Short Communication

Relationship between Maximal Pulmonary Ventilation during Exhaustive Exercise and Postexercise Plasma Potassium Concentration in Man

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Summary The present study was undertaken to examine the relationship between maximal pulmonary ventilation ($\dot{V}_{E_{\text{max}}}$) and potassium concentration ([K⁺]) or lactate concentration ([La]) of venous blood in man. Nine healthy men performed exercise on a bicycle ergometer at a constant rate of 60 rpm until volitional fatigue. $\dot{V}_{E_{\text{max}}}$ ranged from 100.4 to 153.2 l/min. In all subjects, potassium concentration measured at 1 min ([K⁺]₁₀) after maximal exhaustive exercise was the highest, and it returned quickly to the resting level within a few minutes during recovery. $\dot{V}_{E_{\text{max}}}$ was significantly correlated ($r=0.750, p<0.05$) to [K⁺]₁₀, but not to lactate concentration determined at 1 min ([La]₁₀) during recovery. These results suggest that a higher increase in blood [K⁺] may, at least partly, contribute to a greater augmentation of $\dot{V}_{E}$ during exhaustive exercise.

Key words: maximum exhaustive exercise, maximal pulmonary ventilation, plasma potassium and lactate concentration.

Although it is generally accepted that the control of pulmonary ventilation ($\dot{V}_{E}$) in exercise is regulated by a combination of neural and humoral drives, Band et al. [1] have observed the similarity of the time courses of blood potassium concentration ([K⁺]) and ventilation changes during bicycle ergometer exercise. In addition, Linton and Band [2] suggested that potassium released from muscles may be an important drive for ventilation in exercise because there is an increase in carotid chemoreceptor activity, which closely follows the arterial potassium concentration, and an increase in ventilation when intravenous injections of potassium chloride were given to anesthetized cats. In fact, the rise in [K⁺] is directly proportional to the increase in carbon dioxide production or oxygen uptake during

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exercise and is also well correlated with $V_E$ in normal subject [3–7]. Since this correlation is also seen during an incremental exercise test in the patients with McArdle’s syndrome, Paterson et al. [8] described that hyperkalemia may contribute significantly to the drive to breathe, especially during heavy exercise. From these results, it is possible to assume that $[K^+]$ would be higher in those subjects with higher maximal pulmonary ventilation. However, there are no available data as to whether or not maximal pulmonary ventilation ($\dot{V}_{E_{\text{max}}}$) obtained during maximal exhaustive exercise for each subject is related to the $[K^+]$, but not blood lactate concentration ([La]). The present study, therefore, was undertaken to examine the relationship between $\dot{V}_{E_{\text{max}}}$ and $[K^+]$ or [La] in healthy subjects.

Nine healthy male students who had no history of cardiovascular or respiratory disease participated in this study. All subjects received detailed explanations as to the experimental nature and risks before obtaining consent. The average values and their standard deviation of age, weight, and height were 20.0±0.9 years, 63.8±4.9 kg, and 175.4±4.7 cm, respectively.

The subjects came to the laboratory at least twice on separate days. On the first day, each subject was only familiarized with equipment and procedures involved in the study; they performed a preliminary test to become sufficiently accustomed to cycling with incremental loading at a constant rhythm. Few days later, a maximal exercise test was carried out in order to estimate aerobic work capacity of each subject. The experiments were always done 2 h after their last meal. Each individual was weighed prior to testing. After the subject rested in the sitting position on a comfortable chair for 30 min, the subject then performed a warm-up exercise on the bicycle ergometer (Monark, Sweden) at 60 rpm with work load of 360 kg m/min for 2 min. The frequency of the pedaling was maintained at 60 rpm synchronized with a metronome in all experiments. Thereafter, maximal exhaustive exercise was performed on the bicycle ergometer at 60 rpm with incremental loading, i.e., work load was increased each minute by 180 kg m/min until 5 min from the start of exercise, and it was increased each minute by 90 kg m/min until exhaustion. Subjects were given strong verbal encouragement to maintain this frequency and work rate for as long as possible. The incremental work load chosen was based on a preliminary test so that the subjects could drive for about 6–12 min before they were exhausted. The subjects again rested in the supine position for 12 min after the exhaustive exercise.

The expired gas was collected continuously into a Douglas bag every 1 min until exhaustion, through a collecting tube and respiratory facemask. The collected gas was measured with a wet gasometer, and gas analyses were performed with an infrared CO$_2$ analyzer (Capnograph, Godart, Holland) and an O$_2$ analyzer (Model S-3A, Morgan, England). These apparatus were calibrated with two calibration gases that had been checked by the Schoander micro-gas analyzer.

Two milliliters of blood were drawn from the antecubital vein (v. mediana cubiti) with intact circulation before and after exercise. In recovery, it was drawn at 1, 2, 3, 5, 7, 10, and 12 min, respectively. The [La] and [K$^+$] were analyzed...
using an enzymatic method [9] and sodium-potassium analyzer (Radiometer, KNA2, Denmark), respectively.

Mean and standard deviation were calculated by standard methods. Statistical comparisons were applied using one-way analysis of variance (ANOVA). If a significance was found in ANOVA, multiple comparisons were performed by means of Dunnett’s method.

All subjects were exhausted at 6 min 42 s to 12 min. Their maximum oxygen uptake ($\dot{V}_{O_{2,\text{max}}}$) and maximum oxygen uptake per kilogram of body weight ($\dot{V}_{O_{2,\text{max}}}/\text{kg BW}$) ranged from 2.23 to 3.72 l/min and from 38.3 to 54.7 ml/kg/min, respectively. The maximal pulmonary ventilation ($\dot{V}_{E,\text{max}}$) and maximal pulmonary ventilation per kilogram of body weight ($\dot{V}_{E,\text{max}}/\text{kg BW}$) ranged from 100.4 to 153.2 l/min and from 1.73 to 2.09 l/kg/min. Significant correlation ($r=0.745, p<0.05$) was found between $\dot{V}_{O_{2,\text{max}}}$ and $\dot{V}_{E,\text{max}}$.

Average values and standard deviations (±SD) of resting blood $[K^+]$ were 3.89 ± 0.31 mM. In all subjects, blood potassium concentration determined at 1 min after the maximal exhaustive exercise ($[K^+]_{1.0}$) was higher as compared with rest and the highest, and it returned quickly to the resting level within a few minutes during recovery. In contrast, the blood lactate concentration determined at 1 min during recovery ($[\text{La}]_{1.0}$) was lower than peak blood lactate concentration ($[\text{La}]_p$) which was observed at 3–7 min after exercise (Fig. 1). Average values (±SD) of $[\text{La}]_{1.0}$ and $[\text{La}]_p$ were 10.05 ± 2.64 and 11.94 ± 3.12 mM, respectively. The $\dot{V}_{E,\text{max}}$ was significantly correlated ($r=0.750, p<0.05$) with $[K^+]_{1.0}$ but not with $[\text{La}]_{1.0}$ ($r=0.038$) as shown in Fig. 2. Moreover, no significant correlation ($r=-0.115$) was found between $\dot{V}_{E,\text{max}}$ and $[\text{La}]_p$.

Several humoral and neural factors were considered as causes of the exercise hyperpnea. Concerning the neural factors, an increase in ventilation is postulated to occur due to afferent inputs conveyed by the group III and IV fibers [10, 11].

![Graph showing lactate and potassium concentration before and after maximal exhaustive exercise](image)

**Fig. 1.** Lactate and potassium concentration before and after maximal exhaustive exercise (mean ± SD, n = 9). Asterisks indicate significant difference from resting value. *p < 0.05; **p < 0.01.
However, Fernandes et al. [12] have suggested that afferent neural activity from the working muscles is important for blood pressure regulation during dynamic exercise in man but may not be necessary for eliciting the ventilatory responses. In addition, a number of studies indicated that acidosis may not act as an important ventilatory stimulus during exercise [13, 14].

On the other hand, it is well known that during exercise K⁺ is released from working muscle and that the blood [K⁺] increases [15, 16]. Blood K⁺ as a stimulus factor of hyperpnea is recently being watched with keen interest [17]. Since $\dot{V}E$ correlates closely with [K⁺] not only during both light and heavy exercise, but also during recovery from exercise [1, 3–5, 18], it has been suggested that K⁺ released from working muscle might play a role as an important stimulus for ventilation during exercise. In addition, Paterson et al. [8] have recently observed a close relationship between arterial plasma [K⁺] and $\dot{V}E$ during incremental exercise in McArdle's subjects. Busse et al. [19] have recently reported that lactic acidosis had no decisive effect on exercise ventilation and the increase in [K⁺] may contribute to the ventilatory drive during exercise. These observations suggest a possibility that higher $\dot{V}E_{\text{max}}$ obtained during maximal exercise may also be due to the higher increase in plasma [K⁺], rather than lactate.

Since plasma K⁺ concentration decreases quickly after exercise within a few minutes [20, 21], the arterial blood sample should be taken during and/or immediately after exercise in order to examine the relationship between $\dot{V}E_{\text{max}}$ and [K⁺] for each subject. In these experiments, however, it is unfortunate that we could not draw arterial blood samples during or immediately after exhaustive exercise for the following reasons: 1) the subjects were healthy normal students, 2) it is considered dangerous to perform exhaustive exercise with a needle or catheter inserted into vessels during vigorous ergometer exercise in which subjects grasp the handlebars.
with arms undergoing unstable movement. 3) Medbo and Sejersted [21] found no significant difference in the [K⁺] between arterial and femoral-venous plasma before and after 1 min of exhaustive exercise. As shown in Fig. 2, it was found that \( \dot{V}_{E_{\text{max}}} \) was correlated significantly (\( r = 0.750, p < 0.05 \)) with venous blood [K⁺]₁₀. In addition, there was no significant correlation between \( \dot{V}_{E_{\text{max}}} \) and [La]₁₀ or [La]ₚ. It seemed reasonable to predict that the blood [K⁺] level during exhaustive exercise might have been much higher than that determined after exercise, and [K⁺]₁₀ obtained here may be closely related to the arterial [K⁺] at exhaustion. If so, it is possible to assume that a higher blood [K⁺] may elicit a larger ventilatory drive via stimulating peripheral chemoreceptors. However, further studies are needed to confirm this assumption by determining the arterial blood [K⁺] and \( \dot{V}_E \) during maximal exhaustive exercise.

REFERENCES


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