THE O_2 AND CO_2 TENSION IN THE BLOOD OF DOGS BREATHING UNDER EXCESSIVE PRESSURE AT A HIGH ALTITUDE

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The partial pressure of oxygen (pO_2) in the blood is an important index of the oxygen supply of the organism during the action of various external environmental factors [3,5]. The direct determination of this index has become possible as a result of the introduction of the polarographic method of estimation of pO_2 [6], and this has now displaced the method based on the calculation of pO_2 from the concentration of oxygen by volume. We have used the polarographic method to study pO_2 in the arterial and venous blood of dogs during breathing under various excessive intrapulmonary pressures at high altitudes. Simultaneously with the pO_2, determinations were also made of indirect indices of the oxygen balance of the organism—the partial pressure of CO_2 (pCO_2) and the pH of the blood [2]. It was assumed that the results obtained would give some idea of the oxygen requirements of the organism in the conditions studied.

EXPERIMENTAL

Experiments were carried out on dogs. Blood samples were taken with a special syringe through rigid polyethylene catheters introduced under local anesthesia into the aorta and inferior vena cava through the peripheral vessels. By means of an analyzer (Goddart) simultaneous determinations were made of the pO_2 (in mm Hg) by a polarographic method, pCO_2 (in mm Hg) by an electrometric method, and the pH of the blood by means of a glass electrode. The accuracy of the measurements of the pO_2 and pCO_2 was verified on blood samples saturated with gas mixtures containing a known percentage of O_2 and CO_2. The readings of the pH meter were compared with the pH values of standard buffer solutions. Blood for analysis was taken in a pressure chamber at pressures equivalent to an altitude of 4 km (without additional oxygen), 10 km (inhaling pure oxygen), and 20 and 30 km (inhaling under excessive pressure amounting, together with the residual atmospheric pressure, to 150 or 200 mm Hg). The excessive pressure in the lungs was compensated by means of a special suit creating a uniform counterpressure on the body surface of the animal equal to the increased intrapulmonary pressure. The animal's general condition was checked during the experiment by recordings of the EKG, the pneumogram, and the electromyogram of the abdominal muscles.

RESULTS

At ground level the value of pO_2 in the arterial blood of the dogs averaged 87 mm Hg, compared with 49 mm Hg in the venous blood (Table 1). When the pressure in the pressure chamber was equivalent to an altitude of 4 km, the pO_2 fell regularly. The fall in the pO_2 value in the venous blood was less marked than in the arterial, but the difference between the pO_2 levels in the venous blood at ground level and at an "altitude" of 4 km was statistically significant ($t > 3$). Because of the sharp fall in pO_2 in the arterial blood by comparison with venous, the arterio-venous gradient of pO_2 fell from 38 mm Hg (in the original samples) to 15 mm Hg (at an "altitude" of 4 km). A decrease in the arterio-venous gradient, especially if combined with a fall of the arterial pO_2, is known to interfere with the diffusion of oxygen from the blood into the tissues, leading to anoxia of the organism [2, 5].

When the pressure in the chamber corresponded to an altitude of 10 km but the animals breathed pure (nearly 100%) oxygen, the values of pO_2 in both the arterial and the venous blood approximated to the original values (at ground level) (Table 1), indicating that the oxygen supply to the animals was satisfactory. At higher "altitudes"

TABLE 1. Oxygen Pressure in Blood of Dogs at "Ground Level" and a "High Altitude"

Experimental conditions	Blood	M ± m	n
"Ground level", breathing air	A	87.3±1.3	31
	V	49.4±1.6	32
4 km, breathing rarefied air	A	52.5±3.2	8
	V	38.0±2.5	7
10 km, breathing 100% O_2	A	90.0±3.2	16
	V	48.4±2.4	14
P_{abs}:			
150 mm Hg	A	52.5±5.0	6
20 km	V	29.0±3.0	5
200 mm Hg	A	86.3±3.8	7
	V	49.4±3.5	5
P_{abs}:			
150 mm Hg	A	60.9±2.0	17
30 km	V	39.9±1.9	13
200 mm Hg	A	94.8±2.8	13
	V	48.8±2.9	11

Legend (here and in Table 2): A) arterial blood; V) venous; P_{abs}) absolute pressure in the lungs (sum of the excess pressure under the helmet and the residual atmospheric pressure at the given altitude).

TABLE 2. Pressure of CO_2 in the Blood of Dogs at "Ground Level" and a "High Altitude"

Experimental conditions	Blood	M ± m	σ	n
"Ground level", breathing air	A	34.0±0.4	2.1	28
	V	40.2±0.8	4.2	28
4 km, breathing rarefied air	A	26.3±1.9	5.0	7
	V	33.0±1.2	2.9	6
10 km, breathing 100% O_2	A	33.0±0.7	2.5	14
	V	39.0±0.9	3.3	13
P_{abs}:				
150 mm Hg	A	26.0±1.3	2.9	5
	V	30.0±1.2	2.5	4
20 km				
200 mm Hg	A	33.0±0.5	2.6	5
	V	37.0±1.0	2.1	4
P_{abs}:				
150 mm Hg	A	27.3±0.9	3.4	16
	V	31.2±0.6	2.1	12
30 km				
200 mm Hg	A	32.9±0.4	1.3	12
	V	38.3±0.9	2.9	10

(20 and 30 km), the pO_2 level in the blood was determined mainly by the value of the intrapulmonary pressure applied. If the absolute intrapulmonary pressure was 150 mm Hg, the pO_2 of the arterial and venous blood fell approximately to the values observed at an "altitude" of 4 km during inhalation of rarefied air (Table1). These results suggest that in the cases under examination the animals were in approximately identical conditions as regards their oxygen supply, which was clearly inadequate.

When the intrapulmonary pressure was raised to 200 mm Hg (with an equal counterpressure on the surface of the animal's body), the pO_2 of the blood of the dogs at "altitudes" of 20 and 30 km rose almost to the values found at ground level (Table 1). The mean arterio-venous difference of pO_2 was close to the value at "ground level" (37-38 mm Hg). Hence, the conditions for diffusion of oxygen from the blood into the tissues when the intrapulmonary pressure was increased to 200 mm Hg were similar to those observed at ground level.

The carbon dioxide tension in the blood was dependent on the pO_2 level (Table 2). In those cases when the changes in the pO_2 of the blood indicated the development of a state of hypoxia in the animal, lower values of the pCO_2 were observed concurrently in the blood (at a "altitude" of 4 km without oxygen, and of 20 and 30 km when the intrapulmonary pressure was 150 mm Hg). When the pO_2 rose to values close to those found at ground level, pCO_2 also came close to its initial values (at an "altitude" of 10 km during inhalation of oxygen and at "altitudes" of 20 and 30 km when the intrapulmonary pressure was 200 mm Hg).

Measurement of the pH of the blood revealed a shift of the mean values towards the alkaline side (an "ascent" by the dogs to 20 and 30 km and an intrapulmonary pressure of 150 mm Hg) and towards the acid side (when the intrapulmonary pressure rose to 200 mm Hg).

The results obtained showed that the pO_2 of the blood in animals at high altitudes (20 and 30 km) inhaling oxygen under excess pressure, in conjunction with effective external counterpressure, was dependent on the magnitude of the intrapulmonary pressure. The conditions of oxygenation when the intrapulmonary pressure was 150 mm Hg were hypoxic, and so far as the absolute value of pO_2 of the blood is concerned, equivalent to anoxic when the animals were at an "altitude" of 4 km and breathing rarefied air. This equivalence of the degree of deficiency in the oxygen supply to the animal in these conditions can easily be explained. According to calculated and experimental data, the alveolar pO_2 at an "altitude" of about 4 km, when air is breathed, corresponds to that at an altitude of more than 12 km when oxygen is breathed under excess pressure, amounting together with the residual atmospheric pressure to 145-150 mm Hg, in conjunction with the use of an effective system of external compensatory counterpressure [1, 4].

The increase in the intrapulmonary pressure to 200 mm Hg at "altitudes" of 20 and 30 km abolished the oxygen deficiency in the body, as demonstrated by an increase in the pO_2 of the blood to the initial values or to the values observed in the blood of animals at an "altitude" of 10 km and breathing 100% O_2. The equality of the values of the pO_2 of the blood in these conditions likewise was not accidental, for it enabled the animal to maintain an approxmately equal level of its alveolar pO_2 [7].

The relationship between the values of the pCO_2 in the blood and the level of the arterial pressure and pO_2 in the blood at high altitudes is of great interest. In hypoxic conditions of the intrapulmonary pressure (150 mm Hg) hypocapnia was observed, and did not disappear when the hypoxia was removed by increasing the intrapulmonary pressure to 200 mm Hg. A similar picture was observed at low and medium altitudes during ordinary breathing without excess pressure. A hypoxic state (4 km, breathing air) caused hypocapnia; inhalation of 100% O_2 even at an altitude of 10 km did not lower the pCO_2 level.

Hence, during both ordinary breathing and breathing under an excess intrapulmonary pressure at high altitudes, the hypocapnia is mainly the result of the development of a hypoxic state and not the result of the action of the rarefied atmosphere or of the altered intrapulmonary pressure.

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