Changes in Hemodynamics and Respiration in Animals with Different Resistance to Acute Hypoxia

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We studied the effects of acute hypoxia on hemodynamics and respiration in cats. The animals were divided into high-, low- and medium-resistant to hypoxia by the time of respiratory arrest after breathing with 3% O_2 gas mixture. In high-resistant animals, hemodynamic indices remained at a high level throughout the hypoxic episode, while in low-resistant cats they decreased shortly after the onset of hypoxia. It is suggested that the peculiarities of hemodynamic regulation play an important role in individual resistance to acute hypoxia.

Key Words: *acute hypoxia; hemodynamics; respiration; individual resistance to hypoxia, ultrasound techniques*

Recent studies have confirmed the existence of individual, apart from species-specific sensitivity to hypoxia. Special normobaric and hypobaric tests make it possible to classify the animals as high- (HR), medium- (MR) and low-resistant (LR) to hypoxia [1-3,6,9]. Biochemical studies showed that animals with different resistance to hypoxia differ not only in parameters of energy, lipid, and carbohydrate metabolism [2,6], but also in the functional characteristics of hemodynamic regulation. However, complex analyses of cardiovascular resistance to different variants of hypoxia have not yet been performed.

The aim of this study was to investigate the effect of acute hypoxic hypoxia on hemodynamics and respiration in HR, MR, and LR animals.

MATERIALS AND METHODS

Acute experiments were carried out on 35 male and female cats (1.8-4.4 kg) anesthetized with Nembutal (40-50 mg/kg) under conditions of natural ventilation. The linear and volume blood flow velocities in the ascending aorta and pulmonary cone were determined with an ultrasound technique. Blood pressure in the femoral and pulmonary arteries (BP) was measured with an electric manometer [7]. Ultrasonic transducers were placed on the corresponding vessels during open thorax surgery under conditions of artificial ventilation (AV), then the tissues were sutured, and the animal was switched to natural ventilation. Respiratory movements were recorded with a strain transducer. The recorded indices were analyzed on line with a microcomputer to calculate total peripheral and pulmonary vascular resistance, heart rate (HR), stroke volume, and cardiac index. Changes in the cerebral blood supply were analyzed in 8 experiments. The linear and volume blood flow velocities in the common carotid and internal maxillary arteries were studied using miniature ultrasonic transducers with an inner diameter of 1.5 and 0.5 mm. In some experiments the arterial gasses were analyzed according to the method of Astroup—Ziggard—Andersen.

Individual resistance to hypoxia was measured by the time from the onset of respiration with 3% O_2 in nitrogen to respiratory arrest (apnea). Then the gas flow was stopped for 2-3 min. was discontinued and the recovery of respiration was awaited for the following 2-3 min. If spontaneous respiration did not recover, the animals were ventilated artificially until the appearance of spontaneous inspirations.

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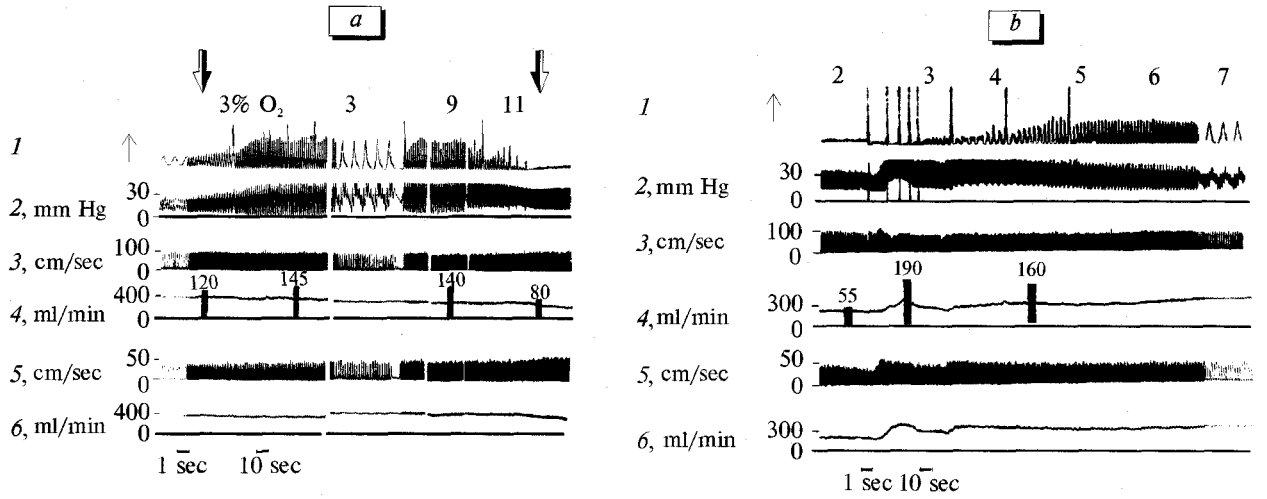

Fig. 1. Hemodynamic and respiratory indices in high-resistant cat during hypoxia (*a*) and recovery (*b*) periods. Here and in Fig. 2, *a*: *1)* respiration (inspiration, upward arrow); *2)* blood pressure in the pulmonary artery; linear *(3)* and volume *(4)* blood flow velocities in the ascending aorta; linear *(5)* and volume *(6)* blood flow velocities in the pulmonary cone. Here and in Figs. 2 and 3; solid line below each curve shows a zero level. Arrows mark the onset and end of breathing with hypoxic mixture. Numbers above the upper curves indicate the time after the onset of hypoxia or recovery, min.

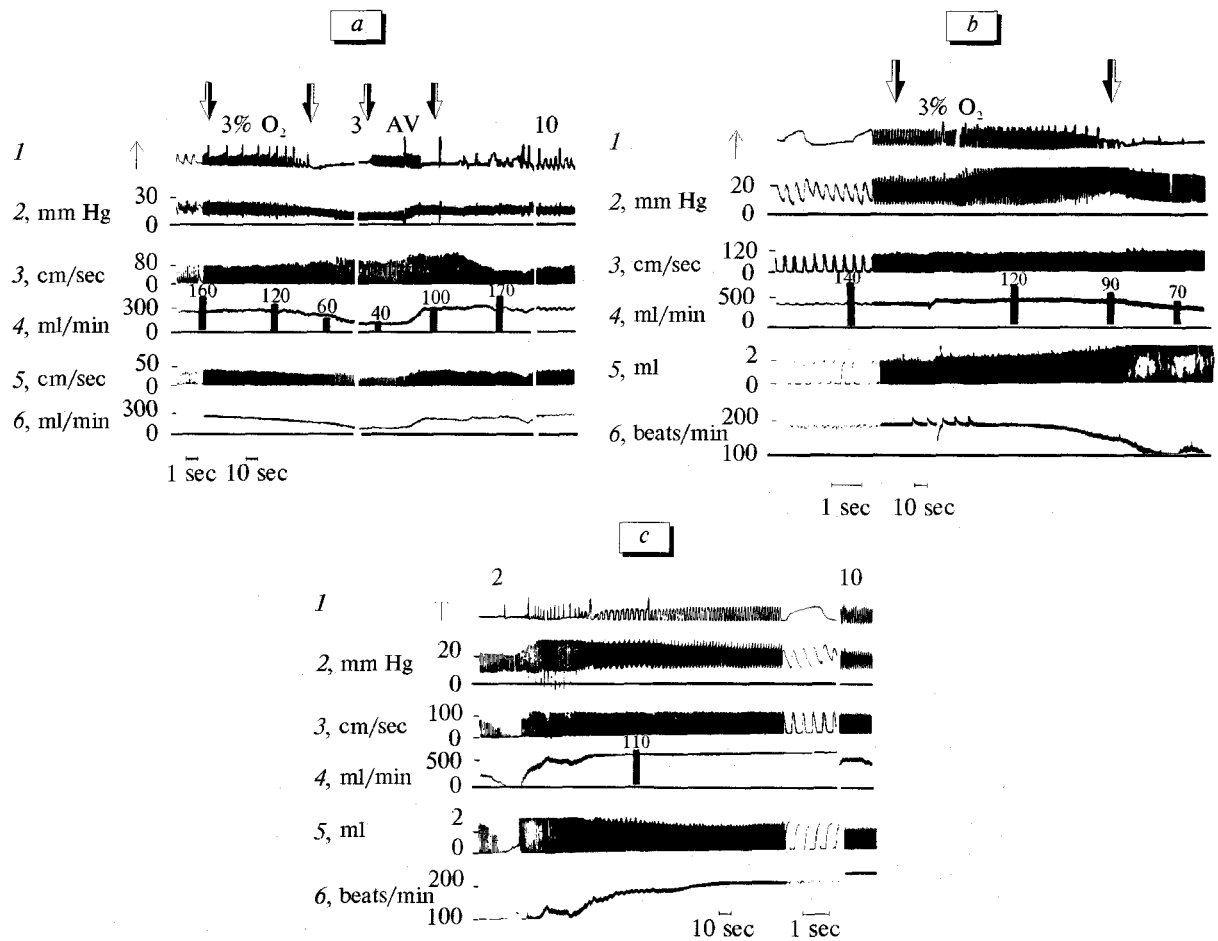

Fig. 2. Hemodynamic and respiratory indices in low-resistant cat during hypoxic episode (*a*), respiratory arrest (*b*), and respiration recovery (*c*). *1)* respiration; *2)* blood pressure in the pulmonary artery; linear *(3)* and volume *(4)* blood flow velocities in the ascending aorta; *5)* stroke volume; *6)* heart rate. Here and Figs 3: AV, artificial ventilation.

The inhalation of gas mixture containing 3% O_2 is incompatible with life [5]. However, animals differ in their resistance to hypoxia: in our experiments, the time to respiratory arrest varied from 1 to 30 min. The animals surviving for 1-4 min were considered as LR, those resisting for 9 min or longer were classified as HR, and those resisting for 5-8 min were classified as MR [2].

RESULTS

Among 35 cats, 13 animals were HR (37.1%), 12 MR (34.3%), and 10 LR (28.6%). In all the groups, the initial indices of hemodynamics and respiration were within normal showing no intergroup difference. At the same time, they showed different dynamics under conditions of acute hypoxia, the most pronounced difference being observed between the HR and LR cats.

The HR cats were characterized by stable hemodynamics during hypoxic exposure, the indices decreased only after apnea (Fig. 1, *a*). Cardiac output and HR remained unchanged or increased by 20-30 and 5-20%, respectively. Systemic BP increased by 10-15% at the beginning of hypoxia, but returned to the baseline before apnea. Pulmonary BP increased 2.5-fold with a parallel increase in the pulmonary vascular resistance. During the first few minutes of hypoxia the rate of respiration surpassed the initial level by on average 150%, but returned to the baseline before apnea. The amplitude of respiratory movements also increased. During apnea the hemodynamic indices decreased to 75% of the initial values. When gas flow was stopped, the respiration usually recovered within 1.5-2 min without AV. During this period the hemodynamic indices exceeded the initial values, but returned to the baseline in 8-10 min (Fig. 1, *b*).

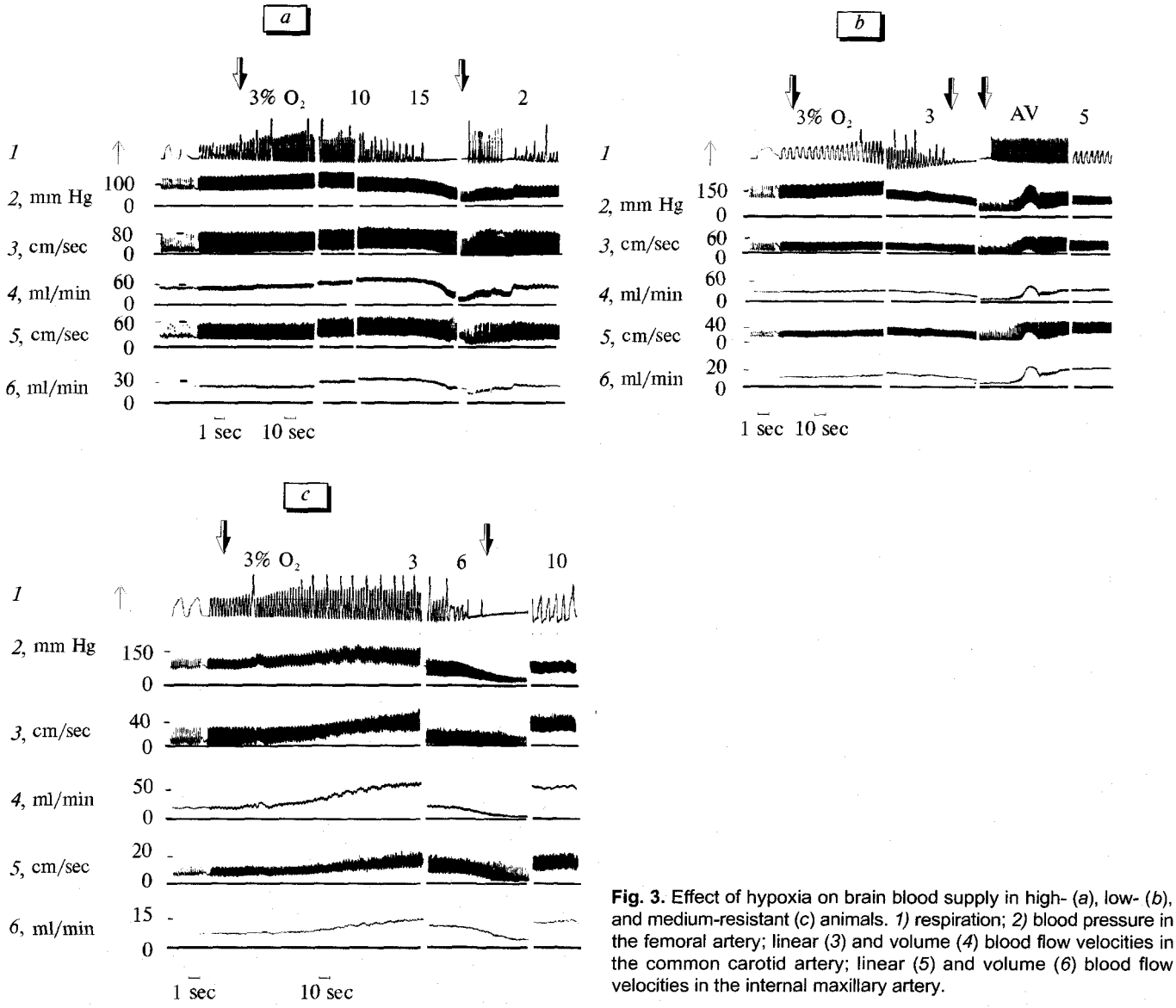

Fig. 3. Effect of hypoxia on brain blood supply in high- (*a*), low- (*b*), and medium-resistant (*c*) animals. *1)* respiration; *2)* blood pressure in the femoral artery; linear (*3*) and volume (*4*) blood flow velocities in the common carotid artery; linear (*5*) and volume (*6*) blood flow velocities in the internal maxillary artery.

In the LR animals, 1-2-min inhalation of hypoxic mixture reduced the hemodynamic indices and upset the balance between the outputs of the right and left ventricles. Apnea occurred when indices decreased to 50-60% of the baseline (Fig. 2, *a, b)*. During apnea, AP, cardiac output, and HR dropped to 40% of their initial values (in some experiments they dropped almost to zero). The respiration was usually restored by AV (Fig. 2, *a, c*). During hypoxic exposure the respiration rate and the amplitude of respiratory movements sharply increased or decreased.

In the MR cats, hemodynamic indices were also reduced during hypoxia, but to a lesser extent than in LR animals. Right- and left-ventricle outputs also got out of balance. A reduced blood flow in the ascending aorta and enhanced flow in the pulmonary cone indicated increased venous return and possible blood deposition in the lungs [10].

Apnea usually lasted for 2-3 min. If spontaneous respiration did not recover during this period, the animal was artificially ventilated. Recovery started with 5-6 gasps (spontaneous or under conditions of AV), followed by rhythmic respiration at a low (below the initial) rate. The HR animals returned to the initial respiration rate within 10-15 min. In the LR animals, the respiration rate did not recover throughout the experiment and remained below or above the initial. In some of MR animals the respiration recovered spontaneously, in others — during AV.

Acute hypoxia is known to cause redistribution of the blood flow increasing blood supply to vitally important organs (brain, heart, respiratory muscles) at the expense of less important tissues [5,8]. Our study showed that severe hypoxia caused different changes in the brain blood supply probably due to different changes in cardiac output, systemic BP, and individual reactivity of brain vessels in animals with different resistance to hypoxia.

Brain blood supply was studied in 8 cats (3 HR, 3 MR, and 2 LR). In the HR animals, blood flow in the common carotid and internal maxillary arteries during hypoxia increased 1.5-2-fold and remained at this level until apnea (Fig. 3, *a*). During apnea blood flow decreased to 50% of the initial values and slightly surpassed them during the recovery period. The initial level of blood flow was restored in 5-7 min.

In the MR cats, cerebral blood flow increased during the first few minutes of hypoxia, but started to decrease long before the respiratory arrest (Fig. 3, *c*). During apnea it decreased to 30-40% of the initial value and returned to the baseline 10-15 min after respiration was restored. In the LR animals, brain blood supply during hypoxia was either unaffected or increased by 15-20%. It dramatically decreased during apnea and returned to the baseline 5-10 min after the onset of AV (Fig. 3, *b*).

The analysis of arterial gases revealed that apnea occurred at the mean Po_2=12.5 mm Hg (9.7-16.7 mm Hg), SaO_2=15.2% (7.1-21%), and Pco_2=21.3 mm Hg (17.1-29.7 mm Hg). These values are slightly lower than the ones reported previously [13].

These wide ranges of the content of blood gases corresponding to respiratory arrest points to considerable variations in individual resistance to hypoxia. In animals with lower Po_2 at respiratory arrest, brain blood supply during hypoxia increased to a greater extent, which allowed them to resist low blood oxygenation, since increased volume blood flow maintained tissue Po_2 abo ve critical level for a long time [4,11,12].

Thus, individual resistance to hypoxia is determined not only by metabolic processes, but also by peculiarities of hemodynamic regulation.

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