DETERMINATION OF COMPONENTS OF THE DIFFUSION CAPACITY OF THE LUNGS AND ALVEOLO-ARTERIAL OXYGEN DIFFERENCE TO EVALUATE OXYGEN-TRANSFER CONDITIONS IN THE LUNGS

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Optimal conditions for determining components of the diffusion capacity of the lungs were investigated. A combination of this method with determination of the mean alveolo-arterial oxygen difference is suggested. By such combined investigations it is possible to identify the disturbed component of oxygen transport from the alveolar air into the blood stream.

Measurement of diffusion capacity of the lungs and its components enables the stages of oxygen transport from the lungs into the blood to be assessed quantitatively. The writers suggest a combination of this method with determination of the mean alveolo-arterial oxygen difference [$p(A-a)O_2$], thereby giving fuller information on the conditions of gas exchange in the lungs. The resistance to diffusion of gases in the lungs ($1/DL$) has been shown [1, 4] to be the sum of the resistance of the alveolo-capillary membrane ($1/D_m$) and the resistance of the intrapulmonary capillaries ($1/\theta V_c$):

$$1/DL = 1/D_m + 1/\theta V_c,$$

where θ is the rate of combination of gas with intracellular hemoglobin and V_c is the blood volume in the pulmonary capillaries at a given moment.

The principle of determination of the components of the general diffusion capacity of the lungs (DL_{CO}) is based on the fact that with an increase in pO_2, as a result of blocking of hemoglobin with oxygen, the rate of binding of CO by the erythrocytes is reduced, with a corresponding decrease in the quantity of CO entering the erythrocytes. The value of DL_{CO} will thus be reduced if pO_2 in the alveolar air is increased. This process is linear and the graph of $1/\theta$ versus pO_2 has been obtained experimentally [1, 4] (Fig. 1).

In the present investigation the optimal conditions for determining the components of the diffusion capacity of the lungs were studied with a Soviet "Diffusiometer" (Medfizpribor Engineering Design Bureau, Kazan'). This instrument is designed to determine DL_{CO} by the steady-state method with the use of very low concentrations of CO. In addition, the design of this instrument is such that, with the aid of a valve of the Rahn and Otis type, averaged alveolar gas can be collected and its partial oxygen pressure (p_AO_2) determined. The averaged p_AO_2 and also the partial oxygen pressure in a sample of arterialized blood (p_aO_2) taken from the patient during the investigation were determined with a "Radiometer" instrument by the micro-Astrup method.

It is best to perform this combined investigation in a certain order. After a rest for 20 min (sitting down) the patient begins to breathe the air in the room through the valve 4 (Fig. 2). Under these circumstances the alveolar gas is collected over a period of several minutes in the rubber bag 5, which is connected to the apparatus at the point where the alveolar gas leaves, and this gas is then analyzed for pO_2. Meanwhile a sample of arterialized blood is taken from the finger of the warmed hand to determine p_aO_2.

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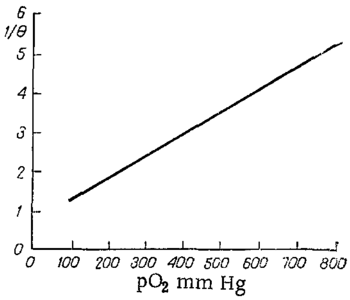

Fig. 1

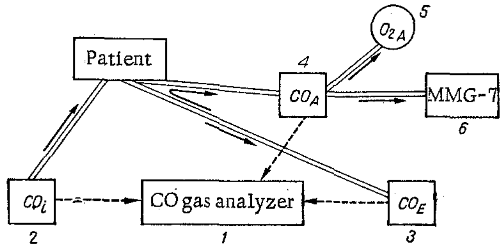

Fig. 2

Fig. 1. Graph of $1/\theta$ as a function of the partial pressure of oxygen. Explanation in text.

Fig. 2. Block diagram of investigation: 1) infrared CO gas analyzer; 2) bag with mixture to be inhaled; 3) bag for collection of expired gas after flushing out of dead space; 4) valve of Rahn and Otis type for sampling alveolar gas; 1-4) components of the "diffusiometer;" 5) chamber for collecting alveolar gas; 6) MMG-7 oxygen gas analyzer. Broken arrows indicate how, by means of appropriate stopcocks on the instrument, any gas can be analyzed in the course of the investigation as required: inspired (CO_I), expired (CO_E), or alveolar (CO_A).

Determination of the diffusion capacity of the lungs then begins. A block diagram of the investigation is shown in Fig. 2. The patient inhales a gas mixture containing 0.04-0.05% CO in air for 5-6 min. During the first 2-3 min of respiration the gas mixture flushes out the dead space of the respiratory tract and tubes of the instrument: the expired gas passes outside along the outlet tube. The last portions of expired gas, in equilibrium with the alveolar air, enter the gas analyzer from valve 4. After the steady state has been established,the expired gas is directed into the bag (by turning the stopcock on the instrument) and collected for 2-3 min, after which the mean CO concentration in the expired air is determined. The value of DL_{CO} is calculated by the standard formula [1, 2].

To determine the components of the total diffusion capacity of the lungs by the method of Roughton and Forster [1, 4] it is necessary to measure DL_{CO} during inhalation not only of air (pO_2 150 mm Hg), but also a mixture with a high oxygen concentration (pO_2 600 mm Hg). To monitor pO_2 continuously, a type MMG-7 oxygen analyzer (Medfizpribor Engineering Design Bureau) was introduced into the system in order to sample the alveolar gas for analysis directly from the valve 4. Knowing the values of pO_2 at which the measurements of DL_{CO} were made, the required values of $1/\theta$ can be found from the graph of the rate of binding of CO by the erythrocytes ($1/\theta$) versus pO_2 (Fig. 1). This gives two numerical values for the equation [1] with two unknowns, which can be solved easily with respect to D_m and V_c.

It must be pointed out that V_c is the volume of blood in which the hemoglobin concentration is assumed to be normal (14.9 g%). If there is any marked change in the hemoglobin concentration, a correlation must be introduced [3]:

$$V_{c\,(corr.)} = V_c \cdot \frac{14.9\,g\,\%}{Hb}.$$

During inhalation of an oxygen mixture the quantity of CO passing into the blood is approximately half that occuring during inhalation of air and the relative error of measurement of CO absorption is increased. It was found that when a mixture of oxygen with 0.05% CO was used, in 12% of cases (6 of 50 determinations) the results of the measurements were unsatisfactory: when the components were calculated, D_m was found to be nearly zero. To avoid such inaccuracies, it was decided to double the concentration of inspired CO during inhalation of the oxygen mixture (0.10-0.15%). It was reckoned that the quantity of hemoglobin blocked by CO would be small and would not exceed 1% of its total content in the blood. Consequently, during inhalation of an oxygen-rich mixture, it would be safe to inhale the increased concentration of CO.

An important condition for the correct determination of the components of DL_{CO} was found to be the time interval between two consecutive determinations of DL_{CO}. So that carboxyhemoglobin did not accumulate in large quantities in the blood, the time interval between two investigations should be not less than 20 min.

Consequently, the following indices are obtained as a result of this investigation.

1. DL_{CO}, the estimated total oxygen transport in the lungs.

2. D_m, the membrane component of DL_{CO}, reflecting the state of the alveolo-capillary membrane (its area, properties, permeability, and so on).

3. V_c, the quantity of blood participating in the transport of oxygen through the lung membrane.

4. The mean p_AO_2, an index of alveolar ventilation, i.e., of the conditions under which DL_{CO}, D_m and V_c are measured.

5. p_aO_2, an index of the final stage of the pulmonary gas exchange.

By this combined investigation it is possible to study the path of oxygen from the lungs into the erythrocyte. Measurement of the diffusion capacity of the lungs and its various components enables a more definite interpretation to be given of the causes of an increase in $p_{(A-a)}O_2$. For example, in a patient with a tuberculoma of the right lung $p_{(A-a)}O_2$ was 127 mm Hg, p_aO_2 79 mm Hg (94% HbO_2), DL_{CO} 10.8 ml/min · mm Hg (60% of normal), D_m 17.1 ml/min · mm Hg (48% of normal), and V_c 88.5 ml. The presence of a high alveolo-arterial oxygen difference (48 mm Hg) was due to changes in the properties of the lung membrane, as shown by the reduction in the value of the membrane component. However, a decrease in diffusion capacity does not always lead to arterial hypoxemia. The results obtained by investigation of a patient with bronchiectasis can serve as an example: DL_{CO} 9.5 ml/min · mm Hg (58% of normal), D_m 13.8 ml/min · mm Hg (43% of normal), V_c 28.2 ml, p_AO_2 118 mm Hg, p_aO_2 98 mm Hg (97% HbO_2). These figures reveal various changes in the value of the second component (V_c), also responsible for oxygen transport, which can be either increased or decreased. Variations in the distribution of diffusion, ventilation, and blood flow are also of definite significance.

This combined investigation thus makes it possible to investigate the mechanisms of disturbance of gas transport in the lungs more accurately.

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