A Comparison of Lactate Threshold and Onset of Blood Lactate Accumulation during Two Kinds of Duration of Incremental Exercises.

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To determine the effect of the duration of incremental exercise on the point at which arterial blood lactate concentration (HLa) increases above the resting value (lactate threshold: LT) and on the point at which HLa reaches a constant value of 4 mM (onset of blood lactate accumulation: OBLA), eight male students performed two different kinds of incremental exercise. In addition, the workloads corresponding to OBLA, which were obtained during both incremental exercises, were investigated for the validity of endurance training intensity. Incremental exercise bicycle tests consisted of 25 watts increase every minute (the 1-min test) and every 4 minutes (the 4-min test), respectively. $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}_E$ were measured by the Douglas bag method. Arterial blood samples were obtained from a catheter inserted into the radial artery. Blood HLa was analyzed by the enzymatic method. LT and OBLA were determined from the relationships between the HLa and $\dot{V}O_2$ during the two kinds of incremental exercise tests. At the level of LT, OBLA, and maximal exercise, there was no significant difference in ventilatory and gas exchange parameters except for the workloads. Each subjects also performed two submaximal bicycle exercises for 15 minutes which intensities were corresponded to OBLA. During the submaximal exercise performed with the workload that had been determined with the 1-min test, HLa increased gradually with duration and attained 8.8 ± 1.2 mM after the end of exercise. On the other hand, when the submaximal exercise was performed with the workload which had been determined with the 4-min test, HLa remained at the predetermined value (4.0 ± 0.4 mM).

It was concluded that the lactate steady state condition was necessary to determine the endurance training intensity.

Key Words: Lactate threshold; Onset of blood lactate accumulation; Arterial lactate concentration; Endurance training intensity

INTRODUCTION

It has been proposed that one of the optimal intensities for endurance training can be obtained on the basis of the point at which the arterial blood lactate concentration (HLa) begins to increase above the resting value (lactate threshold; LT) or attains a given value of 4 mM of HLa (onset of blood lactate accumulation; OBLA) during an incremental exercise test (Katch *et al.* 1978; Kindermann *et al.* 1979; Yoshida *et al.* 1982a).

Since HLa is time-dependently effused from skeletal muscle tissue as a result of an imbalance between the lactate production and uptake in the

muscle tissue during exercise, the duration of sustained workload during an incremental exercise test would influence the relationship HLa and workload. Thus, if the exercise intensity for endurance training determine at LT or OBLA, in other words, it based on blood lactate level, the intensity would be overestimated during rapid incremental exercise compared with during steady state exercise.

The purpose of this investigation, therefore, was to assess the exercise intensity which obtained at LT or OBLA while changing the duration of the incremental exercise test. In addition, it is interest to compare the exercise intensities prescribed in this

method with percent of maximal oxygen uptake ($\dot{V}O_{2\max}$) or metabolic acidosis status.

MATERIALS AND METHODS

a) **Subjects:** Eight healthy male students volunteered to be subjects for the present study. Each subject was fully informed of the purpose of this study and possible risks before signing a written consent form. Prior to the experiment, each subject underwent a medical examination, including an ECG test, blood pressure test, spirometric test, and general medical check-up; none of them showed any abnormalities. The average ($\pm$ SEM) age, height, and weight of the subjects are 21.6 ± 0.4 yr, 169.8 ± 3.5 cm, and 69.1 ± 3.4 kg, respectively.

b) **Incremental Exercise Tests:** Two incremental exercise tests were performed on a Monark bicycle ergometer at 50 rpm. One test consisted of 4-minute unloaded pedalling ("O" watt), and thereafter 25 watts incremental loading every minute until volitional exhaustion (1-min test). The other commenced with 4-minute unloaded pedalling, and thereafter 25 watt increments were given every 4 minutes until exhaustion (4-min test). The two tests were performed separately at least one week apart.

Oxygen uptake ($\dot{V}O_2$) was measured by means of the Douglas bag method. During both incremental exercise tests, the subjects breathed through a low resistance J-valve (Rudolph Non-rebreath Valve) and the expired gas was collected into a Douglas bag every subsequent minute. The collected expired gas was immediately assessed for minute ventilation ($\dot{V}_E$) by a gas meter.

A portion of the gas sample was dried with CaCl_2 and was analyzed for O_2 and CO_2 concentrations by a polarograph oxygen analyzer and an infra-red carbon dioxide analyzer, respectively. All the instrumentation was calibrated against a micro-Scholander gas analyzer prior to each experimental run. Heart rate (HR) was continuously monitored by an ECG with CM_5 lead position.

To obtain blood samples, one Teflon catheter was

inserted into the radial artery with local anesthesia by 0.5% xylocaine. Blood samples were taken at rest and every 1 minute in the 1-min test and every final minute of each workload in the 4-min test (i.e. the last minute at each submaximal workload). At near-maximal and maximal exercise, blood samplings were performed every 1 minute in the 4-min test. The analysis of HLa was performed by the enzymatic method (Boehringer Mannheim, FRG); chilled 0.6N perchloric acid (HClO_4) was used for deproteinization.

c) **Determination of LT and OBLA:** LT was determined as the point at which arterial blood HLa begins to increase above the resting level (Yoshida *et al.* 1981; 1982a; 1982b). OBLA was determined as the point at which arterial blood HLa reaches a given value of 4 mM (Jacobs 1981; Sjödin and Jacobs 1981).

d) **Submaximal Exercise Test for Prescribed Intensity:** From the relationships between HLa and $\dot{V}O_2$, and between the workload and $\dot{V}O_2$ during both incremental exercise tests, the workloads corresponding to OBLA were determined with 1-min and 4-min tests (Fig. 1). Then, each subject performed two submaximal exercise tests with the predetermined workloads for 15 minute on different days (randomly assigned).

During the submaximal exercise tests, ventilatory and gas exchange parameters ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$) were determined every succeeding minute, and HR was monitored by an ECG technique. Arterial blood samples were taken at rest and every 5 minutes from the radial artery with local anesthesia. pH, Po_2 , and Pco_2 of anaerobically drawn arterial blood were analyzed by the electrode at 37°C (Instrumentation Laboratory Model 813/Blood Gas Analyzer). Bicarbonate concentration (HCO_3^-) was calculated by the Henderson-Hasselbalch equation. HLa was analyzed according to the enzymatic method.

e) **Statistical Analyses:** Means and SEM were calculated according to a standard method. Regression analysis and correlation analysis were performed.

Fig. 1 An example of the relationship between HLa and $\dot{V}\text{O}_2$, and between the workload and $\dot{V}\text{O}_2$ during the 1-min test and 4-min test, respectively.

med on the appropriate data. Paired *t*-tests were used to evaluate differences in the appropriate data.

RESULTS

Table 1 shows the descriptive data obtained the two incremental exercise tests (the 1-min and the 4-min tests). No significant difference was observed in maximal measures except the peak workload attained (247.0 ± 12.0 W in the 1-min test, 200.9 ± 9.5 W in the 4-min test, $P < 0.01$). At the level of OBLA, there was no significant difference in ventilatory and gas exchange parameters except in the workload (177.5 ± 5.5 W in the 1-min test, 144.0 ± 7.0 W in the 4-min test, $P < 0.01$). At the level of LT, there was no significant difference in the parameters between two incremental exercise tests. Workload at LT in the 1-min test was significantly higher than in the 4-min test (75.0 ± 6.5 W in the 1-min test, $65.5 \pm$

6.5 W in the 4-min test, $P < 0.05$). Thereafter, the intensities of the submaximal exercise tests were determined from these incremental exercise tests. As a result, from the 1-min test the intensity for submaximal exercise averaged 177.5 W and from the 4-min test the intensity averaged 144.0 W. At predetermined intensity obtained in this way each subject pedalled the bicycle ergometer during 15 minutes.

During the submaximal exercise performed with the workload predetermined with the 1-min test (average 177.5 W), two subjects stopped the exercise due to volitional exhaustion. Arterial HLa increased gradually with exercise duration, and attained 8.8 ± 1.2 mM at 15 minutes of exercise ($n = 6$) as shown in Fig. 2. On the contrary, when the submaximal exercise was performed with the workload predetermined with the 4-min test (average 144.

Table 1. Descriptive data at LT, OBLA and maximal exercise obtained during the 1-min test and 4-min test.

Measures	1-min test	4-min test
maximal exercise		
$\dot{V}O_2$ (l·min ⁻¹)	2.64±0.10	2.58±0.10
$\dot{V}O_2$ (ml·kg ⁻¹ ·min ⁻¹)	39.9±1.7	39.5±1.7
$\dot{V}_E$ max (l·min ⁻¹)	99.6±7.1	96.8±5.3
HR (beats·min ⁻¹)	184±3	191±3
HLa at $\dot{V}O_{2max}$ (mM)	8.66±0.85	7.99±0.78
Work rate (W)	247.0±12.0**	200.0±9.5
OBLA		
$\dot{V}O_2$ (l·min ⁻¹)	2.04±0.05	1.96±0.06
% $\dot{V}O_{2max}$ (%)	77.7±2.7	76.6±2.9
$\dot{V}_E$ (l·min ⁻¹)	56.9±2.2	59.0±2.7
HR (beats·min ⁻¹)	153±5	164±5
HLa at OBLA (mM)	4	4
Work rate (W)	177.5±5.5**	144.0±7.0
lactate threshold		
$\dot{V}O_2$ (l·min ⁻¹)	0.95±0.06	1.00±0.05
% $\dot{V}O_{2max}$ (%)	35.9±2.0	38.8±2.1
$\dot{V}_E$ (l·min ⁻¹)	26.7±2.3	30.7±1.9
HR (beats·min ⁻¹)	105±4	112±4
HLa at LT (mM)	1.39±0.13	1.32±0.07
Work rate (W)	75.0±6.5*	65.5±6.5

 $\bar{X} \pm SEM$

* P<0.05; ** P<0.01

Table 2. Descriptive data obtained during the submaximal exercises of 15 min duration, whose workloads were assessed to be OBLA for the 1-min test and the 4-min test.

	Submaximal exercises at the intensity of OBLA which was obtained with	
	the 1-min test (n=6)	the 4-min test (n=8)
$\dot{V}O_2$ (l·min ⁻¹)	2.34±0.17**	1.76±0.07
% $\dot{V}O_{2max}$ (%)	90.4±5.7**	66.9±4.7
$\dot{V}_E$ (l·min ⁻¹)	87.7±2.5**	51.1±4.0
RER	1.05±0.03**	0.93±0.02
HR (beats·min ⁻¹)	164.4±17.8	151.8±8.3
HLa (mM)	8.8±1.2**	4.0±0.4
Work rate (W)	177.5±5.5**	144.0±7.0

 $\bar{X} \pm SEM$

** P<0.01

Data were obtained during the last minute of the submaximal exercise tests.

Fig. 2 The mean HLa $\pm$ 1SEM during submaximal exercise of which intensities corresponded to OBLA obtained with the 1-min and 4-min test. Open circles indicate time course with the work intensity set with the 1-min test, and closed circles with the 4-min test.

0 W), arterial HLa remained at the individual steady state of 4.0 ± 0.4 mM. Furthermore, $\dot{V}O_2$, % $\dot{V}O_{2max}$, $\dot{V}_E$, respiratory exchange ratio (RER), and heart rate during the submaximal exercise was significantly higher with the workload obtained with the 1-min test than with the 4-min test (Table 2).

DISCUSSION

Regardless of the exercise duration of each workload, there was no significant difference in ventilatory and gas exchange parameters at levels of LT, OBLA and maximal exercise during the 1-min and 4-min tests (Table 1). On the other hand, the workloads at LT and OBLA were significantly higher in the 1-min test than in the 4-min test ($P < 0.01$). This finding agrees with the results by Whipp et al. (1974; 1981) and Davis et al. (1982) who indicated that LT expressed in work load might be overestimated as the work duration decreased.

However, this finding does not agree with the result by Hughson and Green (1982). They obtained arterialized blood from a dorsal hand vein by warming procedure as proposed by Forster *et al.* (1972), who described that a valid estimation of PCO_2 , pH,

and HLa concentration from arterialized venous blood could be obtained if blood samplings were performed under a steady state condition. Since HLa is time-dependently produced from skeletal muscle tissue, the shorter incremental duration of workload resulted in a delay of blood lactate which appeared after a few minutes. As a result, an extremely rapid incremental loading method using HLa might lead to an overestimation of the LT. Furthermore, the previous study showed that the antecubital venous HLa resulted in a delay of lactate inflection point compared with arterial HLa during the 1-min test than the 4-min test (Yoshida 1984). Consequently, the valid estimation of arterialization of venous blood during fast ramp test such as approximately $50\text{--}60\text{ W}\cdot\text{min}^{-1}$ would be doubtful.

As shown in Fig. 1, the relationship between $\dot{V}O_2$ and workload is quite different in the 1-min and 4-min tests. The finding that the workload attained with a given $\dot{V}O_2$ is higher for the 1-min than the 4-min workload steps might be related to $\dot{V}O_2$ on-response at the onset of exercise. It was observed that the half-time of $\dot{V}O_2$ on-response is at the order of 33 to 41 s for untrained male subjects, and by increasing the workloads, $\dot{V}O_2$ on-response is prolonged (Cerretelli *et al.* 1977). Thus, after the 1-min test $\dot{V}O_2$ has not yet attained the steady state value, so that the workload to a given $\dot{V}O_2$ on-response seems to be increased under this condition as compared to the 4-min test. Consequently determination of LT or OBLA expressed in workload leads to a misunderstanding (Table 1).

The second focus of this investigation was to evaluate the usefulness of LT or a given level of blood HLa for endurance training intensity. In the present study, the 4mM HLa level (OBLA) was selected for the intensity of the submaximal exercise, because it was considered to be one of the optimal intensities for endurance training (Kindermann *et al.* 1979). In spite of incremental exercise duration, there was no significant difference in $\dot{V}O_2$ of the OBLA during both incremental exercise tests.

On the other hand, the workload at OBLA was significantly higher in the 1-min test than the 4-min test ($P < 0.01$). To my knowledge, the exact level at which the training should be performed was not clearly defined. When training intensity is regimented by means of LT or a given level of HLa obtained during incremental exercise test, it is necessary to keep in mind that the prescribed workload would differ according to the duration for OBLA determination even if the steady state test (4-min test) of exercise increments.

It is difficult to quantify, however, the relationship between a steady state condition and blood lactate level, because the HLa in blood is the result of complex interactions of the production, diffusion, distribution and removal process. When the submaximal exercise was performed actually at the predetermined intensity with the 1-min test, two subjects attained volitional exhaustion at 10 min and 13.5 min. Furthermore, at 15 minutes, arterial HLa of the rest of the subjects averaged 8.8 ± 1.2 mM (Table 2). Certainly, these values were significantly higher than the predetermined value of 4 mM of HLa ($P < 0.01$). On the other hand, when the submaximal exercise was performed at OBLA obtained with the 4-min test, arterial HLa stayed at the individual steady state and averaged 4.0 ± 0.4 mM at 15 minutes of exercise (Fig. 2).

Davis *et al.* (1982) suggested that when LT was assessed in $\dot{V}O_2$ as a measure of cardiorespiratory function, the desired work incremental rate would be a fast ramp ($20\text{--}50\text{ W}\cdot\text{min}^{-1}$), because LT expressed in $\dot{V}O_2$ was almost the same in spite of work rate. However, when the LT or a given acidosis status is used as the intensity of training or rehabilitation, the selection of the duration of exercise increments is important, since H^+ and HLa were influenced by time-dependent elements. In other words, it is desirable that a lactate steady state should be attained at each state of the incremental exercise test. In the present study, the untrained subjects could maintain a HLa steady state condi-

tion by performing submaximal exercise at a OBLA determined with the 4-min test. Further investigation is necessary using endurance trained subjects who have higher intramuscular oxidative capacity and more capillary density.

It was concluded that an adequate duration of each load is necessary for the incremental test to prescribe the training intensity on the basis of lactate steady state. In untrained subjects the duration was at least 4 minutes.

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