ELECTROMETRIC ASSESSMENT OF THE QUANTITY OF AIR PER UNIT VOLUME OF FUNCTIONING LUNG

B. I. Mazhbich

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The quantity of air in the lungs at a given moment is one of the more important indices of the function of external respiration, but its determination is technically difficult, mainly because of the complexity of determining the residual volume of air. These difficulties are aggravated if the function, not of the lungs as a whole, but of part of them (a lobe, for example) must be evaluated.

An attempt has been made to solve this problem by measuring the electrical resistance of the lung tissue, taking as the index of filling of the lungs with air the number of milliliters of air per 100 cm^3 of the organ. The technique of measurement and the apparatus have been described earlier [2].

Certain assumptions were made in order to solve this problem.

The air present in the alveoli was regarded as a large number of very small spheres of equal size and with an electrical conductivity tending to zero, surrounded by blood and lung tissue with a total (final) magnitude of electrical conductivity.

Since the measurements were made by means of a thin catheter firmly wedged in a small bronchus, it was assumed that the space surrounding the electrodes located at the end of the catheter consisted of lung tissue not containing large bronchi and vessels, which would essentially distort the structure of the object to be measured from the assumed pattern.

It was further assumed that the tissue of the lungs and the blood in the vessels formed a parallel coupling in the electrical sense. If there is a medium conducting electric current (with a certain specific electrical conductivity), in which nonconducting spheres are distributed, the total ohmic resistance of such an aggregate structure may be given by a simple equation, which, as it applies to the present problem, may be written as

$$\rho_{\text{total}} = \frac{3-a}{2a} \cdot \rho_{\text{bt}} \tag{I}$$

where ρ_{total} is the specific resistance of the organ (in $\Omega \cdot$ cm); ρ_{bt} the total specific resistance of the blood and tissue (in $\Omega \cdot$ cm); a is the part of a unit volume occupied by blood and tissue, and b = 1−a, the part of a unit volume occupied by air.

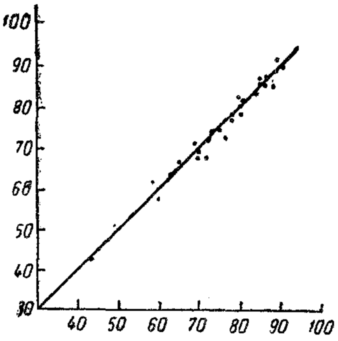
$$\rho_{\text{bt}} = \frac{\rho_{\text{b}} \cdot \rho_{\text{t}}}{\rho_{\text{b}} + \rho_{\text{t}}} \cdot F, \tag{II}$$

where ρ_{b} is the specific resistance of blood (in $\Omega \cdot$ cm); ρ_{t} the specific resistance of the tissue of the organ (in $\Omega \cdot$ cm); F an empirical coefficient, depending on structural and volume relationships within the tissue–blood system.

Solving Eq. (I) relative to a and making the appropriate substitutions, we obtain

$$b = 1 - \frac{3\rho_{\text{b}} \cdot F}{2\rho_{\text{total}}\left(1 + \frac{\rho_{\text{b}}}{\rho_{\text{t}}}\right) + \rho_{\text{b}}}. \tag{III}$$

Laboratory of Pharmacology, Division of Experimental Biology and Pathology, Institute of Cytology and Genetics, Siberian Branch of the Academy of Sciences of the USSR, Novosibirsk. Scientific Adviser – Professor G. P. Konradi, I. P. Pavlov Institute of Physiology, Academy of Sciences of the USSR, Leningrad (Presented by Active Member of the Academy of Medical Sciences of the USSR V. V. Parin). Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 62, No. 7, pp. 115-117, July, 1966. Original article submitted July 27, 1964.



Comparison of the results of determination of the amount of air in the lungs by electrometric and direct methods. Along the axis of abscissas— quantity of air in unit volume of the organ (in %), determined by the direct method (b'); along the axis of ordinates— quantity of air in unit volume of the organ (in %) determined by the electrometric method (b).

The principal error when calculating the quantity of air per unit volume of the organ by this formula depends on the fact that the degree of filling of the lungs is represented only by the mean value of the variable coefficient F.

On the basis of data in the literature [3] and the results of his own experiments, the author concluded that the specific resistance of the lung tissue is about 1000 Ω · cm at 37°.

The experimental determination of the coefficient F gives a mean value of 1.83. Substituting this number for the coefficient F in Eq. (III) and replacing resistance by electrical conductivity (γ), after transformation we obtain:

$$b = \left(1 - \frac{2,7\,\gamma_{\text{total}}}{\gamma_b + \gamma_t + 0,5\,\gamma_{\text{total}}}\right) \cdot 100\%. \qquad \text{(IV)}$$

Since these assumptions cannot be justified a priori, experiments were carried out to compare the results of calculation of the volume of air in the lungs on the basis of the assumptions with those determined by the direct method.

Experiments were carried out on the lower lobes of the lungs in dogs. The extirpated lobe was weighed and its volume determined. Cannulas were introduced into the bronchus and artery, connecting the lobe of the lung, which was immersed in a graduated vessel, with a reservoir for supplying air or blood. The catheter containing the detector for measuring the electrical resistance was passed through the cannula lying in the bronchus. Keeping a constant check on the temperature, the electrical resistance and volume of the organ were simultaneously recorded as they varied as a result of the entry of air or blood. The measured value of the ohmic resistance was converted into specific.

The volume of air was determined by measuring the volume of fluid displaced (oil). Since the removal of the whole of the air from the respiring lung is an extremely complex problem, the following simple expressions may be used to calculate the volume of the lobe when completely free from air

$$P_0 = V_0 \cdot d_0; \; P_n = V_n \cdot d_n,$$

where P_0, V_0, and d_0 are the weight, volume, and specific gravity respectively of the lobe of the lung completely free from air, and P_n, V_n, and d_n are the weight, volume, and specific gravity respectively when the lobe contains n cm^2 of air. Assuming that $P_n = P_0$, we obtain: $V_0 = (P_n/d_0)$, where d_0 is a constant number, equal to 1.055 g/cm^3 (based on the mean specific gravity of the blood and small differences between the specific gravity of the blood and the lung tissue when free from air), and $a' = (V_0/V_n)$, where a' is the part of a unit volume of the organ occupied by blood and tissue (b' = 1—a', the part of a unit volume occupied by air).

EXPERIMENTAL RESULTS

The comparative evaluation of the quantity of air in unit volume of lung tissue (b), determined from Eq. (IV), with that determined directly (b') is given in the figure. As the figure shows, in most cases satisfactory agreement was found between the results of the determination by the two methods. The mean error was about ±5%.

The data for the quantity of air were obtained on the basis of its determination in a limited region, so that this index could be measured separately for each lobe of the lung. To obtain a true picture of the functional state of the lungs as a whole, several such measurements should be made.

SUMMARY

The lung, save for the larger trunks of the bronchial tree and vascular bed, is regarded as a three-component medium (air, blood, tissue). The correlation between the air and the tissue + blood structure is preset on the assumption that the air contained in the alveoli presents closely arranged spheres of identical size, surrounded by a conducting medium (blood + tissue) with summary specific electroconductance determined from the law of parallel connection of these two components. The coefficient depending on the structural and volumetric correlations within the blood + tissue system has been found empirically. A simple formula is given for calculation of the air content in the unit volume of the organ. Experiments on isolated pulmonary lobes have shown that in the majority of cases there is a satisfactory coincidence between the results of determination of the air amount by the direct method and that suggested here.

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