PULMONARY AND BRONCHIAL CIRCULATION IN A MODIFIED ATMOSPHERE

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In the clinical treatment of chronic nonspecific lung diseases, gas mixtures in which nitrogen is replaced by helium are used to make the pulmonary gas exchange more efficient [1, 3, 5]. Because of the physical properties of helium it facilitates passage of the gas mixture along the respiratory pathways and the supply of oxygen to the gas-exchange surface of the lungs [8, 12]. Meanwhile, a distinct change in external respiratory function has been observed [2, 4, 9]. The effect of helium-oxygen gas mixtures on the pulmonary hemodynamics and bronchial circulation has not been studied. The close relations which exist between respiratory function and the hemodynamics suggest possible changes in the pulmonary and bronchial circulation under these conditions. Considering that helium facilitates CO_2 diffusion [4, 5], it was also important to study the effect of addition of low concentrations of CO_2 to the helium-oxygen mixture in order to prevent hypocapnia.

The aim of this investigation was to study the pulmonary and bronchial circulation during breathing a helium-oxygen or helium-oxygen hypercapnic gas mixture.

EXPERIMENTAL METHOD

In acute experiments on 35 cats weighing 3-4.5 kg, under pentobarbital anesthesia (40-50 mg/kg, intraperitoneally) the linear and volume velocity of the blood flow in the left inferior lobar artery and vein and in the common pulmonary and bronchial arteries (at the place where the bronchial artery arises from the thoracic aorta) were studied by an ultrasonic method [6, 10, 11]. The blood pressure in the pulmonary and femoral arteries was recorded by means of an electromanometer [7]. The resistance of the vascular bed (in mm Hg/ml·min) of the lower lobe of the lung was calculated by means of an analog computer as the quotient obtained by dividing mean values of pressure in the pulmonary artery by the mean blood flow along the lobar artery; the resistance of the bronchial arterial bed was calculated as the quotient from dividing the systemic blood pressure (BP) by the mean blood flow along the bronchial artery [6, 7, 10, 11]. When the animals were anesthetized, they were maintained on artificial ventilation of the lungs. Thoracotomy was performed in the fourth left intercostal space. Ultrasonic transducers were applied to the vessels chosen for study. A catheter was introduced through the superior lobar artery into the lumen of the pulmonary artery to measure pressure. The pulmonary hemodynamics were studied under closed chest conditions and during spontaneous breathing. The ends of the leads of the ultrasonic transducers were brought out through the intercostal space next to the operation wound, outside the chest. The intercostal muscles were sutured in layers. By means of a vacuum pump a negative intrathoracic pressure was created, equal to its initial value (−0.59 to −0.88 kPa). The animals were switched to spontaneous breathing. The bronchial blood flow was studied under open chest conditions, with artificial ventilation of the lungs. The diameter of the bronchial artery in cats is about 0.5 mm, and the blood flow in it was recorded by means of a high-sensitivity ultrasonic blood flow transducer of bandage type. The gas composition of the arterial blood and pH were monitored by means of a micro-Astrup analyzer. The effect of the following gas mixtures on the hemodynamics was investigated: 7.5% O_2 in nitrogen, 30% O_2 + 70% N_2, 3% CO_2 in air, 21% O_2 + 79% He, 30% O_2 + 3% CO_2 + 67% He. The gas mixtures were supplied from a Douglas bag through breathing valves. Breathing a hypoxic gas mixture

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TABLE 1. Parameters of Hemodynamics during Breathing Gas Mixtures of Varied Composition (M ± m)

Gas mixture	Blood pressure in pulmonary artery, mm Hg	Blood pressure in femoral artery, mm Hg	Volume velocity of blood flow, ml/min			
			in pulmonary artery	in inferior labor pulmonary artery	in inferior labor pulmonary vein	in bronchial artery
Atmospheric air	12,8±0,3	103,5±5,8	301,5±5,2	65,5±0,6	66,4±0,5	5,8±0,1
7,5 % O_2	16,1±0,4	86,0±5,3	286,0±4,9	62,3±0,4	63,4±0,5	6,5±0,1
30 % CO_2	9,4±0,1	101,4±5,7*	304,5±7,1*	66,2±0,5*	67,0±0,4*	5,0±0,1
3 % CO_2	14,4±0,1	143,1±4,8	318,9±5,1	62,7±0,3	63,5±0,5	5,1±0,2
79 % He + 21 % O_2	12,5±0,2*	105,4±5,6*	291,8±4,1*	60,0±1,1	61,5±0,6	6,4±0,1
67 % He + 3 % CO_2 + 30 % O_2	12,2±0,3*	107,0±5,9*	310,0±4,7	64,0±0,7*	65,0±0,5*	4,5±0,1

Legend. *$p > 0.05$ compared with initial data.

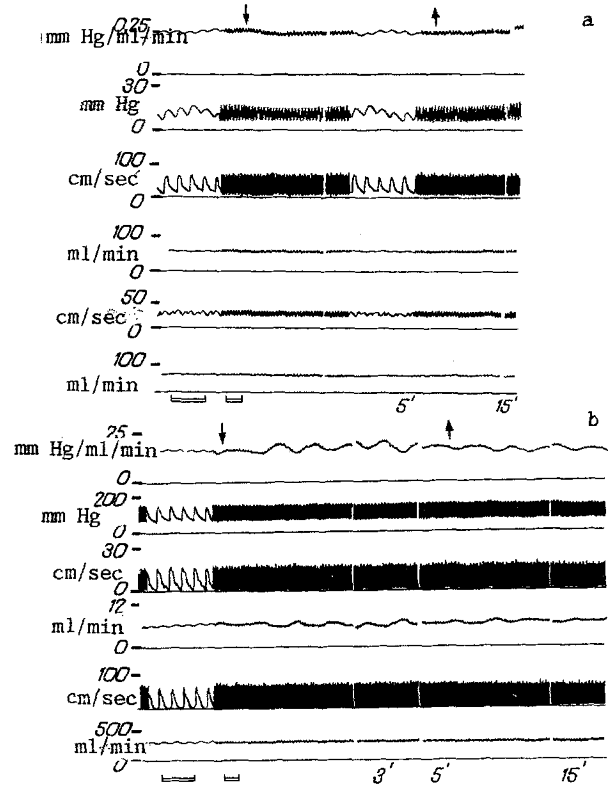

Fig. 1. Changes in parameters of pulmonary and bronchial circulation during inhalation of gas mixture containing 30% O_2 + 70% N_2. a: From top to bottom – vascular resistance of lobe of lung, blood pressure in pulmonary artery, phasic blood flow in inferior lobar pulmonary artery, mean values of blood flow in lower lobar pulmonary artery, phasic blood flow in lower lobar pulmonary vein, mean values of blood flow in lower lobar pulmonary vein; b: from top to bottom – vascular resistance of bronchial arterial bed, blood pressure in femoral artery, phasic blood flow in bronchial artery, mean values of blood flow in conus arteriosus. Here and in Figs. 2 and 3: thin lines beneath each curve indicate zero levels. Arrows show beginning and end of inhalation of gas mixture. Numbers in bottom part of figure denote time (in min) elapsing after beginning or end of inhalation of gas mixture. Time scale: 1 and 10 sec.

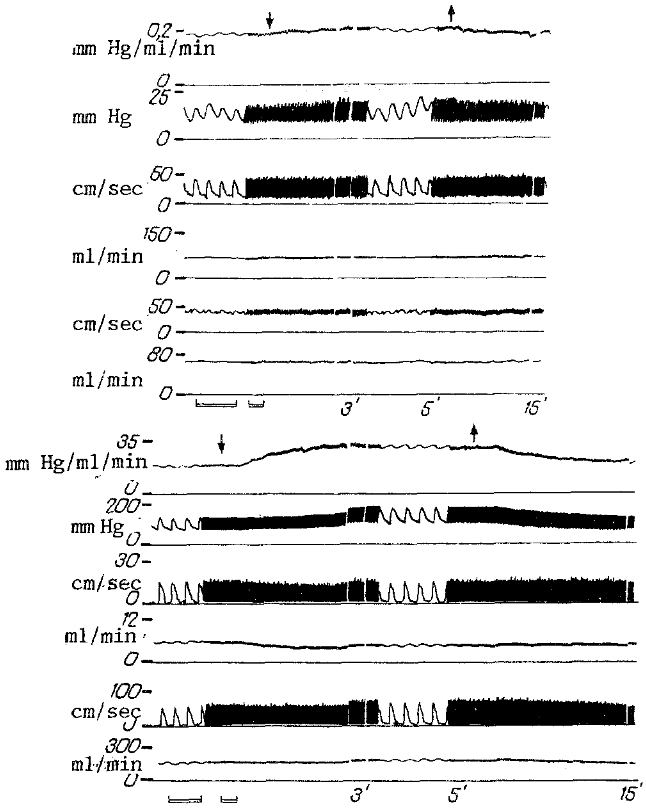

Fig. 2. Changes in parameters of pulmonary and bronchial circulation during inhalation of gas mixture containing 3% CO_2 in air. Legend as to Fig. 1a, b.

(7.5% O_2 in nitrogen) was used as the function test to assess the reactivity of the vascular bed of the pulmonary and bronchial vessels. Hyperoxic and hypercapnic gas mixtures were used to analyze the mechanism of action of the complex helium-oxygen-hypercapnic gas mixture.

EXPERIMENTAL RESULTS

The time course of the parameters of the pulmonary and bronchial circulation during inhalation of the gas mixtures is illustrated in Table 1 and Figs. 1-3. Table 1 gives the initial data and values obtained at the 5th minute of breathing the gas mixtures.

During inhalation of the hypoxic gas mixture the blood pressure in the pulmonary artery rose (by 25.8 ± 2.3%), he pulmonary vascular resistance increased (by 32.2 ± 2.9%), the blood flow along the inferior lobar artery and vein was very slightly reduced, and the cardiac output also fell. Meanwhile the systemic BP (by 16.0 ± 6.2%) and the vascular resistance of the bronchial arterial bed (by 16.6 ± 3.1%) decreased. The bronchial blood flow increased (Table 1).

During inhalation of the hyperoxic gas mixture very slight changes developed in the pulmonary and systemic hemodynamics, opposite to those taking place in hypoxic hypoxia. The pressure in the pulmonary artery fell, the vascular resistance of the pulmonary artery decreased, and the blood flow in the pulmonary vessels increased a little. In some experiments no changes took place in the blood flow in the pulmonary vessels. As a rule the systemic BP was unchanged. The bronchial blood flow fell very slightly but the resistance of the bronchial vascular bed increased. The appearance of wavelike changes in resistance and blood flow in the bronchial artery will be noted, which were not synchronized either with the corresponding changes in BP or with respiration (Fig. 1a, b). Incidentally, "waves" of this kind not infrequently appeared on the curve of bronchial blood flow and vascular resistance of the bronchial artery during exposure to other factors. The mechanism of their appearance is not clear.

During inhalation of the hypercapnic gas mixture, just as when breathing the hypoxic mixture, the blood pressure in the pulmonary artery rose (by 12.5%). The blood flow along the lobar pulmonary artery and vein decreased but not significantly. Meanwhile changes of

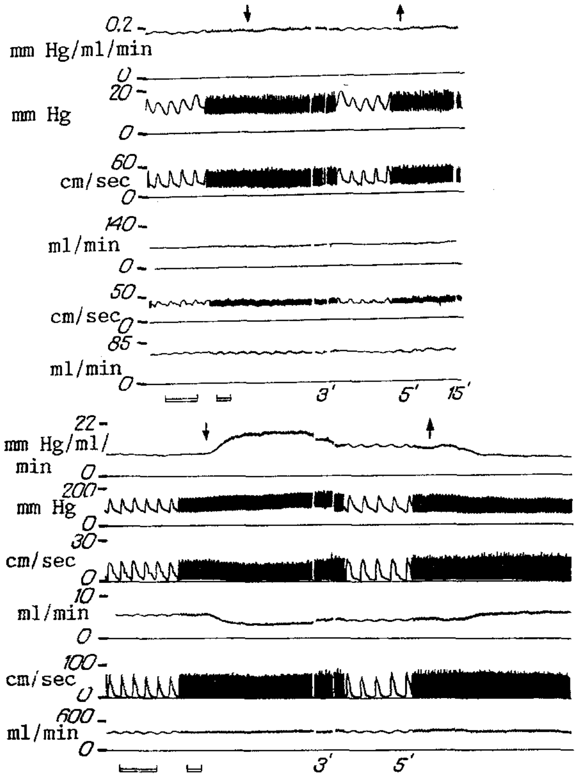

Fig. 3. Changes in parameters of pulmonary and bronchial circulation during inhalation of gas mixture containing 67% He + 3% CO_2 + 30% O_2. Legend as to Fig. 1a, b.

a different character took place in the systemic circulation. The systemic BP rose (by 38.3%). Meanwhile the resistance of the vascular bed of the bronchial artery increased, but the bronchial blood flow decreased (Fig. 2a, b).

During inhalation of a normoxic gas mixture in which nitrogen was replaced by helium, no significant changes took place in the blood pressure in the pulmonary artery or systemic BP. The vascular resistance of the lungs likewise was unchanged. In some experiments there was a very small decrease in the blood flow along the pulmonary artery and vein, evidently due to an equally small reduction of the cardiac ejection. The blood flow along the bronchial artery rose by 10.4%.

During inhalation of a helium-oxygen hypercapnic gas mixture the blood pressure in the pulmonary artery and the pulmonary vascular resistance and blood flow along the pulmonary vessels remained virtually unchanged (Fig. 3a). This can be partly explained by the mutual cancellation of the effects of hyperoxia and hypercapnia, which had opposite effects on the vascular bed of the lungs. However, this is not sufficient to explain the mechanis of the almost complete suppression of the response of the lung vessels to inhalation of the complex gas mixture, for the response to one component of this mixture, namely CO_2, was much stronger than the response to the other component, namely O_2. The systemic BP was characterized by a biphasic reaction (Fig. 3b). During the first minute of breathing the mixture changes characteristic of a hypercapnic gas mixture took place and BP rose. At the 5th minute of breathing the complex mixture these changes became more marked: BP approximated to its initial level, i.e., an effect of concomitant hyperoxia appeared after a short delay. During synchronized exposure to the components of the complex gas mixture the bronchial blood flow fell by a greater degree than during exposure to hypercapnia or hyperoxia alone. What took place was not the simple summation of the constrictor effects of CO_2 and O_2, but mutual potentiation of these effects, which predominated over the weak dilator effect of helium. Corresponding changes also took place in the resistance of the bronchial arterial bed: it increased more than under the influence of the hypercapnic or hyperoxic mixture separately (Fig. 3b).

Investigation of the blood gases showed that hypoxia induced a fall of p_aO_2 and p_aCO_2 (by 65.1 ± 3.2 and 39.2 ± 3.8% respectively), whereas hyperoxia caused an increase in p_aO_2

(by 18.8 ± 3.6%). Hypercapnia was accompanied by an increase in p_aO_2 (by 7.9 ± 2.4%) and p_aCO_2 (by 6.8 ± 2.1%). Breathing a normoxic gas mixture with helium was accompanied by a small decrease in p_aCO_2, which may have been due to an increase in CO_2 diffusion under the influence of helium [5]. The complex helium-oxygen hypercapnic gas mixture caused an increase in p_aO_2 (by 19.1 ± 3.1%), but did not completely abolish the hypocapnia: p_aCO_2 remained depressed (by 2.7 ± 1.1%). Addition of 3% CO_2 only partially abolished the effect of helium, which induces hypocapnia.

Thus breathing a normoxic helium-oxygen gas mixture does not cause any significant changes in the pulmonary and systemic hemodynamics or in the blood gas composition. Meanwhile the presence of helium in complex gas mixtures may modify the reactivity of the pulmonary and bronchial vessels relative to the action of components introduced into the composition of these mixtures (relative to hypercapnia and hyperoxia in the present investigations).

LITERATURE CITED

1. V. A. Berezovskii, A. I. Nazarenko, and T. N. Govorukhina, Fiziol. Zh. (Kiev), 28, No. 3, 353 (1982).
2. I. S. Breslav and E. M. Kasacheva, Fiziol. Cheloveka, 6, No. 2, 317 (1980).
3. A. G. Dianov, R. N. Lebedeva, V. A. Mikhel'son, et al., Sov. Med., No. 4, 56 (1973).
4. L. I. Zhukovskii, E. A. Tsyrul'nikov, L. D. Fesenko, et al., Klin. Med., 67, No. 2, 114 (1989).
5. Yu. F. Isakov, V. A. Mikhel'son, and M. I. Anokhin, Oxygen Therapy and Hyperbaric Oxygenation in Children [in Russian], Moscow (1981).
6. D. D. Matsievskii, Byull. Éksp. Biol. Med., No. 3, 119 (1984).
7. D. D. Matsievskii, Byull. Éksp. Biol. Med., No. 3, 377 (1984).
8. R. W. Pohl, Mechanics, Acoustics, and Heat Sciences [Russian translation], Moscow (1971).
9. E. V. Rozova, Fiziol. Zh. (Kiev), 28, No. 5, 588 (1982).
10. N. V. Sanotskaya and D. D. Matsievskii, Byull. Éksp. Biol. Med., No. 12, 119 (1982).
11. N. V. Sanotskaya and D. D. Matsievskii, Byull. Éksp. Biol. Med., No. 9, 286 (1985).
12. C. V. Paganelli, A. Ar, H. Rahu, and O. D. Wangensteen, Resp. Physiol., 25, 247 (1975).

CHANGES IN RHYTHM OF THE ISOLATED AND INTACT FROG HEART WITH TIME

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The isolated frog heart still remains one of the most widely used experimental objects [2-9]. However, despite many investigations conducted on this object, there has still been no detailed study of the time course of the rhythm of the isolated frog heart, starting with the time of isolation. It is absolutely essential to know this relationship for the intelligent conduct and evaluation of the results of experiments. We know, for example, that there are differences in the relationship between the frequency of excitation of the heat and temperature for the intact and isolated frog heart [2, 4, 5]. Usually they are linked with the influence of the autonomic nervous system [2, 4]. It is interesting to compare these relationships, allowing for changes in the rhythm of the isolated frog heart with time. The investigation described below was carried out to study these problems (specifically, the time course of the rhythm of the isolated frog heart and the effect of this dynamics on the results of experiments).

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