EFFECT OF RESPIRATORY CHANGES ON THE DEGREE OF ARTERIAL OXYGEN SATURATION

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For normal oxygenation of the pulmonary blood, there must be a close correlation between ventilation and blood flow. Disturbance of this correlation is the principal cause of arterial hypoxia in health or disease, as is shown by many experimental and clinical studies [1-7]. However, in studying hypoxia, insufficient attention has been paid to the relative importance of changes in ventilation and in the lesser circulation. Little work has been done either on the mode of action of different disturbances of pulmonary ventilation on the degree of oxygenation of the blood; nevertheless, it is extremely important to have this information in order to determine the causes of hypoxia in different conditions.

The object of the present investigation has been to study the effect of respiratory changes (pulmonary ventilation, rate, rhythm, and amplitude of respiratory movements) on the degree of blood oxygen saturation.

METHOD

In all, 58 experiments on rabbits, cats, and dogs were made, using acute preparations under urethane anesthesia.

Records were made of respiratory movements, arterial pressure, and blood oxygen saturation; in some of the experiments pulmonary ventilation was also recorded.

To determine changes in the degree of arterial blood oxygen saturation, we used the photoelectric recorder proposed by M. E. Marshak, which is a modification of that described by Kramer [8]; the recorder was applied directly to the artery.

Different methods of changing the respiration for the purpose of including hypoxia were used, and these included stimulation of the phrenic nerve (either the whole nerve or its central or peripheral ends), stimulation of the vagus, introducing ammonia vapor into the lungs, and other methods. Also, some experiments were tried using artificial respiration, and varying the respiratory rate, depth, and rhythm.

RESULTS

It was found that actions causing a reduction in the depth or frequency of respiration or a reduction in pulmonary ventilation were always accompanied by a marked reduction in the degree of arterial blood oxygen saturation. Fig. 1, a shows the response to stimulation of the upper respiratory pathways by the vapor from a 30% ammonia solution. There was an arrest of respiration (followed by small occasional respiratory movements), a marked increase in arterial pressure, and a considerable reduction in the arterial blood oxygen saturation, which was reduced more than by inspiring a mixture containing 9-10% of oxygen.

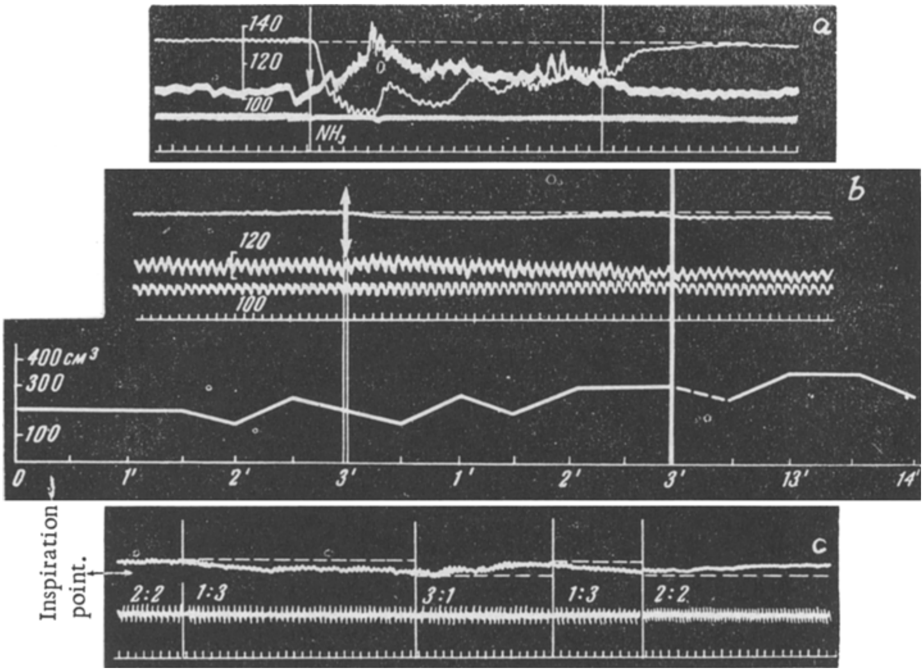

Fig. 1. Changes in the degree of arterial blood oxygen saturation. a) experiment on rabbit, 2.7 kg, 6/6, 1957. Reduction to stimulation of the upper respiratory pathways by vapor from a 30% ammonia solution (beginning and end of stimulation shown by arrows). Curves, from above downwards: degree of arterial blood oxygen saturation, blood pressure, respiration (pneumogram), time marker (5 seconds); b) experiment on dog, 6 kg, 1/20, 1958. Reaction to sectioning the two phrenic nerves. Curves, from above downwards: arterial blood oxygen saturation, blood pressure, respiration, time marker (5 seconds), arterial ventilation in cm^3 per 30 seconds. Thick vertical line – break in recording; c) experiment on cat, 2 kg, 11/28, 1957. Reaction to forced changes in the respiratory rhythm (animal immobilized by injection of 10 mg/kg diplacin; artificial respiration). Vertical lines indicate transition to respiration with a changed ratio of duration of inspiration (first figure) and expiration (second figure), as controlled by strokes from metronome. Curves, from above downwards: degree of arterial blood oxygen saturation, respiration, time marker (5 seconds). Dotted line shows initial blood oxygen saturation level.

A reduced oxygen saturation may occur without a reduction in pulmonary ventilation or, if such a reduction has occurred, may be produced after the rate has already regained its original value or surpassed it. This is found, for instance, on sectioning the phrenic nerves (see Fig. 1, b), when there is an immediate reduction in arterial blood oxygen saturation, but none in pulmonary ventilation; on the contrary, the latter increases somewhat due to increased thoracic respiration. Hypoxia here must be explained as being due to uneven ventilation of different parts of the lungs, since when the diaphragm is put out of action, the lower lobes of the lungs are insufficiently ventilated, while the blood supply to them is maintained. This shows that a high general level of pulmonary ventilation is not the only circumstance necessary for normal oxygenation of blood in the lungs. It is very important that there should be an even ventilation of all parts of the lungs and a corresponding blood supply to these parts.

Failure of coordination, unevenness, and arrhythmia of the respiratory movements may play an important part in the development of hypoxia. Figure 2 shows respiration disturbances occurring during the operation for excision of a lung in man in response to manipulations on the root (on the pulmonary vessels and particularly on the bronchus). It has been shown that it is precisely at these stages in the operation that marked reduction in arterial blood oxygen saturation occurs [5]. In unilateral open pneumothorax, when there is a redistribution of blood supply in the lesser circulation, the greater part flowing to the second (functional) lung, these respiratory disturbances no doubt play an important part in the development of hypoxia.

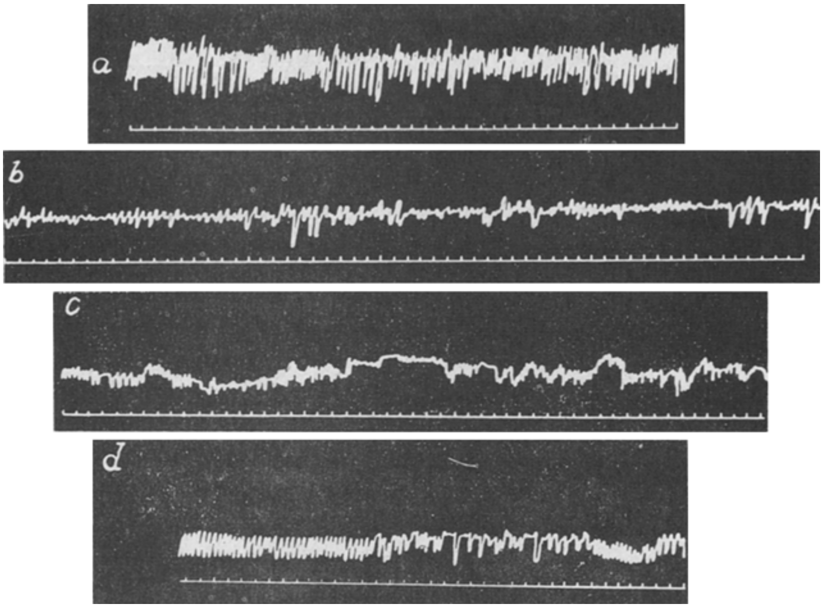

Fig. 2. Respiratory disturbances observed during pulmonary excision in man (pneumograms): a) during anesthesia of lung root; b) while dividing the pulmonary vessels; c, d) during manipulation of the bronchus. Time marker – 1 second.

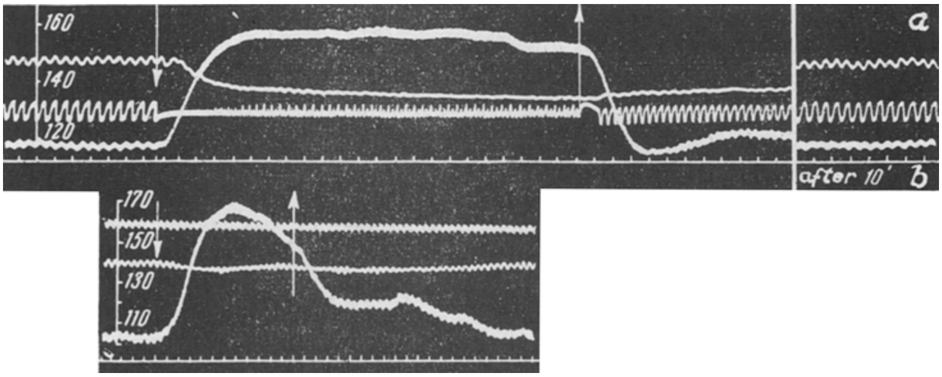

Fig. 3. Changes in the degree of arterial blood oxygen saturation during (a) natural and (b) artificial respiration. Experiment on dog, 9 kg, 1/30,1958. Reaction to simultaneous stimulation of central ends of vagal and cervical sympathetic nerves. Curves, from above downwards: for a) degree of arterial blood oxygen saturation, respiration, blood pressure; for b) respiration, degree of arterial blood oxygen saturation, blood pressure. Arrows indicate onset (↓)and end (↑)of stimulation; thick vertical line indicates break in recording. Time marker – 5 seconds.

Hypoxia can also be observed in response to changes involving the structures concerned in the act of respiration, and when respiratory rhythm is impaired.

Fig. 1, c illustrates changes in arterial blood oxygen saturation occurring during artificial respiration, when the respiratory rhythm, i.e., the ratio of the period of inhalation to exhalation, is arbitrarily changed while maintaining the rate of ventilation constant. An increase in the duration of the inspiration is accompanied by an increased blood oxygen saturation, while reducing the duration of the inspiration and correspondingly increasing that of the expiration leads to a reduction in blood oxygen.

In order to determine the effect of circulatory changes induced by the measures applied by us during the experiment on arterial blood oxygen saturation, other experiments using artificial respiration were carried out. It was found that when respiratory changes were concluded by using artificial respiration, changes in blood oxygen were either absent or much less marked (Fig. 3). This shows that respiratory changes played the principal part in the hypoxia induced by the measures which we applied.

Thus, in our investigations, the arterial hypoxia developed through disturbance of the normal relationship between pulmonary ventilation and blood supply, and was due to inadequate ventilation of different parts of the lungs. The experiment also showed that inadequate pulmonary aeration may take place not only through a fall in the general ventilation level, but also through uneven ventilation of different parts of the lungs, as occurs with discoordinated respiratory movements.

SUMMARY

Acute experiments were performed on rabbits, cats and dogs under urethane anesthesia. The author studied the effect of respiratory changes (pulmonary ventilation, tempo, rhythm, amplitude of respiratory motions) on the degree of arterial blood saturation with oxygen.

As shown by these investigations, the influences provoking the changes of conditions of pulmonary ventilation are associated with the appearance of arterial hypoxia. Insufficient pulmonary aeration may occur when the total level of the pulmonary ventilation is decreased, as well as in irregular ventilation of different portions of the lungs in discoordination of respiratory motions.

LITERATURE CITED

[1] A. M. Kulik, Byull. éksptl. biol. i med., volume 35, No. 4, pp. 16-20 (1953).

[2] M. E. Marshak, Problems of Tuberculosis,* 1951, No. 4, pp.8-14.

[3] M. E. Marshak, Recent Advances in Biology,* 1953, volume 36, issue 2 (5), p. 209.

[4] N. N. Savitskii, Oxygen Therapy,* Leningrad, 1940.

[5] N. V. Sonotskaya, Byull. éksptl. biol. i med., volume 36, No. 8, p.31 (1953).

[6] A. A. Tregubov, Impairment of the Respiratory Function of the Blood in Various Pathological Processes,* Leningrad, 1947.

[7] B. S. Shershevskii, Blood Gases and the Basic Forms of Nonspecific Diseases, and in Damage to the Respiratory Organs.* Dissertation, Leningrad, 1948.

[8] K. Kramer, Ztschr. Biol., 1935, Bd. 96, N 1, S. 61.

* In Russian.