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INEQUALITY OF VENTILATION—PERFUSION RATIOS IN THE LUNGS AND ARTERIAL HYPOXEMIA

L. L. Shik and E. M. Tokareva

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A general analysis was made of the relationship between the degree of inequality of ventilation—perfusion ratios and the blood flow through poorly ventilated regions of the lungs, on the one hand, and arterial hypoxemia, on the other hand. Quantitative data on the onset of arterial hypoxemia during disturbance of ventilation—perfusion ratios were obtained.

KEY WORDS: ventilation—perfusion ratios; arterial hypoxemia; respiratory failure.

Inequality of ventilation—perfusion ratios ($\dot{V}_A/\dot{Q}$) in the lungs is known to be the commonest cause of hypoxemia (a decrease in the partial pressure of oxygen —p_aO_2 — and the degree of oxygen saturation of the arterial blood — HbO_2) during disturbance of external respiration [1, 2]. However, at certain degrees of inequality of $\dot{V}_A/\dot{Q}$ the partial oxygen pressure and oxygen saturation of the arterial blood are normal, as is the case, for example, in healthy human subjects in a vertical position of the body [4].

The object of this investigation was to study quantitative relations between the degree of inequality of $\dot{V}_A/\dot{Q}$ and the onset of arterial hypoxemia.

EXPERIMENTAL METHOD

Certain assumptions were made for the necessary calculations. The first assumption was that at any value of $\dot{V}_A/\dot{Q}$ in a poorly ventilated part of the lungs (i.e., in a part where $\dot{V}_A/\dot{Q}$ is below normal) the mean value of $\dot{V}_A/\dot{Q}$ remains normal (0.86) on account of an increase in $\dot{V}_A/\dot{Q}$ in the remainder of the lungs. This assumption is based on the fact that otherwise the respiratory quotient, determined from the composition of the expired air and connected with the mean value of $\dot{V}_A/\dot{Q}$ [3], would differ from the metabolic respiratory quotient, which is impossible. The second assumption was that the possible gradient between pO_2 in the alveolar air and arterial blood, due to disturbances of diffusion or contamination with venous blood, is in fact absent. In reality, in human subjects with no pathological changes in the diffusion capacity of the lungs and venous shunts, such a gradient exists and lies between 5 and 7 mm Hg. The third assumption was that the dissociation curve of the blood and the gaseous composition of the venous blood were taken to be normal. All calculations were thus aimed at determining the degree of disturbances of equality of $\dot{V}_A/\dot{Q}$ which leads to the appearance of arterial hypoxemia.

On the basis of these assumptions the gaseous composition of the alveolar air and blood flowing from two regions of the lungs (with lowered and raised values of $\dot{V}_A/\dot{Q}$) and the gaseous composition of mixed arterial blood flowing from the lungs were calculated. The calculations were done for all values of $(\dot{V}_A/\dot{Q})_1$ (from normal, namely 0.86, to 0) and for all ratios between the volumes of blood flowing through the part of the lungs where $\dot{V}_A/\dot{Q}$ was below normal and the blood flow through the lungs $(\dot{Q}/\dot{Q}_0)_1$. The calculations were carried out on the BÉSM-6 computer on the basis of programs prepared in accordance with the assumptions made above.

EXPERIMENTAL RESULTS

Samples of the principal results are given in Table 1. The first three vertical columns give data obtained for $(\dot{V}_A/\dot{Q})_1 = 0.6$ in a poorly ventilated region of the lungs, i.e., when $(\dot{V}_A/\dot{Q})_1$ was moderately reduced

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TABLE 1. Gaseous Composition of Alveolar Air and Arterial Blood During Inequality of Ventilation–Perfusion Ratios

Index	1	2	3	4	5	6	7	8	9
$(\dot{V}_A/\dot{Q})_1$	0,6	0,6	0,6	0,4	0,4	0,4	0,2	0,2	0,2
$(\dot{Q}/\dot{Q}_0)_1$, %	10	30	50	10	30	50	10	30	50
Pa^1O_2, $p_A{}^1O_2$, mm Hg	85	85	85	68	68	68	52	52	52
Hb^1O_2, %	95	95	95	93	93	93	87	87	87
$P_A{}^2O_2$, Pa^2O_2, mm Hg	101	104	107	102	106	111	103	108	115
Hb^2O_2, %	99	99	99	99	99	99	99	99	99
P_AO_2, mm Hg	99	100	100	100	101	101	101	104	107
PaO_2, mmHg	99	99	97	99	98	92	98	89	73
HbO_2, %	98	98	97	98	97	96	97	96	94

Legend. $(\dot{Q}_A/\dot{Q})_1$, $(\dot{Q}/\dot{Q}_0)_1$ – Denote ventilation–perfusion ratios and relative part of blood flow in "poor" part of lungs; $p_A{}^1O_2$) alveolar oxygen pressure in "poor" part of lungs; $p_a{}^1O_2$, Hb^1O_2 denote partial pressure of oxygen in blood flowing from "poor" part of lungs and its oxygen saturation; $p_A{}^2O_2$ denotes alveolar pressure of oxygen in "better" part of lungs. $p_a{}^2O_2$, Hb^2O_2 denote partial pressure of oxygen in blood flowing from "better" part of lungs and its oxygen saturation. p_AO_2, p_aO_2, HbO_2 denote mean values of corresponding parameters.

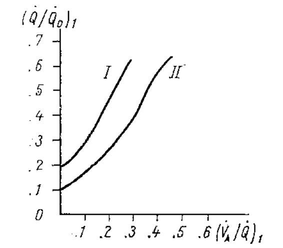

Fig. 1. Partial oxygen pressure in arterial blood (p_aO_2). I) p_aO_2 = 75 mm Hg, II) p_aO_2 = 90 mm Hg. Abscissa, ventilation–perfusion ratio; ordinate, relative part of blood flow in "poor" part of lungs.

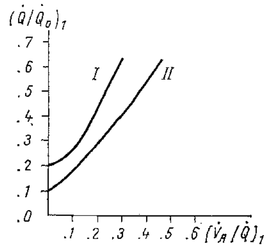

Fig. 2. Degree of oxygen saturation of arterial blood. I) 94%, II) 96% saturation. Remainder of legend as in Fig. 1.

below normal. In this case p_aO_2 and HbO_2 were close to normal both in that part of the lungs and also in the mixed arterial blood. When $(\dot{V}_A/\dot{Q})_1 = 0.4$ (vertical columns 4, 5, and 6), $p_a{}^1O_2$ of blood flowing from the poorly ventilated region of the lungs was reduced to 68 mm Hg and Hb^1O_2 was reduced to 93%. However, these parameters in mixed arterial blood remained normal because of mixing with blood flowing from part of the lungs with high values of $\dot{V}_A/\dot{Q}$. In the case of a very sharply reduced value of $\dot{V}_A/\dot{Q}$ (to 0.2) in the poorly ventilated part of the lungs (columns 7, 8, and 9) both p_aO_2 and HbO_2 in the mixed arterial blood were reduced. This decrease was observed only when 50% of the total pulmonary blood flow passed through the poorly ventilated part of the lungs. Even in that case p_aO_2 fell only to 73 mm Hg and HbO_2 to 94%.

From the curves in Fig. 1 it is possible to determine the combinations $(\dot{V}_A/\dot{Q})_1$ and $(\dot{Q}/\dot{Q}_0)_1$ at which p_aO_2 is normal (90 mm Hg) or slightly reduced (75 mm Hg). As Fig. 1 shows, a large region of low values of $(\dot{V}_A/\dot{Q})_1$ at definite values of $(\dot{Q}/\dot{Q}_0)_1$ is commensurate with a normal gaseous composition of the arterial blood. Only with a combination of very low values of $(\dot{V}_A/\dot{Q})_1$ and high values of blood flow through the poorly ventilated region does hypoxemia develop. Similar data on HbO_2 are given in Fig. 2. The hypoxemic region was taken to begin at 94% saturation. All the region below the curve, corresponding to 96% saturation, was regarded as normal.

Consequently, for arterial hypoxemia to develop the disturbances of equality of $\dot{V}_A/\dot{Q}$ must reach a high level: There must be a part of the lungs with a very low ratio of ventilation to blood flow, and a considerable proportion of the blood entering the lungs must flow through this part of them. In other words, both the degree and the volume of the lesion can give rise to hypoxemia only if they are of great magnitude. In most cases when disturbances of equality of $\dot{V}_A/\dot{Q}$ are considerable, no hypoxemia can arise. The results are in good agreement with the view now predominantly held in the USSR that respiratory failure can exist in many patients in the absence of arterial hypoxemia.

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