GAS EXCHANGE AND THERMOREGULATORY ACTIVITY OF THE MUSCLES IN A HYPOXIC ATMOSPHERE

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Exposure for 1 h to a hypoxic atmosphere containing 11.4% oxygen lowers the gas exchange and the rectal temperature in rats, but the electrical activity of their muscles remains almost unchanged. In an atmosphere containing 7.4% oxygen, besides a decrease in gas exchange to the same level, depression of the thermoregulatory tone of the muscles and a more marked decrease of body temperature are observed. After transfer of the animals from the hypoxic atmosphere to ordinary air, within the course of 1 h in the first case the gas exchange and body temperature rise but do not regain the control level, while in the second case the electrical activity of the muscles returns to normal, the body temperature rises slightly, but the gas exchange remains depressed.

With a decrease in the partial pressure of oxygen in the atmosphere, the total gas exchange is lowered, and in warm-blooded animals this is accompanied by a marked lowering of the body temperature [13, 16, 17]. Different opinions are held on the mechanism of this phenomenon [1, 4, 8-12, 14]. It has recently been considered that the main cause of the decrease in gas exchange in hypoxia is depression of chemical thermoregulation [3]. An important role is also played by the heat output, which is increased in hypoxia [6].

There is little information in the literature on the restoration of gas exchange and thermoregulation after animals are transferred back to breathing air in relation to the degree of preceding hypoxia. The present investigation was carried out to study this problem.

EXPERIMENTAL METHOD

Experiments were carried out on 30 male Wistar rats weighing 200-300 g, divided into three groups with 10 animals in each group. The animals were placed in a chamber with a capacity of 20 dm^3, in which they successively breathed air for 1 h, hypoxic mixture for 1 h, and again air. Every hour, air samples were taken from the chamber and analyzed in a Haldane's apparatus; the gas exchange was calculated by the usual method [7]. The temperature in the chamber was maintained at 25° by means of a thermostat. Thermoregulation was assessed from the muscular activity, which was recorded electrophysiologically. Michel's clips were used as electrodes, and potentials were recorded from the muscles of the neck, which are most active in the thermoregulatory reaction [2]. Changes in the electrical activity of the muscles (EAM) were recorded automatically by a special instrument consisting of a UBP1-01 amplifier, a PS-100 electronic pulse counter a Kozhevnikov [5] type integrator, and an MPO-2 loop oscillograph. The number and area of the muscle oscillations were determined per minute in conventional units consisting of readings of the instruments. The body temperature was measured rectally by means of an electrothermometer.

Two series of experiments were carried out. In series I the oxygen concentration in the hypoxic mixture was 11.4%, and in the second it was 7.4% corresponding to approximate altitudes of 5000 and 8000 m

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TABLE 1. Changes in EAM, Gas Exchange, and Rectal Temperature in Rats in a Hypoxic Atmosphere

Series of experiments	Atmosphere	Number of animals	EAM (in percent of initial level)				Gas exchange (in ml/100 g/h)				Rectal temperature	P
			no. of oscillations	P	area of oscillations	P	O_2 consumption	P	CO_2 excretion	P		
I	A	10	100		100		139,0		116,0		37,5	
	H		92,8	>0,05	98,2	>0,05	106,0	<0,001	89,0	<0,001	36,2	<0,001
	A		102,6	>0,05	112,1	>0,05	121,0	=0,005	100,0	=0,005	36,5	<0,001
II	A	10	100		100		129,0		107,0		37,7	
	H		57,2	=0,025	92,7	>0,05	98,0	=0,001	81,0	<0,001	35,5	<0,001
	A		113,1	>0,05	109,1	>0,05	97,0	=0,001	82,0	=0,001	35,8	<0,001
III	A	10	100		100		138,3		110,2		38,2	
	H		93,2	>0,05	95,9	>0,05	129,2	>0,05	108,0	>0,05	38,1	>0,05
	A		91,8	>0,05	95,9	>0,05	131,2	>0,05	109,7	>0,05	38,0	>0,05

Legend: A) air; H) hypoxic mixture.

above sea level. In series III (control) the animals breathed air under similar conditions for the same periods of time. The results were analyzed statistically by the method of comparison of pairs.

EXPERIMENTAL RESULTS

The experimental results are shown in Table 1.

During moderate hypoxia (series I) the gas exchange of the rats was diminished. Their oxygen consumption fell by 23.8% compared with its initial level, and their excretion of carbon dioxide fell by 23.3%. The decrease in EAM was not statistically significant. The rectal temperature during the stay in the hypoxic mixture fell gradually on the average by 1.3°.

After the animals had been transferred to breathing air, the gas exchange tended to return to normal but the oxygen consumption per hour was on the average 13% lower than initially, while the excretion of carbon dioxide was 13.8% lower. The changes in EAM again were not statistically significant (Table 1). The body temperature rose slightly but still remained 1° below its initial level ($P < 0.001$).

During more severe hypoxia (experiments of series II) the gas exchange was lowered by the same amount; the oxygen consumption fell by 24% and the carbon dioxide excretion fell by 24.3% compared with initially. With respect to the number of oscillations, thermoregulatory activity fell by 42.8% ($P = 0.025$), while with respect to area of the oscillations, it fell by 7.3% ($P > 0.05$) relative to the control. During the stay in the hypoxic medium, the animals' temperature fell by 2.2°.

During a stay for 1 h in air after hypoxia, the animals' gas exchange remained at the same lowered level, while the EAM was slightly higher than initially. The animals' body temperature rose slightly during this period (by 0.3°), but still remained on the average 1.9° below its initial value ($P < 0.001$).

In the control series of experiments when the rats were kept for 3 h in air (the air in the chamber was changed every hour), the gas exchange, EAM, and body temperature were virtually unchanged.

These experiments revealed a decrease in gas exchange, EAM, and rectal temperature of the animals kept under hypoxic conditions, confirming the results obtained by over investigators [2, 3, 15].

During moderate hypoxia, the gas exchange and body temperature are therefore lowered, while the thermoregulatory tone of the muscles is virtually unchanged. In more severe hypoxia the gas exchange falls to the same degree, but an appreciable decrease in EAM and a fall of rectal temperature develop. During hypoxia the gas exchange of the animals falls to a certain level, which is then maintained even if the oxygen concentration in the inspired air is reduced very considerably. The possibility is not ruled out that this uniform level of diminution of the gas exchange in the two series of experiments was due to the relatively high temperature which prevailed. At low temperatures the gas exchange is dependent to a greater degree on the oxygen concentration in the surrounding medium [3]. One of the physiological mechanisms of maintenance of a low level of metabolism during severe hypoxia is probably a decrease in the thermoregulatory tone of the muscles.

Restoration of the investigated physiological functions after the animals had been returned from the hypoxic mixture to ordinary air took place differently depending on the degree of hypoxia. In the experiments of series I (11.4% O_2), for instance, during a stay of 1 h in air the gas exchange rose, but still remained 13% below its initial level, whereas the EAM actually exceeded the control intensity. Similar relationships were observed in the experiments of series II (7.4% O_2), although the gas exchange in this case remained at the low "hypoxic" level during the hour that the animals were kept in ordinary air, while the EAM was increased to a greater degree. In the after-period, recovery of the initial level of gas exchange is evidently preceded by recovery of the thermoregulatory tone of the muscles. The body temperature of the rats during this same period rose by only 0.3° in both series of experiments.

Consequently, after replacement of the hypoxic mixture by air, to begin with the animals' EAM increased, and this is followed by a much slower increase in the gas exchange and body temperature. Under these experimental conditions, a period of 1 h is evidently insufficient for the investigated functions to return to normal. It can be postulated that, with a relatively weak degree of hypoxia, thermoregulatory muscle tone plays hardly any part in the reaction as an adaptive mechanism. In the case of more severe hypoxia, all the studied indices were reflected in the process. The character of recovery suggests that the EAM is most labile, while changes in the temperature and gas exchange were distinctly inert. The last two factors evidently reflect changes at the tissue level.

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