Validity in Noninvasive Prediction of Blood Lactate Accumulation from Excess CO_2 Output During Exercise

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Abstract

HIRAKOBA, K. Validity in Noninvasive Prediction of Blood Lactate Accumulation from Excess CO_2 Output During Exercise. Adv. Exerc. Sports Physiol., Vol.3, No.2 pp.55-58, 1997. This study was designed to theoretically reexamine the validity in noninvasive prediction of blood lactate (La) accumulation from excess CO_2 output (CO_2 excess) generated during exercise based on the data obtained in a previous study of Hirakoba et al. (12). Several assumptions were made; 1) total body water (TBW) corresponds to 60% of body mass, 2) La and hydrogen ion (H^+) are uniformly distributed in a whole TBW, 3) CO_2 excess derives from bicarbonate buffering of H^+ dissociated from lactic acid, and is equivalent to La accumulated in the body. From these assumptions, prediction of blood La accumulation ($\Delta La_{,predicted}$) and distribution volume of La (VLa) were calculated from CO_2 excess, TBW and actually measured blood La accumulation ($\Delta La_{,measured}$) during a three stages of constant work rate exercise test.

The $\Delta La_{,predicted}$ was found to be significantly lower than $\Delta La_{,measured}$ at each stage of constant work rate exercise. The mismatch between prediction and observation in blood La accumulation was larger with an increase of blood La accumulation. VLa throughout the three stages of constant work rate exercise calculated from CO_2 excess and $\Delta La_{,measured}$ was 21.4 ±5.3 l, which means that an average percent of VLa to TBW (%VLa) was 61.9±11.6%. Namely, it was found that the VLa obtained in this study was not equal to the TBW and %VLa was different among subjects.

Therefore, the data indicate that noninvasive prediction error of blood La accumulation from CO_2 excess during exercise would be accounted in part for by individuals' VLa during exercise test used in this study.

Key words: bicarbonate buffering, distribution volume of lactate, total body water

INTRODUCTION

It is generally accepted that a large part of hydrogen ion (H^+) accumulated in the body during exercise derives from dissociation from lactic acid (13). The lactate ion (La) and H^+ are released from exercising muscle to other tissues via both carrier-mediated transport and free diffusion processes (9) and distributed to both intra- and extracellular water. It has been indicated that the H^+ could be mainly buffered by bicarbonate (HCO_3^-) system in both intra- and extracellular water (2, 5, 20) and assumed that the observed excess carbon dioxide output (CO_2 excess) attributable to HCO_3^- buffering of H^+ dissociated from lactic acid ($H^+ + HCO_3^- \rightarrow H_2O + CO_2$) would be equal to HCO_3^- depletion in extracellular water (3, 7). Thus mmol of CO_2 excess has been indicated to reflect both the total mmols of La increase buffered by HCO_3^- and the distribution volume of HCO_3^- associated with the buffering of H^+ in the body (3, 23).

On the other hand, the distribution volume of La has been reported to be equal to the total body water (5, 8) , to about 75% (19, 23) and to about 50 % (1, 3) of the total body water. Thus as far as the distribution volume of La concerns, a definite conclusion has not been drawn yet.

The purpose of this study was to theoretically reexamine the validity in noninvasive prediction of blood La accumulation from CO_2 excess generated during three stages of constant work rate exercise from the distribution volume of La.

METHODS

For theoretical approach for prediction of blood La accumulation and the distribution volume of La during exercise, all data were recalculated based on the CO_2 excess and blood La accumulation obtained in a previous study (12). Therefore, the number and physical characteristics of the subjects and the experimental procedures for analyses used in this study have been described in detail previously (12). Briefly, the average values (±SD) of age, height and body mass of the subjects are 20±1.2 yrs, 170.4±4.7 cm and 57.0±5.5 kg, respectively. The exercise test employed consisted of three stages of constant work rate exercise at 100%, 120% and 150% corresponding to individuals' anaerobic threshold on a cycle ergometer (Monark-Crecent AB, Sweden), which was progressively increased every 4 min (total exercise time = 12 min). Expired gas was collected continuously throughout the exercise test by an automatic gas analyzer (Aerobic Processor 391, San-ei, Tokyo). Blood samples for the determination of La during the exercise test were withdrawn from an antecubital vein through an

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indwelling needle at rest and at the end of each stage of constant work rate exercise. La was analyzed by an enzymatic method.

An individual regression line of $\dot{V}CO_2$ - $\dot{V}O_2$ relationship during submaximal exercise below the anaerobic threshold in an incremental exercise test was used to calculate aerobically produced $\dot{V}CO_2$ (aerobic $\dot{V}CO_2$) during the constant work rate exercise test. CO_2 excess was estimated as the integral of difference between total $\dot{V}CO_2$ and aerobic $\dot{V}CO_2$ during the constant work rate exercise test.

Assumptions for predicting blood La accumulation and calculating distribution volume of La:

Total body water (TBW) was assumed to correspond to 60% of the body mass (3, 15). H^+ buffered in intra- and extracellular water would be stochiometrically equivalent to La accumulated during exercise, and CO_2 excess derived from HCO_3^- buffering of lactic acid would be equal to HCO_3^- depletion in the body. Consequently, blood La accumulation ($\Delta La_{,predicted}$) can be calculated from both CO_2 excess generated in exercise and TBW based on the assumptions that La released from exercising muscle is evenly distributed to the TBW, as shown in following equation;

$\Delta La_{,predicted}$ (mmol · l^{-1}) = CO_2 excess (mmol) / TBW (l) ----- [I]

and distribution volume of La (VLa) can be also calculated from CO_2 excess generated in exercise and actually measured blood La accumulation ($\Delta La_{,measured}$) from rest to exercise as shown in following equation (3)

VLa (l) = CO_2 excess (mmol) / $\Delta La_{,measured}$ (mmol · l^{-1}) ----- [II]

If La is uniformly distributed in the body water, VLa should be almost equal to the TBW.

Statistical analysis:

Values are expressed as mean and standard deviation (±SD). Paired Student t-test was used to compare the mean values between measured ($\Delta La_{,measured}$) and predicted ($\Delta La_{,predicted}$) blood La accumulation at each stage of constant work rate exercise test. Pearsons' product correlation coefficient (r) was calculated to assess the relationship between variables. Significant difference was set at $p<0.05$.

RESULTS

$\Delta La_{,predicted}$ calculated from Eq. [I] was found to be significantly lower than $\Delta La_{,measured}$ at each stage of the exercise test (Fig. 1). The absolute magnitude in the difference between $\Delta La_{,predicted}$ and $\Delta La_{,measured}$ was increased with an increase of blood La accumulation. On the other hand, the predicted values of La at three stages were 63.2% for stage I, 64.8% for stage II and 62.2% for stage III of the measured values, respectively.

Individual and mean (±SD) values in CO_2 excess (mmol) and VLa throughout the exercise test and blood La data at rest and at the end of the third stage are given in Table 1. VLa calculated from Eq. (II) was 21.4±5.3 l, ranging from 12.4 to 23.7 l, which means that an average percent of VLa to TBW (%VLa) was 61.9±11.6%, ranging from 46.6 to 86.9% (Table 1). Namely, it was found that the VLa obtained in this study was not equal to the TBW and %VLa was different among subjects.

DISCUSSION

In this study, it was assumed that La and H^+ were distributed in the body water in equimolar amounts. In addition, the predicted value of La accumulation was calculated from CO_2 excess and TBW, based on an assumption that La was evenly distributed in a whole body water. However, by using these assumptions in an extrapolation to the progressive three stages of constant work rate exercise, the predicted accumulation in blood La corresponded to about 63% of that seen in observed

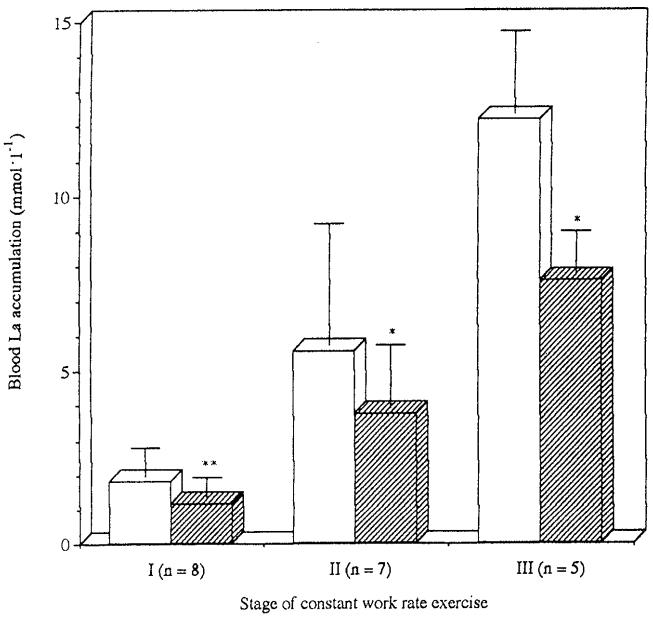

Fig 1. Comparison of measured (open bars) and predicted (cross-hatched bars) blood lactate accumulation at each stage of constant work rate exercise. The number in parenthesis shows the number of data obtained at each stage of the exercise test.
*; $p < 0.05$, **; $p < 0.01$, Significantly difference from the measured value

Table 1. Blood lactate data, excess CO_2 output and distribution volume of lactate from the onset to the end of progressive three stages of constant work rate exercise.

Subj.	CO_2excess (mmol)	La_{rest}	La_{peak} (mmol·l^{-1})	ΔLa_{peak}	V_{La} (l)	$\%V_{La}$ (%)
1	168	0.79	9.08	8.29	20.2	61.3*
2	288	0.76	9.88	9.12	31.6	86.9
3	181	1.73	16.33	14.60	12.4	46.6
4	345	0.90	15.44	14.54	23.7	66.2
5	84	0.88	4.76	3.88	21.6	58.2*
6	230	0.89	12.44	11.55	19.9	56.9
7	232	1.31	13.33	12.02	19.3	57.2*
8	250	0.77	11.89	11.12	22.5	62.5
mean	222	1.00	11.64	10.64	21.4	61.9
SD	79	0.34	3.72	3.53	5.3	11.6

CO_2 excess; excess carbon dioxide output, La_{rest}; blood lactate concentration at rest, La_{peak}; peak blood lactate concentration at the end of third stage of constant work rate exercise, ΔLa_{peak}; peak value of measured blood lactate accumulation, V_{La}; distribution volume of lactate, $\%V_{La}$; percentage of distribution volume of lactate to total body water Total body water was calculated by assuming that total body water is equal to 60% of body mass.

* denotes the data at the end of second stage of exercise, because subjects 1,5 and 7 could not complete the third stage of exercise.

accumulation. The relative magnitude in this mismatch between prediction and observation of blood La accumulation was almost unchanged throughout the exercise test (63.2% for stage I, 64.8% for stage II, 62.2% for stage III), whereas the data revealed a tendency that the absolute prediction error of La was larger with an increase in blood La accumulation (Fig. 1). Therefore, the above mentioned assumptions for La prediction should be verified.

H^+ from lactic acid has been thought to be predominantly buffered by HCO_3^- system (2, 5, 20). However, the decrease of HCO_3^- has been found and indicated to be within 90% of La increase during exercise (11, 16, 20, 21). Medbo and Sejersted (16) reported that the HCO_3^- system neutralized about 75% of the acid load for a decrease in blood pH from 7.4 to 7.07. If La and H^+ were distributed in the body water in equimolar amounts, the decrease of HCO_3^- would be lower than La accumulation, which in turn could be associated with lower volume of CO_2 excess than expected from La accumulation. If this is true, it seems likely that some difference may exist between predicted and measured values in blood La accumulation. According to the previous studies (10, 22), a quantitative relationship between CO_2 excess and blood La accumulation (volume of CO_2 excess per unit increase of blood La) has been found to vary among subjects due to fitness level and training specificity.

It is emphasized that VLa would be a critical factor in evaluating La accumulated in the body (8), because in this study predicted value in La accumulation was calculated from CO_2 excess and TBW. Brechue and Stainsby (4) calculated La release from exercising muscle, and reported that predicted rise in blood La on the assumption that VLa is equal to TBW (or 60% of the body mass) was about one-half of that in observation. Taken together, from the mismatch of prediction and observation in this study, one question rises whether or not La released from exercising muscle was uniformly distributed in a whole body water in this type of exercise test. Piiper (17) proposed a model for calculating VLa during short-term heavy exercise. For calculation of VLa, following assumptions were made;

i) muscle mass (28kg) corresponds to 40% of body mass (70kg)
ii) water contents of intra- and extracellular space are assumed to be 50% and 25% of muscle mass, respectively; muscle mass of 28 kg contains 14 liters H_2O in intracellular space ($[H_2O]$ i) and 7 liters H_2O in extracellular space ($[H_2O]$e)
iii) 4.1 liters of water ($[H_2O]$b) is included in 5 liters of total blood volume
iv) H^+ is distributed to and buffered in only two fluid compartments, i.e., muscle and blood.

If VLa is calculated from the Piiper's model (VLa = $[H_2O]$i + $[H_2O]$e + $[H_2O]$b), it will give VLa = 25.1 liters or %VLa = 59.8% to 42 liters TBW (assuming that TBW corresponds to 60% of body mass). On the other hand, according to Cerretelli et al. (6), changing the Piiper's assumption (iv) into other assumption that H^+ from lactic acid is distributed to all tissues (52 kg) exception of bones, $[H_2O]$i and $[H_2O]$e are 26 and 13 liters, respectively, without changing $[H_2O]$b. This calculation will result in 43.1 liters of VLa (VLa = 26 + 13 + 4.1 = 43.1), which means that La is equally distributed in the whole body water. However, %VLa obtained in this study was approximately 62 % of TBW, which is consistent with the above mentioned Piiper's model (%VLa = 59.8%). Moreover, this is similar to the result of Beaver and Wasserman (3) that the VLa was calculated by the same method as this study. Thus it is inferred in this study

of progressive three stages of constant work rate exercise that La could not be evenly distributed in the whole body water.

There have been many studies regarding the distribution volume of La under resting state and exercise. VLa has been found to be equal to the TBW (5, 8), to be about 75% (19, 23) and 50% (1, 3) to the TBW. The variation of VLa among literature might be considered to be associated with the differences in analytical techniques employed and experimental situation when the determination was made (13). Furthermore, production rate of La in and La efflux out of exercising muscle depending on muscle capillary density and muscle blood flow (3, 14, 18) appear to be the most important factors in determining VLa during exercise. The VLa would be therefore considered to be greatly changed by intensity and duration of exercise test. When predicting blood La accumulation from CO_2 excess and body water, one should take into account for VLa during exercise.

Consequently, it is concluded that noninvasive prediction error of blood lactate accumulation from CO_2 excess during exercise would be accounted in part for by individual's VLa during exercise.

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