CHANGES IN THE ALVEOLAR DEAD SPACE DURING PHYSICAL EXERTION

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During physical exertion the excess ventilation of the alveoli of the lungs regularly increases, as is shown by a significant increase in the alveolar dead space. The subsequent increase in the blood flow in the lungs connected with the increased intensity of muscular work reduces the excess alveolar ventilation. The index of excess ($\dot{V}_{DP}/\dot{V}_A$) thereupon returns to its resting values. During physical exertion the real and effective alveolar ventilations are best regarded as independent parameters. The difference between them corresponds to the ventilation of the alveolar dead space.

The analysis of changes in the alveolar dead space during muscular work is of great importance to the study of excess ventilation of the alveoli of the lungs under various physiological conditions. When it was shown that the physiological dead space is practically always greater than the anatomical dead space, it became clear that it was necessary to distinguish the "alveolar" or "parallel" [5, 7] dead space, meaning a volume of air which, although reaching the alveoli, takes no part in the gas exchange.

The increase in the physiological dead space during physical exertion recorded by a number of workers [2, 5, 10] indicates that under these conditions the alveolar dead space changes.

The object of this paper is to analyze these changes.

EXPERIMENTAL METHOD

The subjects were 71 well-trained athletes aged 19-31. Physiological indices were recorded at rest (sitting on a bicycle ergometer) and during physical exertion at the rates of 600, 1200, 1300, and 1500 kg·m/min. The exercises were carried out on different days, and not more than twice on the same day. The physiological indices were recorded after 5 min of muscular work in the steady state. In all subjects the volumes of the dead space were calculated, and respiration rate, tidal volume (V_T), alveolar ventilation ($\dot{V}_A$), the partial CO_2 pressure in the alveolar gas (P_ACO_2), the CO_2 excretion, and the minute volume of the circulation by the CO_2 rebreathing method, were recorded.

Later in the text the physiological dead space will be designated V_D, as is the custom for the respiratory dead space as a whole. The anatomical dead space will be designated V_{DA}, and the alveolar (parallel) dead space V_{DP}. It follows that $V_D = V_{DA} + V_{DP}$.

The value of V_D was calculated for the resting state and for physical exertion [3]. The value of V_{DP} at rest was calculated by a special equation [4] which, for an arterio−alveolar CO_2 gradient of 1 mm Hg [2, 5], had the following form:

$$V_{DP} = \frac{V_T \cdot V_A}{V_T + V_A \cdot PACO_2}$$

The value of V_{DA} was calculated as the difference between V_D and V_{DP}. During muscular work the value of V_{DA} rises a little because of dilation of the respiratory passages associated with deepening of

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breathing [6, 8]. This increase (V_{DA}) can be calculated from the increase in the tidal volume (V_T). Taking the mean maximal V_{DA} as 70 ml (6) and the mean inspiratory volume as 3 liters [9], a coefficient of proportionality is obtained between these values : 23 ml/liter. Since the inspiratory volume in the vertical position is two-thirds of the maximal V_T [9], it follows that $V_{DA} = 16\ V_T$. The value of V_{DA} calculated by this equation was added to the V_{DA} at rest, thus giving V_{DA} for the conditions of physical exertion. The value of V_{DP} during exertion was calculated from the difference between V_D and V_{DA}, for the equation given above is applicable only to resting conditions.

TABLE 1. Changes in the Respiratory Dead Space and in Some Physiological Indexes during Physical Exertion (M ± m)

Intensity of molecular work (in kg·m/min)	Volumes of respiratory dead space (in ml)			Tidal volume (V_T) in liters/min	Respiration rate (per minute)	Alveolar ventilation V_A (in liters/min)	CO_2 excretion (in ml/min)	Minute volume of circulation (in liters/min)	V_D/V_T	$\dot{V}_{DP}/\dot{V}_A$
	physiological (V_D)	anatomical (V_{DA})	alveolar (V_{DP})							
Rest	236±12	211±8,0	25±0,7	650±24	16,6±0,3	6,6±0,2	290±7,5	5,30±0,1	0,36±0,007	0,06±0,0009
600	574±25	233±8,6	341±21	2084±63	20,7±1,0	30,0±0,9	1450±43	14,4±0,3	0,27±0,006	0,23±0,005
1200	506±50	247±16	259±21	2900±178	26,3±1,0	62,7±2,4	3130±107	21,8±0,7	0,17±0,006	0,10±0,004
1300	457±33	250±15	207±16	3083±193	26,4±1,8	70,0±2,3	3390±79	21,2±0,8	0,13±0,007	0,07±0,002
1500	412±27	247±13	165±8,8	2905±94	32,4±1,8	80,4±2,9	3870±181	23,7±0,8	0,14±0,007	0,06±0,002

EXPERIMENTAL RESULTS AND DISCUSSION

During physical exertion a significant excess ventilation of the alveoli of the lungs regularly develops. This is shown by the increase in V_{DP} compared with its value at rest (Table 1). The physiological significance of this fact is not quite clear. It seems, however, that the excess ventilation of the alveoli is aimed at making the work of the external respiratory system more reliable. Because of this, any sudden increase in the blood flow in the lungs associated, for example, with a change in the conditions of exertion, will be provided for by the ventilation which is sufficient to ensure normal saturation of the blood with oxygen.

During an increase in the intensity of physical exertion, despite stabilization of V_T (for loads exceeding 1200 kg·m/min) subsequent optimization of external respiratory function was observed. This was shown by a decrease in the ratio V_D/V_T on account of a relative decrease in the volume of the respiratory dead space. This last decrease was associated with a relative, statistically significant decrease in V_{DP} during muscular work of very high intensity.

The dynamics of the excess alveolar ventilation during an increase in the intensity of muscular work can be examined most clearly by analysis of the ratio V_{DP}/V_A, described as the index of excess of alveolar ventilation. For loads of 1300-1500 kg·m/min this coefficient fell to reach values recorded at rest. Consequently, under these conditions the necessary optimization of alveolar ventilation was achieved. Without examining the whole range of different mechanisms of the relative decrease in alveolar hyperventilation, although new ideas are being put forward in this field [1], it will suffice to say that the ratio V_{DP}/V_A becomes normal only when the minute volume of the circulation exceeds 22 liters/min. Under these circumstances the arterio–venous difference reaches near-maximal values.

In conclusion it must be emphasized that the traditional concept of alveolar ventilation does not correspond exactly to the conditions of physical exertion, for the actual volume of air ventilating the alveoli is 7-20% greater than the effective alveolar ventilation $\dot{V}_A$. This difference is equal to the volume of ventilation of the alveolar dead space.

LITERATURE CITED

1. L. A. Sidorenko, Byull. Éksperim. Biol. i Med., No. 6, 10 (1972).
2. E. Asmussen and M. Nielsen, Acta Physiol. Scand., 38, 1 (1956).
3. C. Bohr, Skand. Arch. Physiol., 2, 236 (1891).
4. A. Bühlmann and P. Rossier, Klinische Pathophysiologie der Atmung, Berlin (1970).

5. A. Bouhuys, in: Handbook of Physiology, Vol. 1, Respiration, Washington (1964), p. 699.
6. J. Comroe, Physiologie de la Respiration, Paris (1967).
7. B. Folkow and J. Pappenheimer, J. Appl. Physiol., 8, 102 (1955).
8. A. Huizinga, Pflüg. Arch. ges. Physiol., 238, 767 (1937).
9. A. G. Whitfield, J. Brit. Soc. Med., 4, 90 (1950).
10. A. Young, J. Appl. Physiol., 8, 91 (1955).