DISCREPANCY BETWEEN RESULTS OF DIRECT AND INDIRECT CALORIMETRY IN HYPOXIA

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In hypoxic hypoxia direct calorimetry yields higher results than indirect.

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Hypoxia disturbs the physiological responses of the organism to cold. Since this is an important practical and theoretical problem, it has been the subject of numerous investigations [1, 3, 4, 7-15]. However, the physiological mechanisms of these disturbances have been inadequately explained. This is true, in particular, of the quantitative relationships between heat emission, "direct" heat production (as obtained in a calorimeter), and heat formation calculated from gas exchange data [9]. E. A. Kartashevskii [4] found many years ago that heat emission of dogs was increased in hypoxia, which could be an important cause of the disturbance of temperature homeostasis. The gas exchange likewise is known to be disturbed in hypoxia [3, 4, 7, 8, 11, 13-15].

The object of the present investigation was to examine, by means of a thermoelectrical dynamic calorimeter, changes in the results of direct and indirect calorimetry with changes in the oxygen concentration in the inspired air.

EXPERIMENTAL METHOD

The calorimeter used in the experiments was designed and made by the Department of Caloric and Measuring Instruments, Leningrad Institute of Precision Engineering and Optics. It gave simultaneous readings of the heat and gas exchange over a period of time in experiments of any duration. A description of the calorimeter, with its graduations and the method of determining the gas exchange and the "direct" heat production with it, has been published previously [2, 5, 7, 9, 10].

Heat production by the direct method was calculated from the formula:

$$Q = Q_{cal} + Q_{H_2O} \pm Q_t ,$$

where Q represents the total heat production (DHP), Q_{cal} the heat emission of the animal by convection and radiation, Q_{H_2O} the heat emission by evaporation, $Q_{cal} + Q_{H_2O}$ thus constituting the total heat emission (HE); Q_t represents the heat given off or retained by the animal's body depending on a change in its body temperature. This term is calculated from the formula

$$Q_t = c \cdot M \cdot \Delta t,$$

where c represents the mean specific thermal capacity of the body, M the body weight of the animal, and Δt the temperature difference over the given time interval (in °C). By addition (with a rise of body temperature) of this value to, or by its subtraction (with cooling of the body) from the total heat emission (HE) over the given time interval, the actual heat production of the animal (DHP) is calculated.

Investigations were carried out in a calorimetric chamber with a capacity of 1.5 liters. Ventilation was supplied at the rate of 0.5 liter/min. The graduations of the instrument were periodically verified at the same ventilation rate, with the same composition of the gas mixture, and at the same external air temperature as in the experiments.

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TABLE 1. HE, DHP, and IHP for Albino Rats in Normal Conditions and during and after Exposure to Various Degrees of Hypoxia (in kcal/kg/h)

No. of animals	Period of observation (in min)	Normal conditions: HE	DHP	IHP	% of diff.	body temp. (in degrees)	Hypoxia: HE	DHP	IHP	% of diff.	body temp. (in degrees)	After hypoxia: HE	DHP	IHP	% of diff.	body temp. (in degrees)
							A									
10	0–20	9,9±0,4	8,2±0,5	7,7±0,6	+7	36,5±0,5	8,8±0,4	5,8±0,5	2,5±0,7	+134	33,5±0,5	9,0±0,8	12,4±0,6	10,2±0,7	+22	34,7±1,4
10	20–40	9,7±0,4	8,9±0,5	9,1±0,8	−1	36,2±0,5	8,3±0,4	6,4±0,3	4,4±0,3	+46	32,8±0,5	9,6±0,8	10,5±1,1	11,6±2,2	−10	35,1±1,4
10	40–60	9,6±0,4	8,6±0,5	8,9±0,5	−2	36,0±0,5	7,7±0,4	6,5±0,3	5,1±0,2	+28	32,2±0,6	9,7±1,0	9,9±1,1	11,0±2,0	−10	35,2±1,3
							B									
9	0–20	8,4±0,7	7,4±0,5	6,7±0,5	+9	36,1±0,7	7,9±0,6	3,9±0,6	2,7±0,7	+41	32,0±0,4	5,9±1,0	7,6±1,4	9,0±1,5	−16	31,8±0,6
9	20–40	8,3±0,6	7,8±0,5	7,9±0,8	−2	36,0±0,6	6,4±0,8	4,1±0,8	3,0±0,5	+36	30,9±0,6	6,1±1,0	7,0±1,2	8,3±1,3	−16	32,2±1,1
9	40–60	8,1±0,6	7,7±0,7	7,5±0,6	+2	35,8±0,3	5,6±0,7	3,7±0,9	3,2±0,6	+17	30,7±0,6	6,5±0,8	7,7±0,7	7,9±1,2	−3	32,7±1,1

Legend: A – 10% O_2, B – 7% O_2.

The control graduation investigations showed that the error of determination of liberation energy did not exceed ±5% even at a time of sudden change. The time required by the instrument to get into working order likewise did not exceed 5 min.

To lower the oxygen concentration in the calorimeter and produce hypoxic conditions a mixture of gases with a reduced oxygen concentration was passed through the calorimetric chamber.

Experiments were carried out on male Wistar albino rats weighing 190-200 g. Calorimetry began 10-15 min after the animal had been placed in the chamber.

In the course of the investigations the heat emission, "direct" heat production, and the gas exchange were initially determined while the animal breathed an atmosphere of air. The calorimetric experiment continued for 1 h. The values of heat and gas exchange were investigated repeatedly at 20-min intervals. The corresponding measurements were then carried out in the same way (also for 1 h), when the oxygen concentration in the calorimeter was reduced to 10 or 7%. The calorimeter was then ventilated with atmospheric air and all measurements determined a third time. The whole experiment lasted for approximately 3.5 h and the external air temperature was 19-21°.

The animals' body temperature was measured continuously throughout the experiment by means of a thermocouple fixed in the rectum at a depth of 2.5 cm.

EXPERIMENTAL RESULTS

As Table 1 shows, heat production as given by the results of given calorimetry (DHP), and the quantities of heat calculated from the gas exchange (IHP) during inhalation of atmospheric air, agreed quantitatively. The slight discrepancies of less than 5-10% were not statistically significant.

After a fall in the oxygen concentration in the calorimeter to 10%, both DHP and IHP fell distinctly. However, IHP was below DHP. In the first 20 min, this difference reached 134%. In the next two 20-min intervals the differences diminished but remained statistically significant ($P > 0.05$). The values of HE fell significantly in the first, second, and third 20-min intervals by 20, 15, and 20% respectively compared with the control. The value of DHP fell by a greater degree in these same time invals – by 30, 28, and 25% compared with the DHP values before exposure to hypoxia.

After a change to inhalation of atmospheric air, the values of HE, DHP, and IHP all increased. No statistically significant differences were found between DHP and IHP, although the mean values of IHP in the next two 20-min intervals were slightly greater than those of DHP.

The body temperature fell during hypoxia and rose again in the period after hypoxia (see Table 1, A).

When the oxygen concentration in the air fell to 7%, the values of heat production (both direct and indirect) on the whole fell more sharply than in the previous experiments. However, with this degree of lowering of the oxygen concentration in the inspired air, the differences were not statistically significant, although the mean values of DHP were higher than those of IHP. The slight decrease in HE observed in these experiments was statistically significant only in the last 20-min interval. In this case also a larger decrease in DHP than in HE was observed by comparison with the controls (before hypoxia). The heat emission thus fell in the first, second, and third 20-min intervals by 12, 21, and 30% respectively, while the heat production fell by 48, 48, and 52% respectively.

On returning to inhalation of atmospheric air, the differences between DHP and IHP again were not statistically significant. The body temperature during exposure to more severe hypoxia showed a correspondingly greater fall (see Table 1, B).

Hence, with a reduction in the oxygen concentration in the inspired air, marked differences were found between the actual heat production of albino rats (measured by direct calorimetry), and the heat production calculated from the gas exchange. With a decrease in the oxygen concentration in the inspired air to 10%, DHP exceeded IHP by a statistically significant amount. It may, therefore, be postulated that during exposure to hypoxia the body utilizes sources of energy not directly connected with oxygen consumption. Such sources could be an increase in the energy-yielding power of glycolysis, and also high-energy compounds present in certain amounts in the tissues.

The discrepancy between the values of DHP and IHP could also be produced by disturbance of the heat balance and by inequality of the temperature in different parts of the animal's body [9].

In albino rats at an air temperature of 19-21°, an intensive thermoregulatory tone of the muscles and elements of a muscular cold shiver are found, for to maintain temperature homeostasis under these conditions they need an increased heat production. The hypoxic decrease in oxygen utilization by albino rats is correlated with depression of these forms of muscular activity [3]. It may be presumed that the "residual" level of thermoregulatory muscular activity in hypoxia is provided for to some degree by the energy sources mentioned above.

With deeper hypoxia (7% oxygen in the inspired air), no statistically significant difference was found between DHP and IHP. Evidently in deeper hypoxic conditions anaerobic energy sources also are depressed.

The decrease in body temperature observed with oxygen concentrations of 7 and 10% in the inspired air may be associated both with a marked fall of heat formation and with inadequate retention of heat in the animal's body.

LITERATURE CITED

1. P. N. Veselkin, Transactions of the Military Medical Academy [in Russian], Vol. 40, Leningrad (1947), p. 51.
2. G. N. Dul'nev, Izv. Vyssh. Uchebn. Zaved. Priborostroenie, No. 2, 123 (1958).
3. K. P. Ivanov, Fiziol. Zh. SSSR, No. 12, 1476 (1964).
4. E. Kartashevskii, Izv. Voen.-Med. Akad., 16, 259 (1908).
5. A. M. Mindlin, Izv. Vyssh. Uchebn. Zaved. Priborostroenie, No. 2, 129 (1958).
6. A. M. Mindlin, Izv. Vyssh. Uchebn. Zaved. Priborostroenie, No. 2, 132 (1962).
7. R. P. Ol'nyanskaya, Outlines of Regulation of Metabolism [in Russian], Moscow-Leningrad (1964).
8. A. D. Slonim, Animal Heat and Its Regulation in Mammals [in Russian], Moscow-Leningrad (1952).
9. L. K. Cherednichenko, Physiological Calorimetry [in Russian], Moscow-Leningrad (1965).
10. L. K. Cherednichenko, Fiziol. Zh. SSSR, No. 8, 1012 (1966).
11. L. L. Shik, in the book: Regulation of Respiration, the Circulation, and Gas Exchange [in Russian], Moscow (1948), p. 129.
12. E. Gellhorn, Regulatory Functions of the Autonomic Nervous System [Russian translation], Moscow (1948).
13. I. Giaja, Biol. Méd. Paris, 42, 545 (1953).
14. A. Goebel and W. Vlante, Z. Ges. Exp. Med., 121, 84 (1953).
15. I. Pichotna and T. Suthardt, Pflüg. Arch. Ges. Physiol., 269, 417 (1959).