CHANGES IN THE GAS EXCHANGE DURING EFFORT IN PATIENTS AFTER OPERATIONS ON THE LUNG

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Certain pathological processes affecting the lung tissue or surgical operations on the lung interfere with external respiration. Under these circumstances the bodily functions are reorganized in accordance with the necessity of delivering oxygen to the tissues in order to maintain oxidative processes at the required level. In chronic pathological conditions of the lung (carcinoma, bronchiectasis) it is difficult to detect before operation the compensatory mechanisms which are gradually brought into play. Nevertheless the problem of the ways of compensation of the disorders of gas exchange in chronic pulmonary diseases, and also after major interference with the respiratory apparatus associated with operations on the lungs, is one of theoretical and practical interest.

P. K. Anokhin considers that the ordinary mechanisms of maintenance of the stability of the bodily functions in normal conditions have much in common with the mechanisms of compensation of these functions when disturbed [1].

One of the conditions causing reorganization of several bodily functions is physical effort. Much research has been done to study the changes in the bodily functions of healthy persons during effort in the course of athletic training, manual work and so on [5, 7, 11, 13, etc.]. Some interesting work has been done by Hemingway et al. [14], who investigated the changes in gas exchange with age, using physical effort for this purpose. Physical effort is widely used as a functional test nowadays in the examination of patients with diseases of the heart and lungs, since investigations at rest often fail to show certain defects of the respiratory and vascular systems [12, 15-19].

These authors, however, did not dwell on the special features of the adaptive reactions in different patients, which from our point of view is of definite interest in the problem of elucidating the compensatory mechanisms brought into play as the result of an increasing disability of the respiratory apparatus.

In this connection we examined 44 patients with pulmonary diseases at rest and after physical effort, before and after operation, in order to discover any individual peculiarities of the nervous regulation of respiration and the circulation of the blood in response to a raised level of the oxidative processes.

EXPERIMENTAL METHOD

We used the Douglas-Haldane method of investigation of the gas exchange and, in individual cases, Krogh's method. The examinations were carried out in the morning, on fasting animals, in basal metabolic conditions. Measurements were made of the pulmonary ventilation (in liters per minute), the oxygen demand and the excretion of carbon dioxide (in ml per minute), the percentage utilization of oxygen in the lungs, the respiratory coefficient, and the basal metabolism (in calories and as a percentage of normal). At the same time

the pulse and respiration rate were counted. The patients then performed moderate physical exercise (going up and down steps 30 times in 1½ minutes, or sitting down 20 times in 1½ -2 minutes). After the exercise the gas exchange was again investigated in the course of 7-8 minutes (see table).

Details of the Character of the Disease and the Number of Patients Examined

Character of the disease	Total number of patients investigated	Number of patients examined before and after operation
Carcinoma of the lung	22	4
Bronchiectasis	15	3
Benign tumors, cysts, hydatid disease, etc.	7	5
Total	44	12

EXPERIMENTAL RESULTS

As we know, the increased oxygen demand of the tissues during and after effort is brought about by several interconnected functions taking part in the transport of oxygen. Under these circumstances increases take place in the pulmonary ventilation, the minute volume of the heart, the arteriovenous oxygen difference of the blood and so on.

In response to brief physical effort the pulmonary ventilation in all our patients examined increased 1½-2 times, and in the course of 5-6 minutes after the exercise it decreased to approximately the initial value. The oxygen demand (in ml per minute) was 2-3 times greater than the original before the physical effort (measurements were made in individual cases) and twice as great as the initial value in the first 3 minutes of the recovery period, gradually decreasing with rest. The percentage utilization of oxygen in the lings during brief physical effort increased by comparison with the resting state at the beginning of the recovery period and sometimes fell below the initial value at the end of this period, when the oxygen demand did not exceed its initial value. Only in a few cases was the percentage utilization of oxygen below the initial value in the first minutes of the recovery period.

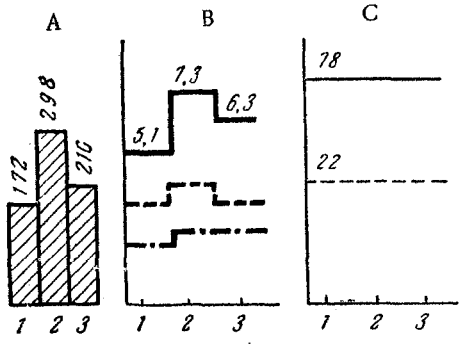

Fig. 1. Changes in the gas exchange, pulse and respiration after physical effort in the patient K., aged 40 years. Diagnosis: carcinoma of the left lung. The pulse and respiration rate were unchanged after the exercise. 1) before exercise, at rest; 2) during the 1st-3rd minutes after exercise; 3) during the 4th-7th minutes after exercise. A) Oxygen demand in ml per minute; B) pulmonary ventilation in liters per minute; percentage utilization of oxygen in the lungs - - - - ; percentage of expired carbon dioxide -.-.-.-. ; C) pulse rate ——— and respiration rate - - - -.

On the basis of an analysis of the results obtained, it was found that the performance of physical exercises, which in all patients doubled the oxygen demand, was achieved by various forms of nervous regulation of respiration and the circulation of the blood. Four main types of reaction of respiration and the blood circulation to brief effort could be noted.

1). In 12 cases an increased delivery of oxygen to the tissues after effort took place as the result of deepening of the respiration and increased utilization of oxygen, as might be assumed, on account of an increase in the stroke volume of the heart. The pulse and respiration rates under these circumstances remained unchanged (Fig. 1).

2). In 17 cases the increased oxygen demand after physical effort was satisfied by an increase in the depth and the rate of respiration and an increase in the percentage utilization of oxygen. The heart rate was unchanged or even became slower, from which an increase in the stroke volume of the heart could be deduced (Fig. 2). The subjects forming the first and second groups had practiced sports in the past.

3). In 8 patients there was a considerable rise in the heart rate after effort, whereas the respiration rate remained unchanged or became slower. The increased oxygen demand was met by a deepening of the breathing and an increase in the minute volume of the heart, in this case mainly on account of an increased rate of contraction. The percentage utilization of oxygen in the lungs was unchanged.

4). In 19 cases all the reactions which we studied were enhanced: the depth and rate of respiration, the percentage utilization of oxygen and the heart rate were all increased (Fig. 3).

In 12 patients whom we were able to examine before and after operation on the lung, it was found that after operation the leading components of the reaction were brought into play to a greater degree (see Fig. 3, A). For example, in the postoperative period the respiration rate in patient L. increased after effort from 14 to 24 per minute, and before operation from 14 to 18 per minute. It must be pointed out, however, that the character of the changes in respiration and in the action of the heart in response to effort remained just as before the operation in 6 of the 12 patients. It may be postulated that this was in consequence of the absence of change in the stereotype of reactions of the nerve centers controlling respiration and the circulation of the blood. A change in the excitation level of these centers after pneumonectomy or other lung operations led in several cases to a considerable increase in the respiration or heart rates in comparison with the preoperative period and also to an increase in the difference between their rates at rest and after exercise. This change in the level of excitation of the centers could possibly be the reason for the fact that in some patients the character of the reactions of respiration and of the circulation of the blood in response to exercise changed after operation.

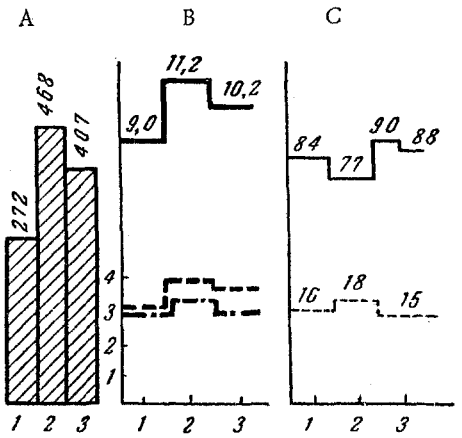

Fig. 2. Changes in the gas exchange, pulse and respiration after physical effort in the patient K., aged 20 years. Diagnosis: bronchiectasis of the right lung. Legend as in Fig. 1. In the first minutes after exercise the pulse rate became slower and the respiration slightly quicker.

In assessing the gas exchange findings particular interest was due to the percentage utilization of oxygen by the lungs; this depends on the minute volume of blood passing through the lungs, on the arteriovenous difference in oxygen concentration, and partly on the oxygen capacity of the blood. In 4 healthy persons whom we examined as controls of the standard exercise usually assigned to the patients, the percentage utilization of oxygen in the lungs was increased considerably after effort (by 1.5-2%). The heart rate under these circumstances was changed to a much lessor degree, which showed an increase in

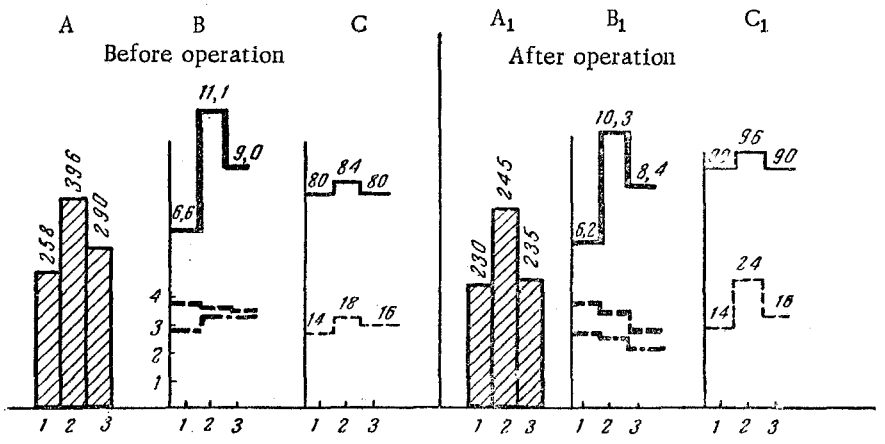

Fig. 3. Changes in the gas exchange, pulse and respiration after physical effort in the patient L., aged 32 years, before and after operation. Diagnosis: hydatid disease of the left lung. The pulse and respiration rates were increased after exercise. The character of the changes as a result of effort was the same before and after operation. A, B, C) Before operation; A_1, B_1, C_1) 3 weeks after removal of a hydatid cyst associated with considerable involvement of lung tissue. Legend as in Fig. 1.

the stroke volume of the heart. It is known from the literature that during training the stroke volume of the heart increases, and that this is probably a more economical mechanism for the transport of the same amount of oxygen than an increase in all the functions.

In more severe disorders of the heart or lungs the opposite was observed.

With insufficiency of the blood flow through the pulmonary circulation a demand was created for an increase in the pulmonary ventilation, the respiration rate was increased and the percentage utilization of oxygen in the lung fell. We observed such reactions in individual patients who had not undergone operation and in some patients in the postoperativeperiod (patient F. and others). Such a state borders on exhaustion of the possibilities of compensation i.e., on decompensation.

From an analysis of the results of the examinations on patients before and after operation, it may be stated that the increased oxygen demand of the body after the performance of physical exertion, just like the compensatory reactions directed toward the delivery of the necessary amount of oxygen to the tissues during a disorder of the respiratory apparatus, may result from different forms of reaction of the cardiovascular and respiratory systems.

Depending on the functional integrity of each of these systems, and also on the system of control developed in the course of the life of each individual subject, the compensatory reactions mainly follow one or other of these courses.

It can be seen from the foregoing that if, in a patient with a disorder of the lung, light physical effort entails a considerable increase in the respiration and heart rate, and under these circumstances the percentage utilization of oxygen in the lungs falls, the compensatory possibilities of such a patient are strained to the limit. The postoperative period will be attended in this patient with great difficulties, and the state of compensation after operation will be established much later on. Compensation in these patients will be unstable.

The four different categories of reactions which we found may be either different types of compensatory shifts in the body in response to the increased gas exchange requirements, or different stages of bringing into play of the individual reactions; they depend on the state of excitation of the nerve centers controlling respiration and the circulation of the blood.

SUMMARY

The author studied the gas exchange, pulse rate and frequency of respiration at rest and following moderate physical exertion in 44 patients suffering from diseases of the lungs.

Both the increased oxygen requirement following physical exertion and compensatory reactions occurring with disturbed respiratory apparatus are effected in diverse groups of individuals through different pathways of nervous control of respiration and circulation. Four types of respiratory and circulatory reactions in response to exertion were revealed. In all patients these reactions were intensified after the operation; in 50% of them modifications of respiration and cardiac activity were of the same type as preoperatively.

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