MEASUREMENT OF THE SPECIFIC ELECTRICAL RESISTANCE IN THE FUNCTIONING LUNG OF MAN AND THE DOG

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An important method widely used to study the physiology and pathology of the circulation in experimental and clinical practice is that of electroplethysmography, sometimes called impedance plethysmograpny or rheography. To conduct the current to the test object, electrodes of different sizes and shapes are used, and the interelectrode distances are varied.

The choice of electrodes and interelectrode distances as a rule depends on the shape and size of the test object, the properties of the measuring apparatus, and so on. Differences in electrodes complicate the comparison of the results of the measurements obtained in different observations, for these are determined not entirely by the properties of the test object, but also to some extent by the construction of the electrodes. To determine the electrical characteristics of a test object, it is desirable to use the specific value of the ohmic resistance, which is known to be independent of the method of measurement, and to be determined entirely by the conductive properties of the organ on which measurements are made.

The object of this communication is to calculate the value of the specific electrical resistance of the lungs, which may be of interest as a physical index of the functional state of the organ and, what is particularly important, it may serve as a basis for the quantitative assessment of certain physiological indices of the state of the circulation and respiration in the normally functioning lung.

A thin (1.9 mm) catheter with two equal cylindrical ring-shaped electrodes (4 mm) situated at its end, was introduced through the respiratory passages into the lungs until it wedged into one of the small bronchi. The position of the catheter was verified by fluoroscopy. By means of wires situated inside the catheter, the electrodes were connected to the recording system.

Measurements were carried out at a frequency of 5 kc/s with an inductive, partially balanced, ac bridge, by means of which the ohmic component of the impedance could be distinguished and recorded graphically. The technique and apparatus have been described in detail earlier [2].

Calculation of the value of the specific resistance from the well-known formula $R = \rho^1/S$ cannot be done because of the irregular shape of the test object and the absence of information about its size. If the area of the electrodes and the interelectrodistance are smaller than the organ to be measured and the electrodes are not too close to the edges of the organ, the specific resistance can be calculated in accordance with the principle of its determination in an infinite medium. The calculation is simplest for electrodes of spherical shape [1].

$$R = \frac{\rho}{2\pi a}\left(1 - \frac{a}{d}\right), \qquad (1)$$

where R and ρ are the measured (in Ω), and specific (in Ω/cm) resistance; a is the radius of the spherical electrode (in cm); d the distance between the centers of the electrode (in cm).

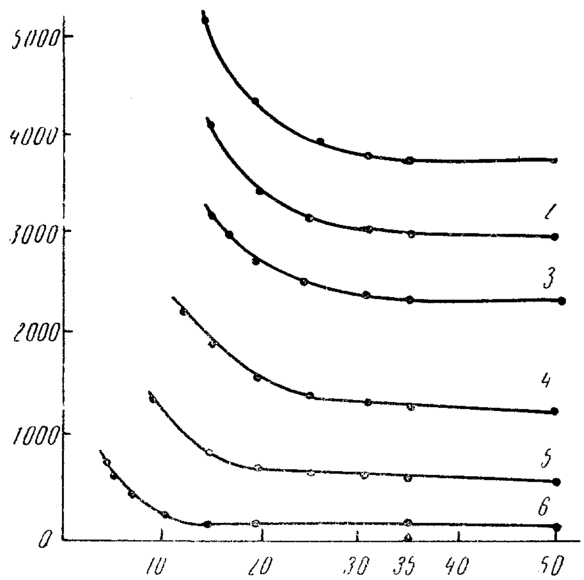

Fig. 1. Relationship between magnitude of resistance and diameter of vessel for the given concentration of sodium chloride solution during measurements with electrodes of the chosen construction. Along axis of abscissas – diameter of calibration vessel (in mm); along the axis of ordinates – magnitude of resistance of sodium chloride solution of different concentrations measured (in Ω). 1) 0.01%; 2) 0.02%; 3) 0.03%; 4) 0.05%; 5) 0.15%; 6) 0.85%.

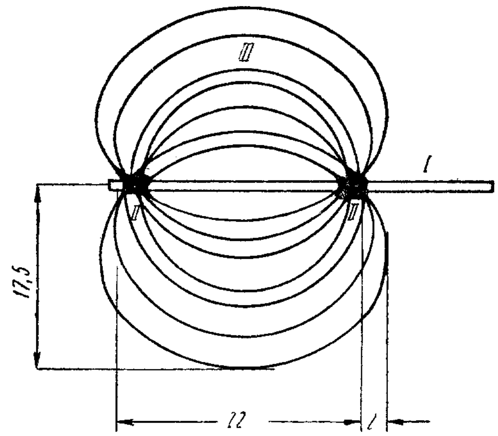

Fig. 2. Part of volume of an organ cut out by conventional lines of force of a current in which, in practice, the boundaries of the organ have no influence on the magnitude of the resistance (scheme): I) catheter; II) electrodes; III) conventional representation of lines of electrical force. Measurements given in millimeters, remainder of explanation given in text.

However, spherical electrodes are unsuitable in practice for measurements of this type, for they do not ensure firm contact with the tissues to be measured over the whole area of the electrode. The accurate calculation of the value of the specific resistance for electrodes of any other shape is complicated, and it is evidently easier to solve this problem experimentally.

For a very approximate devaluation of the resistance, formula (1) may be used if the cylindrical electrodes are identified with spherical electrodes of equal area. Whilst the construction of the electrodes was being chosen, an attempt was made to take account of the following requirements. The dimension of the electrodes must be chosen to correspond to the volume of the organ (for determination of the radius of action of the electrodes, see below). The order of the values of the resistance to be obtained must be suitable from the point of view of the technique of measurement. The shape of the electrodes must ensure firm contact with the tissue over the whole surface of the electrode. The catheter, with the detector electrodes, must be atraumatic.

Finally, it would be desirable for the value of the resistance to be measured to be not too different from the specific resistance, for this makes it convenient to give a quick approximate indication of the results of the measurement.

Determination of Radius of Action of Electrodes

As mentioned above, calculation of the specific resistance can only be done if the object to be measured is much larger than the electrodes themselves or the distance between them. The radius of action, or the depth of the measurements, is known to depend on the construction of the electrode system, so that it is essential to know what volume of test material may be regarded in practice as infinitely large for the electrodes chosen.

To determine this, solutions of sodium chloride of different concentration, each of known electrical conductivity, were placed in cylindrical glass vessels of different diameters. By means of a simple device, the test electrodes were introduced into each vessel containing electrolyte in turn, and the ohmic component of the impedance was measured at a constant temperature of the solution (Fig. 1).

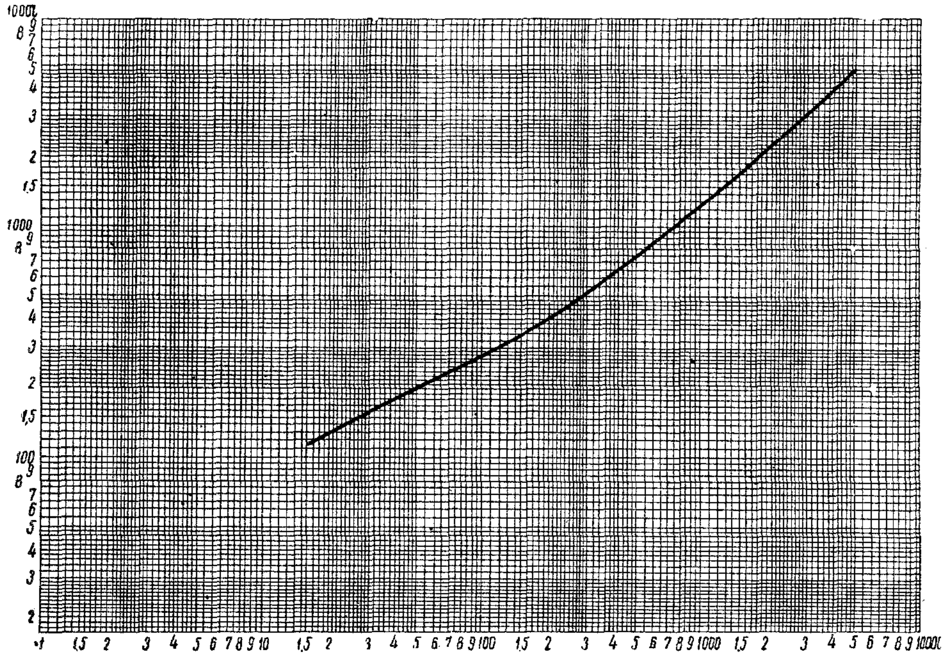

Fig. 3. Relationship between values of measured and specific resistance for electrodes of the chosen construction. Along the axis of abscissas – specific resistance (in Ω/cm), along the axis of ordinates – measured resistance (in Ω).

Value of Specific Ohmic Resistance in Lower Lobes of the Human and Dog's Lung (in Ω/cm)*

Index	Human lung		Dog's lung	
	Intact	Collapsed	Intact	Edematous
Number of observations	24	4	10	10
Value of specific resistance	1 000–2 000	250–1 000	900–1 450	150–400

*The measurements of the electrical resistance of the human lung were made at the Institute of Experimental Biology and Medicine, Siberian Division, USSR Academy of Sciences in 1962.

It can be seen from Fig. 1 that an increase in the diameter of the vessel lowered the electrical resistance of the solution, although the diameter of the vessel greater than 35 mm had no significant effect on the resistance of the sodium chloride of the concentration indicated.

In other words, the electric current spread in practice in a radius of not more than 17.5 mm from the axis of the electrodes for the values investigated, covering the whole range of resistances of practical importance in this case.

At the same time, it was shown that the electric field does not extend more than 2 mm outside the facing ends of the electrodes (Fig. 2).

The results of the determination of the radius of action of the electrode system, obtained in electrolyte solution, are fully applicable to material of any composition, for the radius of action is determined by the construction of the electrodes and is not directly dependent on the nature of the object to be measured.

To calculate the specific resistance, a calibration graph was plotted. The test electrodes were immersed in sodium chloride solutions of different but accurately known concentrations, and consequently, of accurately known (from the table) electrical conductivity. Measurements were made at constant temperature in a glass vessel of dimensions larger than the radius of action of the electrode system. The results of these measurements are given in Fig. 3.

Next, having recorded the resistance of the test organ by means of the catheter-detector of the chosen construction, the value of the specific resistance was found on the graph, for its magnitude bears a constant relationship to the magnitude of the measured resistance through the constant electrode system, being dependent only on the construction of the electrode.

The analytical expression of this relationship (within the range of practical importance) between the magnitude of the resistance corresponding to the lung strongly filled with air, and the value corresponding to the airless lung or the lung overfilled with blood, may be obtained with sufficient accuracy by the equation:

$$\log \rho = \frac{4\sqrt{5}}{7} \log R - 1{,}01, \qquad (2)$$

where ρ and R are the specific and measured resistance, respectively.

No mention could be found in the literature of the value of the specific resistance in the human lung, or of segmental electroplethysmographic studies of the lung. The only experimental investigation known is the work of Schwann [3], who gives values of the specific electrical resistance of several organs, including the lungs, obtained by the excision of pieces of tissue and measurements in situ in dogs (800-1300 Ω/cm at body temperature). In the present experiment on dogs in which the specific resistance was measured, similar values were obtained (see table), despite differences in the technique of measurement. The determination of the specific resistance of the lungs in man shows that the fluctuations of this value extend over a wider range. It is clear from the table that the state of the lung (the volume of air and fluid – blood, transudate – per unit volume of lung tissue) mainly determines the magnitude of the resistance.

On the basis of the model versions of the structure of the lungs and of the possibility of determining the value of the specific resistance (the specific electrical conductivity), it was found that the quantity of air per unit volume of the functioning lungs could be determined at any desired moment of time:

$$b = 1 - \frac{1.5\,\gamma_{tot} \cdot F}{\gamma_{bl} + \gamma_{tis} + 0.5\,\gamma_{tot}},$$

where b is the number of millimeters of air per 100 cm^3 organ; F an empirical coefficient equal to 2.33; γ_{tot} the specific electrical conductivity of the total organ; γ_{bl} the specific electrical conductivity of the blood; and γ_{tis} the specific electrical conductivity of the tissue, itself.

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