THE EFFECT OF CARBON DIOXIDE ON THE OXYGEN TENSION OF THE BRAIN AND SKELETAL MUSCLE IN ACUTE HYPOXIA

N. V. Sanotskaya

From the Laboratory for the Physiology and Pathology of Respiration and Blood Circulation (Head, Corresponding Member of the AMN SSSR Prof. M. E. Marshak) of the Institute of Normal and Pathological Physiology (Dir., Active Member of AMN SSSR V. V. Parin) of the AMN SSSR, Moscow

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It is known that the intensified breathing associated with hypoxia, arising as a result of a decrease in the partial pressure of the oxygen in the arterial blood, leads to an excessive loss of carbon dioxide from the organism, and to the development of hypocapnia. This, in turn, leads to a reduction in the effectiveness of the mechanisms involved in adaptation to hypoxia: under conditions of hypoxia, hypocapnia limits the increase in pulmonary ventilation [12], and effects the affinity of hemoglobin for oxygen in such a way that the transfer of oxygen from the blood to the tissues becomes more difficult [9]. In addition, while hypoxia by itself causes an increase in the blood supply to the brain and heart, the hypocapnia developing in association with it leads to a gradual reduction of the increase in blood supply to these organs [3].

It has been established that the addition of small concentrations of carbon dioxide to inspired air during hypoxia prevents the development of hypocapnia, and shows a favorable action [2, 3, 4, 11, 12, 13]: it causes an increase in pulmonary ventilation and a rise in the oxygen pressure of the alveolar air and the arterial blood [8, 10, 12, 14], it reduces gas metabolism, thanks to a decrease in the oxygen requirement of the organism [1, 7], and finally, it enables a redistribution of the blood in the organism in such a way that organs essential to life – the brain and heart – are supplied with an abundance of blood at the expense of the blood supply to the skeletal muscles [2, 3].

It is of great importance to attain data on the changes in the oxygen tension within the tissues under these conditions, since this index can yield concepts relative to the degree of effectiveness of the adaptive reactions.

It has been shown [6] that hypercapnia, associated with a normal concentration of oxygen in the inspired air, causes an elevation in the oxygen tension within the brain, and, in the majority of cases, its reduction in the muscles. These oxygen tension changes in the different tissues basically depend on changes in their blood supply associated with hypercapnia (blood supply of the brain increases, of the muscles, decreases).

This work was devoted to studying the effect of carbon dioxide on the oxygen tension of the brain and skeletal muscle in acute hypoxia. This question not only presents theoretical interest, but also holds practical importance.

EXPERIMENTAL METHOD

Short-term experiments were set up on cats under urethane narcosis (the method of their preparation has been presented in detail in previous reports [5, 6]). During the experiment, the cat was made to breathe a gas mixture containing a decreased concentration of oxygen (7, 10 or 13% O_2 in the different trials) for 3-10 minutes, followed by a gas mixture containing the same percent of oxygen but with the addition of 5-7% carbon dioxide. These mixtures were given to the animal in the same order several times in the course of the experiment, at intervals of 30-40 minutes. In addition, the reactions were compared with inspiration of pure nitrogen and asphyxia.

EXPERIMENTAL RESULTS

The addition of carbon dioxide to the hypoxic mixture has varying effects on the direction of the changes in oxygen tension within the different tissues: the addition of carbon dioxide to the hypoxic mixture always showed itself to be favorable for the brain, preventing, or significantly decreasing, the drop in oxygen tension which was observed in the brain with the same hypoxia but without the addition of carbon dioxide (Fig. 1); in the skeletal muscle, on the other hand, this addition usually enhanced the decrease in oxygen tension, that occurred with hypoxia without the addition of carbon dioxide (Fig. 2). However, in certain cases the addition of carbon dioxide to the hy-

poxic mixture had almost no effect on the oxygen tension in the muscles, or even caused a certain elevation in the oxygen tension.

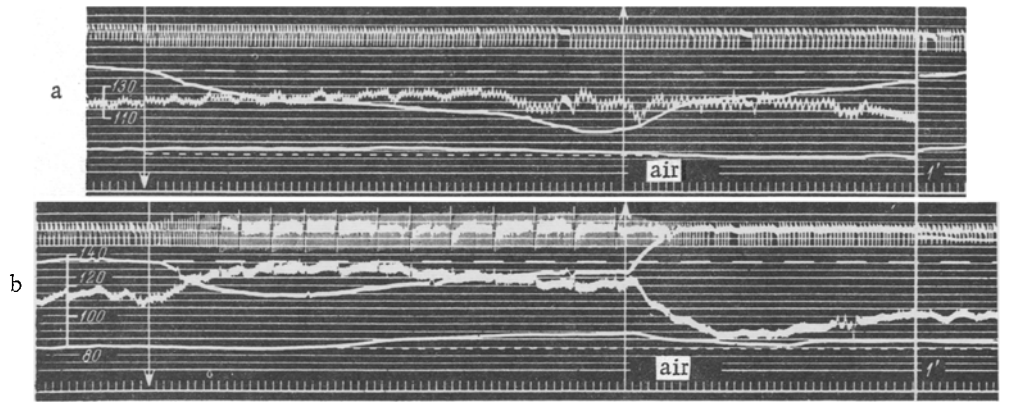

Fig. 1. Changes in the oxygen tension within the brain associated with inspiration of a mixture (↓↑) containing: a – 13% O_2; b – 13% O_2 and 7% CO_2. The curves (from above downward): respiration, oxygen tension in the brain, arterial pressure, volumetric rate of blood flow in the cerebral membranes, time markings (5 seconds). Vertical lines – interruptions in the recording of one minute.

It was shown earlier [6] that, for a number of reasons, even with a normal concentration of oxygen in the inspired air the direction of the changes in oxygen tension within the brain during hypercapnia differs, with great constancy, from that seen in the skeletal muscle. In addition, it should be taken into consideration that, under condi-

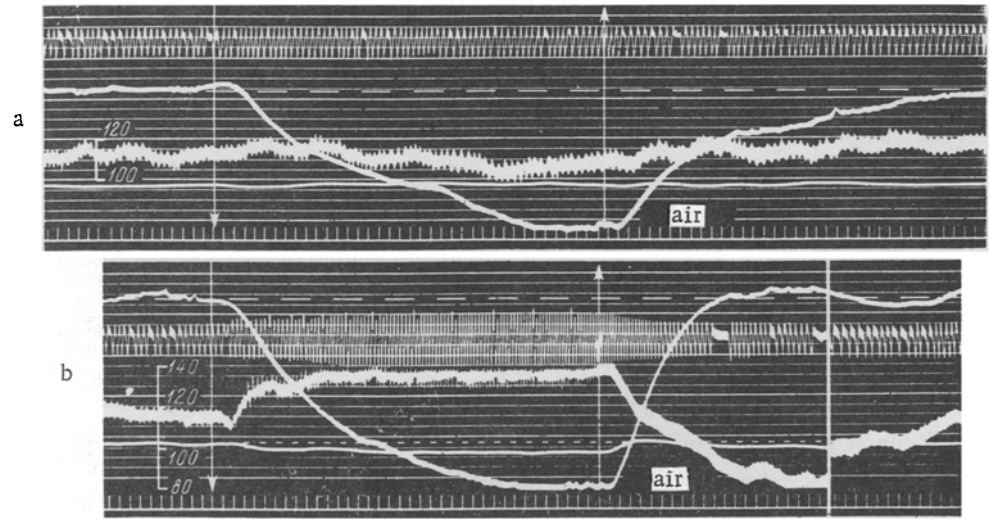

Fig. 2. Changes in the oxygen tension within the skeletal muscles associated with inspiration of a mixture (↓↑) containing: a – 13% O_2; b – 13% O_2 and 7% CO_2. Curves (from above downward): a – respiration, oxygen tension in the muscles, arterial pressure, volumetric rate of blood flow in the femoral artery, time markings (5 seconds); b – oxygen tension in the muscles, respiration, arterial pressure, volumetric rate of blood flow in the femoral artery, time markings (5 seconds). Vertical line – interruption in the record for one minute.

tions of hypoxia, the addition of carbon dioxide can cause an increase in the oxygen saturation of the arterial blood, due to intensification of pulmonary ventilation; apparently, in certain cases this may exert a stronger influence on

the oxygen tension within the muscles than the simultaneous vasoconstrictive action of carbon dioxide on the vessels supplying the musculature.

Thus, with the joint action of hypoxia and hypercapnia, there is a summation of those effects which each of these factors alone exerts on the oxygen tension within the different tissues [5, 6]. As a result, the addition of carbon dioxide to the hypoxic mixture, preventing the development of hypocapnia, creates conditions for the redistribution of blood in the organism in such a way that, at the expense of the skeletal musculature and, possibly, other organs less sensitive to oxygen insufficiency, the brain is more favorably supplied with oxygen. What is more important is that the washing out of carbon dioxide and the development of hypocapnia has an especially negative effect on the supply of oxygen to the brain [6]. The effect of carbon dioxide on the path of the changes in oxygen tension within the tissues was graphically demonstrated by comparison with the reaction to asphyxia and to inspiration of pure nitrogen;in both cases the entrance of oxygen into the organism is completely stopped, but with asphyxia there is a simultaneous accumulation of carbon dioxide).

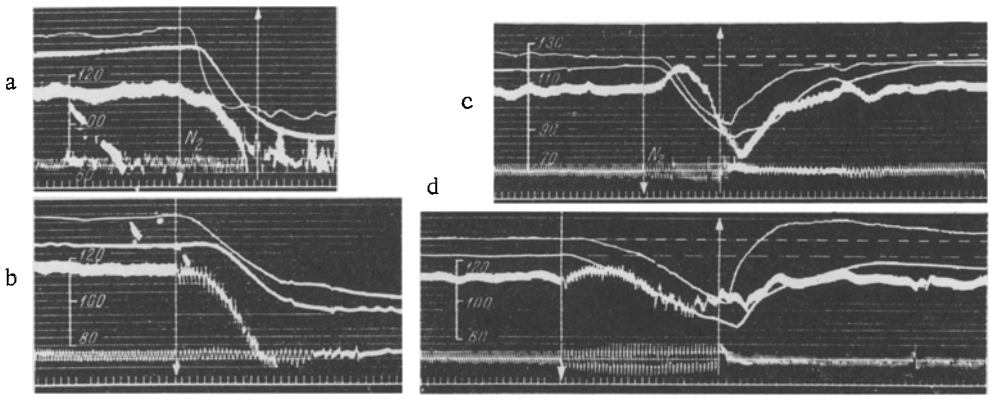

Fig. 3. Changes in the oxygen tension within the brain and skeletal muscle associated with inspiration of nitrogen—a, c (↓↑) and with asphyxia (b—↓, d—↑). Curves (from above downward): oxygen tension in the brain, oxygen tension in the skeletal muscle, arterial pressure, respiration, time markings (5 seconds).

While the changes in the oxygen tension within the skeletal muscle were almost identical with nitrogen breathing and asphyxia, the direction of these changes in the brain were different in both cases. With asphyxia (Fig. 3 b), the oxygen tension in the brain usually decreased much less severely than with inspiration of nitrogen (Fig. 3 a), and attained its minimum constant level after a longer period of time. With death occurring from asphyxia, the time required to establish the constant minimum level of the oxygen tension within the brain was greater, as a rule, than for the oxygen tension in the musculature; with inspiration of nitrogen, the reverse relationships were observed. If the asphyxia or nitrogen breathing were continued for only a given time interval, it was then possible to see clearly the difference in the pathway of the oxygen tension restorations in both cases: following asphyxia (Fig. 3 d) the oxygen tension in the brain rose to a higher level than the original after 1-2 minutes, while after inspiration of nitrogen (Fig. 3 c) complete restoration was either not seen at all or it occurred much more slowly. The oxygen tension in the musculature after inspiration of nitrogen (see Fig. 3 c) was restored more rapidly than after asphyxia (see Fig. 3 d).

Thus, even when the access of oxygen from the outside is completely stopped, the accumulation of carbon dioxide permits the maximum supply of oxygen possible under these conditions to be delivered to the organs most essential to life (the brain and, probably, the heart), and enables the maximum prolongation of life.

SUMMARY

Acute experiments were performed on cats under urethane anesthesia. An inquiry was made into the effect of carbon dioxide on the oxygen tension in the brain and skeletal muscle (polarographic method) in acute hypoxia. As established, an addition of 5-7 percent carbon dioxide to hypoxic mixture had a different effect on the course of changes of the oxygen tension in various tissues: addition of carbon dioxide to hypoxic mixture usually aggravates the oxygen tension reduction in the skeletal muscle occurring with the same hypoxic level, but without carbon dioxide; carbon dioxide addition to hypoxic mixture prevents or decreases the oxygen tension reduction in the brain observed in hypoxia without the addition of carbon dioxide.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.
