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Effect of exercise duration during incremental exercise on the determination of anaerobic threshold and the onset of blood lactate accumulation

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Summary. 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 (anaerobic threshold: AT) 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. A comparison of arterial HLa and venous HLa was made under both conditions of incremental exercise. The incremental bicycle exercise tests consisted of 25 W increase every minute (1-min test) and every 4 min (4-min test). At maximal exercise, there were no significant differences in either gas exchange parameters or HLa values for the two kinds of incremental exercise. However, the peak workloads attained during the two exercises were significantly different ($P < 0.01$). At OBLA and AT, there were no significant differences in gas exchange parameters during the 1-min and 4-min tests except for the workload (at OBLA $P < 0.01$; at AT $P < 0.05$). When venous blood HLa was used instead of arterial HLa for a 4-min test, AT was not significantly different from that obtained by arterial HLa, but OBLA was significantly different from that obtained by arterial HLa ($P < 0.05$). On the other hand, for the 1-min test, venous HLa values yielded significantly higher AT and OBLA compared with those obtained using arterial HLa ($P < 0.01$).

It was concluded that when arterial blood was used, there was no effect of duration of workload increase in an incremental exercise test on the determination of the AT and OBLA expressed in $\dot{V}_{O2}$. On the other hand, when venous HLa was used instead of arterial blood, these points might be overestimated when a fast increase in workload, such as the 1-min test, is used.

Key words: Anaerobic threshold – Onset of blood lactate accumulation – Arterial blood – Exercise duration

Introduction

Maximal oxygen uptake ($\dot{V}_{O2\,max}$) is the most objective index of endurance ability (Åstrand and Rodahl 1970). However, direct measurement of $\dot{V}_{O2\,max}$ requires maximal exercise tolerance, so that the subject must exercise to physical exhaustion. This method is, of course, accompanied by health risks and is influenced by the subject's motivation.

Recently, anaerobic threshold (AT) has been used as a measure of endurance ability, because it has a close relationship with endurance performance (Farrell et al. 1979; Kumagai et al. 1982; Tanaka et al. 1983), $\dot{V}_{O2\,max}$ (Davis et al. 1976; Weltman and Katch 1979; Yoshida et al. 1981) and oxidative capacity in skeletal muscle (Ivy et al. 1979). Furtherhmore, AT is obtained during a submaximal exercise test and is not influenced by motivation. Since AT is defined as $\dot{V}_{O2}$ or work rate at which metabolic acidosis occurs, it can be determined as the point at which blood lactate concentration (HLa) begins to increase above the resting value during an incremental exercise test.

As well as AT, a similar concept has been developed by using a given HLa value of 2 or 4 mM during a submaximal exercise test, and is called onset of blood lactate accumulation (OBLA) (Jacobs 1981; Sjödin and Jacobs 1981), or aerobic-anaerobic transition (Kindermann et al. 1979), or anaerobic threshold (Rusko et al. 1980). This point is also related to $\dot{V}_{O2\,max}$ (Jacobs 1981), endurance performance (Jacobs 1981, Sjödin and Jacobs 1981), and activities of oxidative enzymes in muscle tissue (Rusko et al. 1980).

Since arterial blood sampling is accompanied by pain, hyperventilation due to discomfort, technical difficulty, and use of local anesthesia, during exercise it is not always a practical procedure. Thus, arterialized capillary or warmed hand dorsal venous blood has been substituted for arterial blood. There have been, however, previous studies which observed that

AT differs according to the site of blood sampling (Yoshida et al. 1982b; Yeh et al. 1983). Furthermore, there are inconsistencies concerning the exercise testing mode with reference to AT and OBLA.

Therefore, the purpose of this study was to compare AT with OBLA using arterial- and venous-HLa during short- and long-duration incremental exercise tests.

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 ECG, blood pressure, spirometry, and a general medical check-up; none of them showed abnormalities. The physical characteristics of the subjects are shown in Table 1.

b) Incremental exercise. Two incremental exercise tests were performed on a Monark bicycle ergometer at 50 RPM. One test consisted of 4-min unloaded pedalling ("0" W), and thereafter 25 W incremental loading every minute until volitional exhaustion (1-min test). The other commenced with 4-min unloaded pedalling, and thereafter 25-W increments were given every 4 min until exhaustion (4-min test). The two tests were performed separately at least 1 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 Nonrebreath 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. All the instrumentation was calibrated against a micro-Scholander gas analyzer prior to each experimental run. Heart rate was continuously monitored by an ECG with CM_5 lead positions.

To obtain blood samples, one Teflon catheter was inserted into the radial artery under local anesthesia with 0.5% xylocaine, and another catheter was inserted into the antecubital vein. The arterial and venous blood samplings were simultaneously performed by two physicians. Blood samples were taken at rest, and every 1 min in the 1-min test and every final minute of each workload in the 4-min test. The analysis of blood lactate concentration (HLa) was performed by the enzymatic method (Boehringer Mannheim, FRG); chilled 0.6 N perchloric acid ($HClO_4$) was used for deproteinization.

c) Determination of AT and OBLA. AT 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 value of 4 mM (Jacobs 1981; Sjödin and Jacobs 1981).

Table 1. Physical characteristics of the subjects

	Age (years)	Height (cm)	Weight (kg)
X̄	21.6	169.8	69.1
± SEM	0.4	3.5	3.4

d) Statistical analyses. Means and SEM were calculated according to a standard method. Regression analysis and correlation analysis were performed, and paired *t*-tests were used to evaluate differences.

Results

Table 2 shows the descriptive data obtained at maximal exercise during the 1-min and 4-min tests.

Table 2. Descriptive data at AT, OBLA, and maximal exercise obtained during 1-min test and 4-min test

Measures	1-min test	4-min test
Maximal exercise		
$\dot{V}_{O_2}$ ($l \cdot min^{-1}$)	2.64 ± 0.10	2.58 ± 0.10
$\dot{V}_{O_2}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	39.9 ± 1.7	39.5 ± 2.4
$\dot{V}_E$ at $\dot{V}_{O_2\,max}$ ($l \cdot min^{-1}$)	99.6 ± 7.1	96.8 ± 5.3
HR ($beats \cdot min^{-1}$)	184 ± 3	191 ± 3
HLa at $\dot{V}_{O_2\,max}$ (mM)	8.66 ± 0.85	7.99 ± 0.78
Workload (watts)	247.0 ± 12.0**	200.0 ± 9.5
OBLA		
$\dot{V}_{O_2}$ ($l \cdot min^{-1}$)	2.04 ± 0.05	1.96 ± 0.06
$\%\dot{V}_{O_2\,max}$ (%)	77.7 ± 2.7	76.6 ± 2.9
$\dot{V}_E$ ($l \cdot min^{-1}$)	56.9 ± 2.2	59.0 ± 2.7
HR ($beats \cdot min^{-1}$)	153 ± 5	164 ± 5
HLa (mM)	4	4
Workload (watts)	177.5 ± 5.5**	144.0 ± 7.0
AT		
$\dot{V}_{O_2}$ ($l \cdot min^{-1}$)	0.95 ± 0.06	1.00 ± 0.05
$\%\dot{V}_{O_2\,max}$ (%)	35.9 ± 2.0	38.8 ± 2.1
$\dot{V}_E$ ($l \cdot min^{-1}$)	26.7 ± 2.3	30.7 ± 1.9
HR ($beats \cdot min^{-1}$)	105 ± 4	112 ± 4
HLa (mM)	1.39 ± 0.13	1.32 ± 0.07
Workload (W)	75.0 ± 6.5*	65.5 ± 6.5

X̄ ± SEM
* $P < 0.05$; ** $P < 0.01$

Table 3. Comparison of AT and OBLA obtained with arterial- or venous HLa during the 1-min or 4-min test

	AT obtained by	
	Arterial HLa	Venous HLa
1-min test	0.95 ± 0.06**	1.50 ± 0.16***
4-min test	1.00 ± 0.05	1.02 ± 0.10
	OBLA obtained by	
	Arterial HLa	Venous HLa
1-min test	2.04 ± 0.05**	2.37 ± 0.10***
4-min test	1.96 ± 0.06*	2.09 ± 0.07

X̄ ± SEM
Significant difference between arterial and venous blood:
* $P < 0.05$, ** $P < 0.01$
Significant difference between the 1-min and 4-min test:
*** $P < 0.01$
Data are expressed in $\dot{V}_{O_2}$ ($l \cdot min^{-1}$)

No significant difference was observed in any of the physiological measures except for the peak workload attained ($P < 0.01$).

Table 2 also shows OBLA and AT during the 1-min and 4-min tests. At OBLA and AT, there was no significant difference in ventilatory and gas exchange parameters except in the workload (at OBLA, $P < 0.01$; at AT, $P < 0.05$).

When OBLA and AT were determined using antecubital venous HLa during the 1-min and 4-min tests, the results were listed in Table 3 in comparison with those obtained with arterial HLa. During the steeper incremental exercise of the 1-min test, OBLA as well as AT obtained by venous HLa were significantly higher than those obtained with arterial HLa ($P < 0.01$). On the other hand, during the 4-min test, AT obtained by venous HLa was not significantly different from arterial AT. In contrast, OBLA obtained by venous HLa was significantly higher than that by arterial HLa ($P < 0.05$).

Discussion

Regardless of the exercise duration of each workload, arterial HLa yielded a quite similar pattern during the two incremental exercises (Fig. 1). As a result, there was no difference in ventilatory and gas exchange parameters at AT, OBLA, and maximal exercise during the 1-min and 4-min tests (Table 2). This finding agrees with the results described by Wasserman et al. (1973); Wasserman and Whipp (1975); Whipp et al. (1974, 1981), and Davis et al. (1982), who indicated that AT occurred at the same $\dot{V}_{O_2}$, independent of the duration of work increment, and regardless of the determination by gas exchange parameters or HLa. In the present study, the workloads at AT and OBLA were significantly higher in the 1-min test than in the 4-min test ($P < 0.01$). This finding agrees well with the results of Whipp et al. (1974, 1981) and Davis et al. (1982), who indicated that AT might be overestimated as work duration decreased.

Our result does not agree with the results of Hughson and Green (1982). They obtained arterialized blood from a dorsal hand vein by the warming procedure proposed by Forster et al. (1972), who suggested 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 it is well known that HLa is time-dependently produced from skeletal muscle, the shorter incremental duration of the workload resulted in a delayed appearance 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 AT.

As shown in Fig. 2, 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 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 of the order of 33–41 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 speeded up under this condition as compared to the 4-min test. Consequently, determination of AT or OBLA expressed in workload leads to a misunderstanding (Table 2).

When the workload of the incremental exercise test was increased every 4 min as employed in this study, there was no significant difference in the AT obtained with arterial and antecubital venous blood (Fig. 3). On the other hand, during the non-steady state condition of the 1-min test, the inflection point

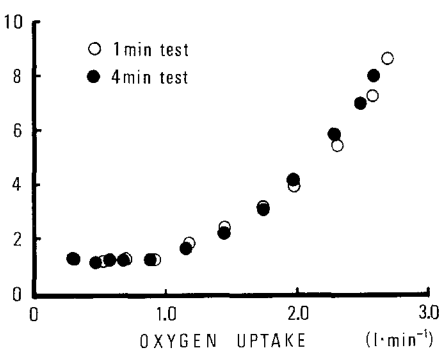

Fig. 1. The mean arterial blood HLa during 1-min test *(open circles)* and 4-min test *(closed circles)* are plotted against $\dot{V}_{O_2}$

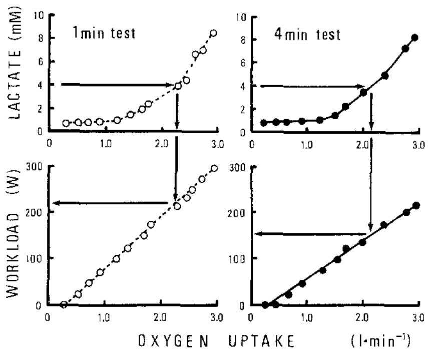

Fig. 2. An example of the relationship between arterial blood HLa and $\dot{V}_{O_2}$, and between the workload and $\dot{V}_{O_2}$ in 1-min and 4-min test

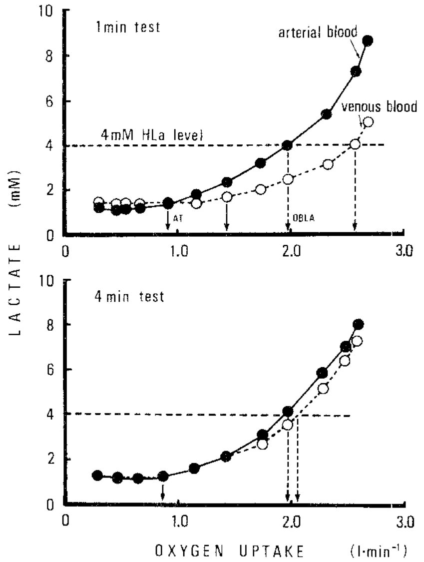

Fig. 3. The mean values of arterial and venous blood HLa during 1-min test and 4-min test, respectively. AT as well as OBLA are indicated

of venous blood HLa was significantly delayed as compared with the arterial HLa ($P < 0.01$), and OBLA obtained by venous HLa was also significantly delayed ($P < 0.01$). These findings are in agreement with those of previous studies (Yoshida et al. 1982b, Yeh et al. 1983), which suggested that the sampling site of blood should be considered when the metabolic acidosis status was assessed from blood HLa during the 1-min test.

It is concluded that when arterial blood was used, there was no effect of the duration of the workload increase in an incremental exercise test on the determination of AT and OBLA which was expressed in $\dot{V}_{O_2}$. On the other hand, venous HLa was not suitable for OBLA determination even if the steady state test (4-min test) was applied.

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