with the use of the cutaneous folds technique of with a *Lange* compass. Next, the participants were submitted to an incremental test on a cyclo-ergometer (*Lode mod. Excalibur*). Criteria for exclusion from the study included the presence of peripheral and autonomous neuropathy, orthopedic complications, or the use of exogenous insulin, or any other secondary cardiovascular problem that could limit the participation in the exertion test. The main features of the sample are presented on table 1.

Incremental Test

An incremental test on a cyclo-ergometer was applied starting at 1 minute' heating at 0 Watt power, and 15-Watt increments for every three-minute stage, maintaining cycling at 60 revolutions per minute until voluntary exhaustion or other interruption criteria were adopted, such as a sudden increase of systolic and diastolic blood pressure to 250/115 mmHg, rate of perceived exertion (RPE) at 19-20[19] or unlevelness of the ST segment in the ECG or any other abnormal cardiovascular response. Besides, any hypoglycemia episode would also be a reason for interrupting the test, although none of the participants demonstrated such a condition. During the incremental exercise test, several measurements were taken repeatedly, such as heart rate (HR), blood pressure, RPE, ventilatory and blood variables (blood lactate – [Lac] and blood glucose - Gluc).

Sample Collecting and Analysis of Ventilatory Variables

Gas samples were collected on a breath to breath basis (*Cortex Metalyzer 3B system*). The results obtained for ventilation (VE), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) were analyzed based on the average of the last 20 seconds of each stage of the incremental test. The greatest VO_2 reached at the end of the test was considered as the VO_2 peak, owing to the fact that most participants, mainly from the SD group reported they had not reached a point of exhaustion by central mechanisms, but due to peripheral fatigue.

Sample Collection and Analysis of Blood Variables

During the last 10 seconds of each stage, 25 µl of capillary blood were collected from the earlobe from with capillary tubes, being then deposited into *Eppendorf* tubes containing a1% solution 50 µl of sodium fluoride (NaF) at for further analysis of [Lac] and Gluc through the electro-enzymatic method in a lactate and glucose analyzer (*Yellow Springs 2700 S*).

Table 1. Characteristics of sedentary type-2 diabetics (SD), physically active type-2 diabetics (AD), and physically active non-diabetics (AND) (n=28) participants.

	Age (years)	Weight (kg)	Height (cm)	% Fat	VO_2peak (ml.kg.min^{-1})	Ambulatorial Glycemia (mg.dL^{-1})	SBP (mmHg)	DBP (mmHg)	Physical activity/ Week (hours)	Diabetes (years)
SD (n=9)	56.7 ± 11.9	80.2 ± 12.6	166.6 ± 10.9	29.4* ± 8.8	20.2* ± 6.4	194.1† ± 54.5	136.8 ± 25.8	84.2 ± 9.0	0.9* ± 1.1	7.1 ± 8.0
AD (n=9)	50.6 ± 12.7	78.4 ± 14.2	172.9 ± 5.3	20.4 ± 5.3	29.0 ± 6.3	164.3† ± 68.3	121.1 ± 8.3	79.0 ± 9.5	4.0 ± 2.6	5.4 ± 4.4
AND (n=10)	48.1 ± 10.8	73.9 ± 6.3	170.0 ± 5.5	19.3 ± 2.2	31.8 ± 5.9	70.5 ± 10.8	120.4 ± 9.6	78.4 ± 8.0	3.6 ± 1.7	-

* $p < 0.05$ in relation to groups AD and AND; † $p < 0.05$ in relation to group AND for the same variable.

Anaerobic Threshold Determination by Different Parameters

In order to determine LT, [Lac] kinetics was inspected during the increments of the cycloergometer test, with LT being considered the intensity of the exercise during which an exponential increase of [Lac] curve was observed[2] (Figure 1). VT was determined by the analysis of O_2 (VE/VO_2) and CO_2 (VE/VCO_2) ventilatory equivalents, were considered to be the intensity correspondent to the moment in which VE/VO_2 presented a disproportional augment in relation to VE/VCO_2[12] (Figure 1).

In order to determine IGT, glucose kinetics were analyzed during the intensity increments, which were considered to be the point of balance between the capture and the production of blood glucose, or minimal glycemia[11], (Figure 1).

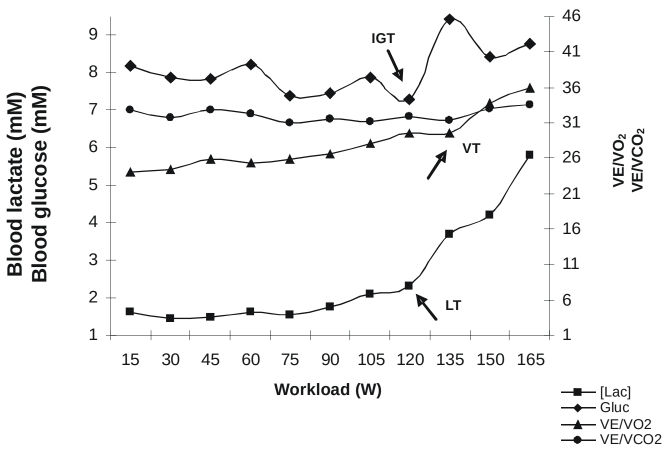

Figure 1. Determination of lactate threshold (LT), ventilatory threshold (VT) and individual glucose threshold (IGT) for a physically active type-2 diabetic volunteer (AD).

Statistical Treatments and Mathematical Procedures

Descriptive statistics of average values and standard deviation were calculated. For the demonstration of physiological responses between the groups, relative moments of the test were selected for all volunteers, namely: *Beginning* (beginning of incremental test), *(AP1)* (average point between beginning and LT), *LT* (lactate threshold), (AP2) (average point between LT and the end of the test) and *End* (moment of exhaustion in the incremental test). In order to make comparisons between the groups, an *ANOVA* was adopted for independent samples, and for comparisons within the respective groups, ANOVA was applied for repeated measures, with *Tukey*'s technique in *post hoc* analyses. *Pearson*'s Linear Correlation was adopted and the agreement between AT determination protocols was confirmed by Bland and Altman's technique[20]. The level of significance of the study was $p < 0.05$ (*Statistica® version 5.0*).

RESULTS

The identification of AT stemming from [Lac], VE and Gluc responses was possible both for the diabetics and non-diabetics (Figure 2). Table 2 shows AT intensities of occurrence from the different methods, which seemed to be similar within groups SD, AD and AND ($p > 0.05$). Meaningful differences ($p < 0.05$) occurred between absolute intensities (Watts) correspondent to the AT identified from the three protocols for the group SD and the groups AD and AND (Table 2). The values corresponding to the variables VO_2, [Lac], Gluc, HR and RPE during the determination of LT, VT and IGT for the groups studied are also presented in Table 2 with the respective comparisons within and between groups.

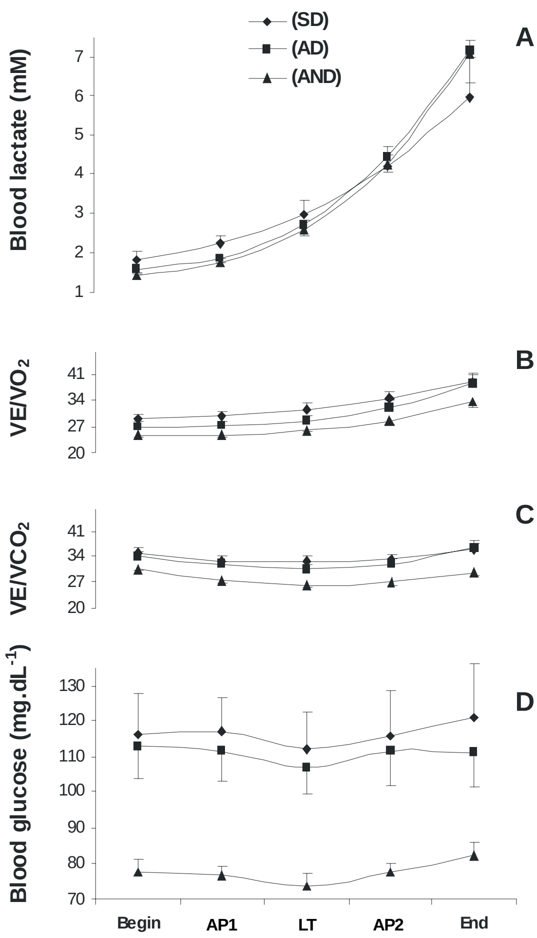

Figure 2. Responses to lactate concentrations ([Lac]) (A), oxygen ventilatory equivalent (VE/VO_2) (B), carbon dioxide ventilatory equivalent (VE/VCO_2) (C) and glucose (Gluc) (D) during incremental test with relative intensities for sedentary type-2 diabetics (SD) (n= 9), physically active type-2 diabetics (AD) (n= 9) and physically active non-diabetics (AND) (n= 10).

Table 2. Average (±SD) of intensity, oxygen uptake (VO_2), lactate concentration ([Lac]), glucose (Gluc), heart rate (HR) and rate of perceived exertion (RPE) corresponding to lactate threshold (LT), ventilatory threshold (VT), individual glucose threshold (IGT), and moment of exhaustion (peak values) obtained during incremental test (n= 28).

Parameter	Group	Workload (Watts)	VO_2 (ml.kg.min^{-1})	[Lac] (mM)	Gluc (mg.dL^{-1})	HR (bpm)	RPE (Borg)
LT	**SD**	59.4±22.6*	14.1±4.5	2.5±1.0	112.1±32.5 ^{b}	117.3±16.8	13.1±2.0
	AD	96.7±33.6	18.7±5.7	2.2±0.8	109.6±23.4	123.2±23.8	13.6±1.9
	AND	97.5±24.7	20.6±4.2	2.1±0.7	73.9±9.7 ^{a}	117.7±17.7	13.8±1.4
VT	**SD**	56.1±23.4*	13.1±3.3†	2.2±0.7	117.8±31.7 ^{b}	113.3±17.9	12.7±2.6
	AD	96.7±36.8	17.8±5.5	2.3±0.7	117.6±32.7	120.8±21.8	13.6±2.1
	AND	94.5±33.2	20.7±5.9	2.1±0.6	80.5±9.7	117.4±13.0	13.6±1.5
IGT	**SD**	65.6±24.0*	14.4±4.1	2.8±0.8	109.0±30.7 ^{b}	122.0±12.3	14.3±2.7
	AD	101.7±35.0	19.6±5.7	2.5±0.9	104.0±23.7	126.7±27.2	13.7±2.2
	AND	96.0±29.3	20.3±4.9	2.1±0.8	71.3±7.9 ^{a}	117.5±18.9	13.4±1.3
Exhaustion	**SD**	100.6±37.4 ^{c}	20.2±6.4 ^{c}	5.4±3.2	121.1±43.9‡	144.1±26.1	18.0±2.2
	AD	153.3±38.8	29.0 ±6.3	6.6±2.5	111.0±28.4	158.6±29.0	17.8±3.0
	AND	158.5±26.3	31.8±5.9	6.6±1.1	82.4±12.6	166.0±12.5	18.0±1.6

* $p< 0.05$ in relation to groups AD and AND for LT, VT, and IGT; † $p< 0.05$ relative to group AND for LT and VT; ^{a} p< 0.05 in relation to the same group for VT and to group AD for LT, VT, and IGT; ^{b} p< 0.05 in relation to group AND for LT, VT, and IGT; ^{c} p< 0.05 in relation to groups AD and AND for exhaustion; ‡ $p< 0.05$ in relation to group AND for exhaustion. (*NB.: The present study did not intend to set comparisons between threshold parameters and exhaustion*).

Table 2 also shows the averages at the moment of exhaustion of the incremental test of maximum oxygen uptake (VO_2peak), heart rate (HRpeak), power (Ppeak), lactate concentration ([Lac]peak), glucose (Glucpeak) and rate of perceived exertion (RPEpeak). These results made it possible to calculate %VO_2peak and %Peak corresponding to LT for the selected groups, which did not differ between the groups (%VO_2peak - SD= 69.8 ± 5.9 vs. AD= 64.3 ± 13.5 vs. AND= 64.4 ± 6.9; p> 0.05 e %Ppeak - SD= 60.0 ± 10.0 vs. AD= 62.7 ± 13.8 vs. AND= 61.0 ± 9.0; p> 0.05). On the other hand, upon setting %HRpeak the AND group reached LT in a significantly smaller percentage than group SD (SD= 82.2 ± 7.8 vs. AD= 78.0 ± 7.9 vs. AND= 70.7 ± 6.9; p< 0.05 for SD vs. AND).

Meaningful correlations were observed between LT and IGT for groups SD (*r*= 0.76), AD (*r*= 0.88) and AND (*r*= 0.93), as well as between VT and IGT for SD (*r*= 0.77), AD (*r*= 0.80) and AND (r= 0.84), and between LT and VT for SD (*r*= 0.85), AD (*r*= 0.89) and AND (r= 0.87). The agreement between AT identification methods was confirmed by Bland and Altman's technique[20] (Figure 3).

In addition, by analyzing all participants, AT was inversely correlated to fat percentage (*r*= -0.52; p= 0.004), also showing a tendency of inverse correlation with ambulatorial glycemia (*r*= -0.33; p= 0.08). On the other hand, for the hemodynamic variables (systolic and diastolic blood pressure) there were no AT significant correlations found.

DISCUSSION

The main results of this study showed that the methods used made it possible to identify ventilatory (VT), glucose (IGT) and lactate thresholds (LT) both in diabetics and non-diabetics alike, and there were no differences between these techniques within each group (Figure 2 and Table 2). These thresholds showed an agreement and meaningful correlations among themselves (Figure 3). In addition to this, differences were observed only concerning absolute intensity (Watts) between group SD in relation to groups AD and AND (Table 2). Nevertheless, it is worthwhile to highlight a limitation of the present study in regards to forming more representative sample groups, a shortcoming that was due to the difficulty in finding volunteer diabetics to engage in

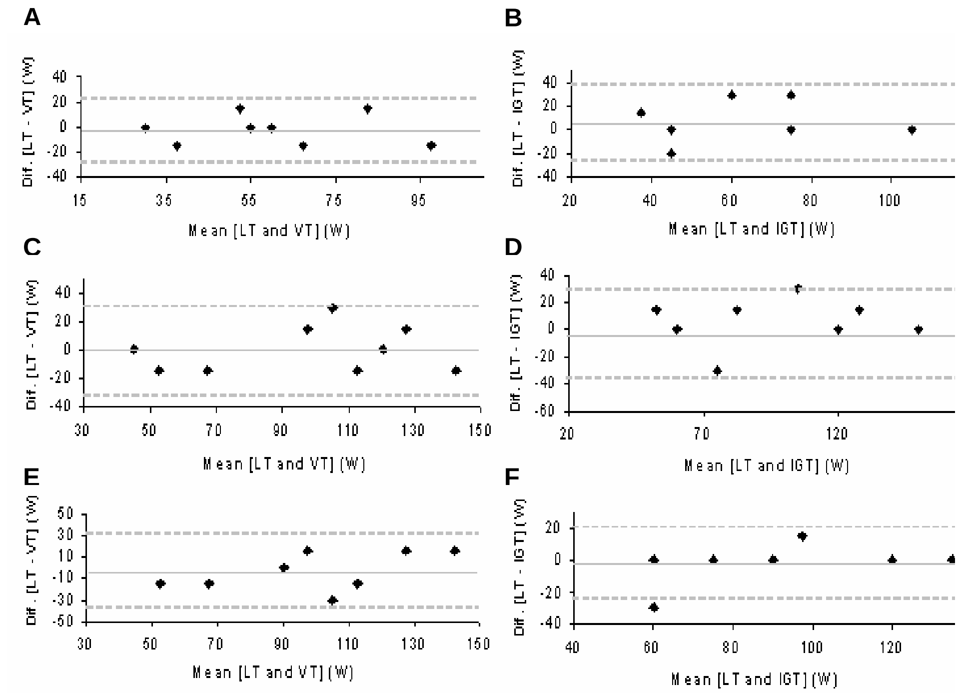

Figure 3. Agreement analysis by Bland and Altman's technique[20], between lactate threshold (LT) and ventilatory threshold (VT) and individual glucose threshold (IGT) protocols for the groups of sedentary type-2 diabetics (SD) (A and B), physically active type 2 diabetics (AD) (C and D) and physically active non-diabetics (AND) (E and F).

the research. The fact that the intensities of the anaerobic threshold and VO_2peak in the AD and AND groups did not differ from each other is probably due to the similar levels of physical activity of these participants (Tables 2 and 1).

The differences observed between groups SD and AND for %HRpeak in which LT was identified can be explained because most of the diabetics-sample participants, especially the SD group, were perhaps unable to reach VO_2max and HRmax due to peripheral limitations, thus reaching a VO_2peak[1] with a corresponding HRpeak, whereas active individuals (AND) were able to get more exercise time (more stages) at intensities above anaerobic threshold which led to a greater HRpeak and, as a result, a smaller %HRpeak corresponding to LT when confronted with group SD. When the HRpeaks reached in the test were analyzed, the following values were recorded: 144.1 ± 26.1 bpm; 160.2 ± 33.5 bpm and 166.0 ± 12.5 bpm for SD, AD and AND respectively (Table 2). If these values were extrapolated towards an HRmax estimated by age (202-0,72*age)[21] of each group (Table 1 e 2), we noticed the SD that group finished the test with around 17 bpm less to reach maximum values when age estimates were made; groups AD and AND, in turn, finished with about 7 bpm and 1 bpm less than expected for their age groups, which can be explained by a possible peripheral process triggering fatigue, due to the fact that the equation used for HRmax was specific for exercise on the cyclo-ergometer.

For the SD group, they were believed to have a greater intolerance to exercise in relation to the active groups (DA and NDA) which, in turn, resulted in a significantly greater Ppeak (Table 2). The smallest Ppeak reached for SD reinforces the occurrence of peripheral restrictions in maximum rate of perceived exertion conditions, because upon analyzing the [Lac]peak variable, this group tended to show smaller values in relation to the active groups (Table 2 and Figure 2A), which reflects a smaller recruitment of motor units and which explains the smaller Ppeak and VO_2peak values for SD when compared to the active groups (Table 2).

LT and VT identification is well established in the literature for different populations[12,9,2,8], which corroborates the findings of the present study, that showed high correlations between AT determined by these parameters in diabetic and non-diabetic individuals. In a given exercise intensity, [Lac] and hydrogen ions (H^+) began to accumulate, indicating the occurrence of metabolic acidosis which is initially blocked by bicarbonate (HCO_3^-), resulting in an augmented VCO_2 in the attempt to compensate for the metabolic acidosis with the respiratory alkalosis as a result of stimuli from CO_2 and H^+ ions in the respiratory centre [22].

Glucose kinetics made it possible to identify the glucose threshold (Figure 1 and 2D) in a way similar to other studies with healthy individuals exercising both on the cyclo-ergometer[7] and running[10]. The increase of glucose during the incremental test, in intensities above AT, can be explained due to greater levels of catecolamins and circulating glucagon, resulting in a production of hepatic glucose superior to its cellular capture [24].

The use of IGT for the prescription of aerobic exercise for type 2 diabetics delimitates a point of extreme relevance related to that disease, since hyperglycemia is the main characteristic of diabetes, and the fact that incremental exercises performed until that limit resulted in a greater glucose capture than its production (Figure 2D) suggests that intensities related to AT contribute acutely to a better control of these patients' blood glucose, who even with basal conditions demonstrate Gluc values that are above desired levels.

Besides altered Gluc, approximately 80% of diabetics are overweight or obese, and show high systemic blood pressure[14], as observed especially in group SD (Table 1). The percentage of fat of the participants in the present study was inversely correlated with the absolute intensity of AT occurrence ($p < 0.05$). Furthermore, we observed a tendency for ambulatory glycemia and AT ($p = 0.08$) to correlate. Therefore, type 2 diabetics are advised to perform exercises in accordance with AT relative intensities that contribute to the improvement of this parameter in the medium and in the long run, with a consequent reduction of fat percentage and a better glucose control which on balance, will enhance these patients' health conditions.

The use of the RPE scale in the present study represents an interesting application possibility in the prescription of exercise for diabetics. RPE indicates the perception of discomfort or fatigue at a given moment in the exercise[19], and some studies have demonstrated RPE values in AT around 12 and 13 points in *Borg*'s 15-point scale[25,7]. Such studies are in accordance with the findings of the present study, in which AT was observed between 12.7 and 14.3 on the scale (Table 2), with a general average of around 13 points. The use of RPE as a measuring tool for the control of workload for type 2 diabetics, restricting intensities of exercise in which there may occur a predominance of capture (intensities below RPE 13) or in the hepatic production of glucose, causing glucose levels to increase (intensities with RPE above 14), seems to be especially important for diabetics. Nonetheless, additional studies must be carried out on the use of RPE for AT estimates for special populations such as type 2 diabetics, as well as its application in the prescription of training and its chronic effects.

As for the agreement among the different protocols used, high correlations between IGT and VT and LT (Figure 3) were found. LT is considered the gold standard in aerobic capacity evaluation, however it requires invasive methods and expensive equipment for the analysis of blood dosages. On the one hand, although IGT also requires invasive methods, perhaps it can be applied with low-cost equipment that are also easy to operate and available on the market (glucose meters). This could provide the individual with both a report of their glycemic levels during exercise and their aerobic capacity (AT), and such information is highly relevant, particularly if the evaluated individual suffers from diabetes. On the other hand, VT has its advantages for not being an invasive method but which, for its determination, requires high-cost equipment for the analysis of the gas variables such as O_2 and CO_2. There is there need for more studies which try to reproduce LV with more accessible, more user-friendly equipment (e.g., a ventilometer).

By comparing intensity variables of (W), HR, [Lac] e VO_2 corresponding to AT, there were no differences between the groups (Table 2). Moreover, the identified thresholds showed themselves to be highly related to functional performance, with meaningful correlation coefficients between the threshold intensities and performance ($r = 0.89$ for LL vs. Ppeak, $r = 0.87$ for LV vs. Ppeak and r= 0.80 for IGT vs. Peak) of the samples covered in this study.

CONCLUSIONS

AT could successfully be identified from blood lactate, ventilation and glucose in type 2 diabetics and non-diabetics, with no differences found between the adopted techniques. This occurred in greater absolute intensities for physically active individuals when compared to those who were sedentary. On the other hand, both the presence of a pathology as well as the level of physical fitness on the part of the participants did not interfere with the relative intensities for the observed thresholds.. Finally, it was pointed out that the absolute intensity of AT occurrence was inversely correlated to body composition, showing a tendency to correlate itself with the participants' glucose control.

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