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Oxygen Deficit and Debt in Submaximal Exercise at Sea Level and High Altitude

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This study was designed to follow $\dot{V}_{O_2}$ changes at onset and offset of exercise in order to compare by indirect method the relative role played by the two creditors of complementary energy, creatine phosphate and anaerobic glycolysis, in lowlanders studied at sea level (SL) and after translocation to high altitude (HA).

Subjects and Methods

Three subjects were studied comparatively at SL (Paris) and after 3 weeks in La Paz (3800 m). Protocols and equipment were identical in the two places. A 30-min rest period preceded exercise performed on a bicycle at a pedaling frequency of 60 rpm, at three different work loads for two durations, 10 and 25 min. Each test was performed twice; $\dot{V}_{O_2}$ was measured by open circuit method every minute during the transient phases at the beginning and end of exercise and over longer periods of time when the changes expected were not so abrupt. Initial O_2 deficit was computed by adding the sequential differences between steady state V_{O_2} ($V_{O_2\ s \cdot st}$) and actual $\dot{V}_{O_2}$ during the initial transient phase. Final debt was computed as the sum of the differences between actual sequential $\dot{V}_{O_2}$ measured during recovery and rest $\dot{V}_{O_2}$. The first minute of deficit and debt was considered as representative of the fast components. The slow component was estimated as the difference between total value and the value of the first minute. Blood samples were drawn repeatedly for determinations of plasma lactic acid concentration, [La], during the 25-min exercise performed at the highest work load. Maximal O_2 uptake ($\dot{V}_{O_2\ \mathrm{max}}$) was determined by Maritz's indirect method (8); the maximal heart rate at HA was taken as equal to that at SL minus 10 (7).

Results

Steady State Data

$\dot{V}_{O_2\ s \cdot st}$ is linearly related to the mechanical work and the slope is the same at SL and HA. $\dot{V}_{O_2\mathrm{max}}$ is decreased at HA by about 15%.

Transient Phases Data

The first minute deficit follows a linear relationship with $\dot{V}_{O_2\ s \cdot st}$. The slope has the dimension of time and has the same value at SL and HA (SL, 53 min; HA, 54 min). Similarly, the actual values of the first minute debt plotted against $\dot{V}_{O_2\ s \cdot st}$ describe a slope identical at SL and HA, but steeper (60 min) than that described by the first minute deficit. There is no significant difference in the slopes made with 10- or 25-min exercises. Thus, the first minute debt is independent of the duration of exercise and inspired P_{O_2} (Fig. 14-1). The slow component of the deficit increases linearly with relative work load; the intercept suggests that anaerobic threshold appears at about 45% of $\dot{V}_{O_2max}$ at SL and HA.

When the values of total debt at SL are plotted against relative work load, the mean points describe a curvilinear relationship. Moreover, the points corresponding to 25-min exercise are always situated above those corresponding to 10-min exercise. Therefore, total debt increases not only with intensity but also duration of exercise. At HA, these findings are noted again, but for given conditions of work load and duration, total debt is always smaller at HA than at SL (Fig. 14-2).

Peak values of [La] reached during exercise are higher at HA, but the time course of [La] during exercise and recovery follows the same pattern at HA and SL.

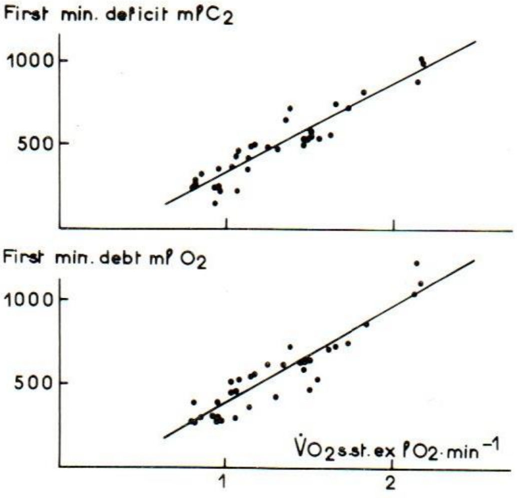

Fig. 14-1. Actual values of first minute deficit and debt, which are assumed to be an index of the fast component of deficit and debt, are plotted against $\dot{V}_{O_2}$ at steady state of exercise. These slopes are defined by data obtained at SL and the corresponding equations are:

y (first min deficit) = 0.53×-198; $r = 0.94$
y (first min debt) = 0.60×-221; $r = 0.95$
At HA, the following equations are obtained:
y (first min deficit) = 0.54×-200; $r = 0.95$
y (first min debt) = 0.60×-215; $r = 0.90$

Slope and intercept at HA are identical to those at SL.

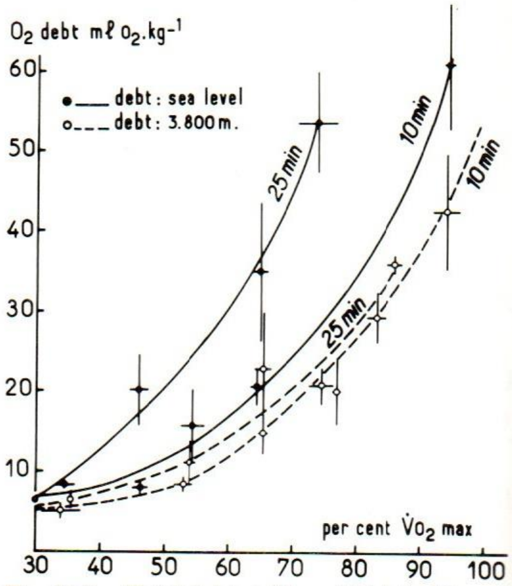

Fig. 14-2. Total debt at SL and HA in 10- and 25-min exercises. Debt increases with duration of work and is smaller at HA. Differences between the SL and HA curves are much more obvious in 25-min than in 10-min exercise.

Discussion

$\dot{V}_{O_2\ s \cdot st}$ at a given work load shows no difference at HA and SL despite a larger increase in cardiac and ventilatory rates. Thus, gross efficiency is independent of physical fitness and is unaffected by altitude.

Oxygen deficit is always larger at HA

than at SL. The mean effect of HA is to reduce the P_{O_2} gradient from air to the tissues. Oxygen conductance would have to increase at HA in order to deliver the same amount of O_2 to the working muscles as at SL. However, the necessary improvement in conductance is not attained and O_2 transport is impaired in its time course and reduced in its maximal value: O_2 deficit increases and $\dot{V}_{O_2max}$ decreases. However, the deficit remains related to relative workload by the same relationship at SL as at HA.

Oxygen debt was calculated by subtracting rest $\dot{V}_{O_2}$ from sequential $\dot{V}_{O_2}$ during recovery. Rest $\dot{V}_{O_2}$ seems a better reference for determination of O_2 debt than the "asymptotic" value reached during recovery. The term "asymptotic" demonstrates that debt is not over and consequently a part of the studied phenomenon is disregarded. Debt as a whole is always larger than deficit at HA and SL. However, conditions such as work intensity, duration, and environment modify the discrepancy.

It was arbitrarily assumed that the lack or the excess of anaerobic energy represented by the first minute of deficit and debt was mainly related to the splitting and the restoration of the fast creditor. The step of 1 min was chosen in the light of conclusions presented by authors (9,10) who have studied the time course of muscular creatine phosphate concentration in dog and man and have shown that split creatine phosphate is proportional to load and complete splitting and replenishment are accomplished within 2 min for a given work load (6). Additionally, it was assumed that anaerobic glycolysis comes into play late and its role is insignificant during the first minute of work. Keeping in mind these limitations, the slopes can be interpreted as time constants of the fast processes of exponential character. They are identical (0.54 min) at SL and HA. This result is consistent with data previously reported (9,10). Since Lohman's reaction is independent of P_{O_2}, it was expected that the deficit fast component kinetics be unchanged at HA; this hypothesis was experimentally verified. Such a result was already suggested by Cerretelli (3). The time constant of the fast component of debt is the same at SL and HA. Therefore, replenishment of the stores is affected neither by altitude nor by duration of exercise.

The slow component of the deficit theoretically estimates the energy released by anaerobic glycolysis. It is larger at HA compared to SL and this increase is confirmed by higher concentration of La at HA. It is linearly related to $\dot{V}_{O_2max}$ wherever the exercise is performed. Hermansen and Saltin (5) also report that when blood [La] is related to relative work load, all values from different acute altitudes fall on the same line.

The interpretation of the slow component of the debt is more questionable. There was no attempt to find two or three slow components in extra $\dot{V}_{O_2}$ during recovery, since fitting more than one exponential curve to scattered experimental data is unreliable. Therefore, after subtracting the fast component, independent of duration and environment as seen above, from the total debt, the whole remaining extra O_2 volume was considered as a single slow component. Classically, a part of extra $\dot{V}_{O_2}$ during recovery is supposed to oxidize La. However, [La] attains peak value around the tenth minute of exercise. The disappearance rate is not affected by termination of exercise; it would therefore be risky to attribute the slow component of the debt entirely to La metabolism, all the more because a higher [La] occurs at HA simultaneously with a smaller debt slow component. A similar finding was observed by Reynafarje and Velasquez (11). Consolazio et al. (4) have reported too that a significant decline in O_2 debt occurred at HA. This challenging result has given rise to another series of experiments at HA (12). It was shown that in subjects translocated to HA the body shell cools off during exercise and for about 30 min of recovery due to decreased cutaneous blood flow and greater evaporative rate. On the contrary, at SL the shell warms up during exercise and skin temperature returns slowly to rest value during recovery. Thus, one-fifth of body mass is not in the same thermal conditions at HA as at SL.

In conclusion, these results argue in favor of a role of temperature in the long-lasting increased $\dot{V}_{O_2}$ after exercise. Cain (2) has pointed out the interaction of temperature with other more specific factors related to exercise and environment on O_2 consumption during exercise. On the other hand, Brooks et al. (1) have emphasized the striking effect of temperature on mitochondrial functions. However, the results reported here do not allow quantification of the contribution of the temperature factor to the magnitude of O_2 debt.

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