A Theoretical Approach to Excessive CO₂ Expiration Due to Lactate Production in Exercise

Tokuo YANO

*Laboratory of Exercise Physiology, Faculty of Education,
Hokkaido University, Kita-ku, Sapporo, 060 Japan*

Summary CERRETELLI *et al.* (1982) proposed a model to estimate pH changes due to lactate production in exercise. This model was modified in the present study so as to express the relationship between CO₂ excess and lactate production. The modified model fitted to the data reported on endurance-trained men.

Key words: CO₂ excess, lactate production, exercise.

It is well known that lactic acid produced (Δ LA) in exercise causes excessive expiration of CO₂ (CO₂ excess). CLODE and CAMPBELL (1969) were the first to examine this fact in theory and experiment. They assumed then that a 1-mol increase in lactic acid produced one mol of excessive CO₂ expiration. On the other hand, PIIPER (1971) proposed a model to estimate pH changes due to Δ LA distributed mainly in muscle and blood in exercise. Thereafter, CERRETELLI *et al.* (1982) modified this model to apply to whole body. With some additional assumptions on the modified model, it is possible to theoretically express the interrelationship between Δ LA and CO₂ excess. Thus, the present purpose was to decide which model was suitable on the basis of the previously reported data (YANO, 1987).

As shown in Fig. 1, CERRETELLI *et al.* (1982) tentatively estimated on blood, interstitial and intracellular fluids the water volume and the buffer values by bicarbonate as well as nonbicarbonate systems, respectively. They also employed the following equation observed in the interrelationship of pH changes between intracellular (Δ pH_i) and extracellular (Δ pH_e) fluids by HEISLER (1975):

$$\Delta\text{pH}_i = (1/2) \cdot \Delta\text{pH}_e. \quad (1)$$

In the present study, it was further assumed that H⁺ buffered by a bicarbonate system was almost equal to the decrease in HCO₃⁻ (Δ HCO₃⁻). For example, in intracellular fluid, the HCO₃⁻ reduced by the change in pH could be calculated as

Fig. 1. Buffering of H^+ ions formed in muscle. Unshaded areas, bicarbonate; shaded areas, nonbicarbonate; ICS, intracellular space; ECS, extracellular space. Ordinate: buffer values. Abscissa: volume (liters H_2O). Area: buffer capacity (CERRETELLI *et al.*, 1982).

$11 \cdot 26 \cdot \Delta pH_i$. When Eq. (1) was taken into consideration, the total change in the HCO_3^- value was estimated as follows:

$$\Delta HCO_3^- = 686 \cdot \Delta pH_e. \quad (2)$$

The H^+ value almost equivalent to the H^+ produced from lactic acid (ΔLA) could be buffered. For example, in intracellular fluid the buffered value could be calculated as $83 \cdot 26 \cdot \Delta pH_i$. When Eq. (1) was taken into consideration, the total buffered value (ΔH^+) was estimated as follows:

$$\Delta LA = \Delta H^+ = 173 \cdot \Delta pH_e. \quad (3)$$

From Eqs. (2) and (3),

$$\Delta HCO_3^- = 0.397 \cdot \Delta LA. \quad (4)$$

It was also assumed in the present study that a 1-mol decrease in ΔHCO_3^- caused 22.26 ml of excessive CO_2 expiration. Furthermore, when the CO_2 excess was divided by body weight (w : CERRETELLI *et al.* (1982) did not describe the body weight in his model; it was estimated in the present study to be about 70 kg on the assumption that the total water volume constitutes 60% of body weight), the following equation was obtained:

$$CO_2 \text{ excess}/w = (22.26/70) \cdot \Delta HCO_3^-. \quad (5)$$

Fig. 2. Relationship between average lactate accumulation (ΔLa) and CO₂ excess per body weight. Straight line was theoretically obtained from the present model. Dashed line was the estimate by CLODE and CAMPBELL (1969). The data plotted was cited from YANO (1987, endurance-trained men).

Furthermore, when ΔLA was divided by the total water volume, the average lactate accumulation (La) was obtained by the following:

$$\Delta La = (1/43.1) \cdot \Delta LA. \quad (6)$$

By substituting the Eqs. (4) and (6) for Eq. (5), the following was obtained:

$$CO_2 \text{ excess}/w = 5.44 \cdot \Delta La. \quad (7)$$

On the other hand, CLODE and CAMPBELL (1969) assumed that $\Delta LA = \Delta HCO_3^- = 43.1 \cdot \Delta La = (70/22.26) \cdot CO_2 \text{ excess}/w$. That is,

$$CO_2 \text{ excess}/w = 13.7 \cdot \Delta La. \quad (8)$$

In Fig. 2, the theoretical relationships obtained from Eqs. (7) and (8) are shown as the straight and dotted lines, respectively. Since there had been no available data about CO₂ excess/ w and ΔLa measured on untrained men so far, the relationships reported on long-distance runners (YANO, 1987) were plotted in Fig. 2. These data were fairly close to the line calculated theoretically from the modification of Cerretelli's model. The CO₂ excess- ΔLa ratio reported was 5.55 ± 2.05 (mean $\pm$ S.D.). The theoretical ratio fell in the 95% confidence interval (6.97–4.13) on the mean of population to the experimental data.

The results of muscle biopsy indicated no difference in the muscle buffer values

between the untrained and endurance-trained men or marathon runners (PARKHAUSE *et al.*, 1983; SHARP *et al.*, 1986). The results of blood sample comparison showed no difference in blood buffer values between the endurance-trained and untrained men (SHARP *et al.*, 1983). Therefore the buffer values shown on Fig. 1 could be applied to untrained men. However, the Eq. (1) might not quantitatively be valid for untrained men, although its equation worked well enough for explaining the data of the endurance-trained men, because untrained men may have the hindrance of H^+ and lactic acid effluxes which would be influenced by the diffusion area, i.e., capillary density in muscle. It is well known that untrained men have fewer muscle capillaries than endurance-trained men (SALTIN *et al.*, 1977). The smaller efflux of H^+ and lactic acid may transiently cause a smaller pH difference between intracellular and extracellular fluids before the equilibrium as assumed by Eq. (1) is attained.

In conclusion, the present study indicated that with the modified Cerretelli's model, one could explain the interrelationship between CO_2 excess/ w and ΔLa in endurance-trained men.

REFERENCES

- CERRETELLI, P., VEICSTEINAS, A., and MARCONI, C. (1982) Anaerobic metabolism at high altitude: The lactacid mechanism. *In: High Altitude Physiology and Medicine*, ed. by BRENDEN, W. and ZINK, R. A., Springer-Verlag, New York, pp. 94–102.
- CLODE, M. and CAMPBELL, E. J. M. (1969) The relationship between gas exchange and changes in blood lactate concentrations during exercise. *Clin. Sci.*, **37**: 263–272.
- HEISLER, N. (1975) Intracellular pH of isolated rat diaphragm muscle with metabolic and respiratory changes of extracellular pH. *Respir. Physiol.*, **23**: 243–255.
- PARKHAUSE, W. S., MCKENZIE, D. C., HOCHOCHKA, P. W., MOMMSEN, T. P., OVALLE, W. K., SHIN, S. L., and PHODES, E. C. (1983) The relationship between carnosine levels, buffering capacity, fiber type and anaerobic capacity in elite athletes. *In: Biochemistry of Exercise*, ed. by KNUTTGEN, H. G., VOGEL, J. A., and POORTMANS, J., Human Kinetics Publishers Inc., Champaign, IL., pp. 590–594.
- PIIPER, J. (1971) Buffering of lactic acid produced in exercising muscle. *In: Symposium on the Onset of Exercise*, ed. by GIBERT, A. and GUILLE, P., University of Toulouse, Toulouse, pp. 175–185.
- SALTIN, B., HENRIKSSON, J., NYGAARD, E., ANDERSEN, P., and JANSSON, E. (1977) Fiber types and metabolic potentials of skeletal muscles in sedentary man and endurance runners. *In: The Marathon; Physiology, Medical, Epidemiological, and Psychological Studies*, ed. by MILVY, P., N. Y. Acad. Sci., New York, pp. 3–29.
- SHARP, R. L., ARMSTRONG, L. E., KING, D. S., and COSTILL, D. L. (1983) Buffer capacity of blood in trained and untrained males. *In: Biochemistry of Exercise*, ed. by KNUTTGEN, H. G., VOGEL, J. A., and POORTMANS, J., Human Kinetics Publishers Inc., Champaign, IL., pp. 595–599.
- SHARP, R. L., COSTILL, D. L., FINK, W. J., and KING, D. S. (1986) Effects of eight weeks of bicycle ergometer sprint training on human muscle buffer capacity. *Int. J. Sports Med.*, **7**: 13–17.
- YANO, T. (1987) The differences in CO_2 kinetics during incremental exercise among sprinters, middle, and long distance runners. *Jpn. J. Physiol.*, **37**: 369–378.