TECHNIQUE OF SEPARATE RECORDING OF OHMIC AND CAPACITANCE COMPONENTS OF THE ELECTRICAL RESISTANCE OF HUMAN LUNG TISSUE

B. I. Mazhbich

Laboratory of Physiology (Head – Candidate Medical Science T. S. Vinogradova), Institute of Experimental Biology and Medicine (Director – Lenin Prizewinner Professor E. N. Meshalkin), Siberian Division, USSR Academy of Sciences, Novosibirsk

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The resistance of living tissues possesses ohmic and capacitance components. The ohmic component of the total electrical resistance (or impedance) is determined by the ionic conductivity. The origin of the capacitance component is more complex, and it seems to be largely dependent on the structure of the tissue and its biological properties. Fluctuations in the electrical resistance of the body in connection with the cardiac activity (rheocardiography, rheography) have been studied in many workers [1, 3-6, 8, 11-14], all of whom used electrodes applied to the body surface and employed the impedance as the index of the dynamics of vascular filling. However, the measure of electrical resistance obtained by application of surface electrodes is a composite index, depending not only on the resistance of the part of the body under investigation, but also on the resistance of neighboring organs and tissues.

In researches into impedance plethysmography [16, 17], in particular, it was found that electrical resistance can be recorded by means of electrodes introduced directly into the part to be studied. The index of vascular filling also was the impedance which, at the frequency of current recommended by Schvan [17] (about 1 kc), largely reflects the ohmic resistance. The use of the impedance as indicator of the dynamics of the vascular filling has fully justified itself in practice [10, 16].

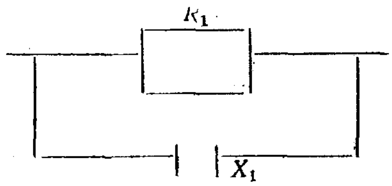
The separate graphic recording during the study of cardiac and pulmonary pathology, for besides giving an electrical reflection of the dynamics of the pulse waves of vascular filling, they also indicate the absolute values of the ohmic and capacitive impedances.

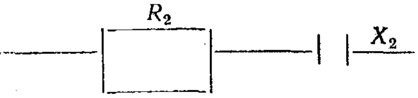
The principal object of the present investigation was to develop a technique and apparatus for this purpose and to apply the technique in practice.

When small electrodes are used and the interelectrode distance is short and constant, the geometrical shape and size of the object, for example, the lobe of the lung, has no significant effect on the magnitude of the impedance. The error during measurement of the impedance due to differences in the salt composition of the blood and due to fluctuations in body temperature and in the velocity of the blood is small (1-2%) by comparison with the large variations in impedance resulting from changes in the degree of vascular filling [9, 15]. At a current frequency greater than 1 kc, the magnitude of the electrode polarization may be disregarded [17].

We used cylindrical electrodes, mounted in the end of a catheter. The strength of the current during measurement was 0.05 mA, and its frequency 5 kc.

Equivalent electrical scheme of object. A simple equivalent electrical scheme of the object is given by a chain of capacitive and active impedances connected in parallel or in series.





We consider that the choice of one of these two schemes is unimportant in principle, for neither actually reflects the true distribution of current within the object; moreover, cross calculations can be made from one scheme to the other

$$R_1 = \frac{R_2^2 + X_2^2}{R_2} \; ; \quad X_1 = \frac{R_2^2 + X_2^2}{X_2} \; ; \quad R_2 = \frac{R_1 \cdot X_1^2}{X_1^2 + R_1^2} \; ; \quad X_2 = \frac{R_1^2 \cdot X_1}{X_1^2 + R_1^2} \, .$$

For technical reasons it was more convenient for us to regard the test object as serial combination of capacitive and ohmic impedances.

Description of the electrical part of the apparatus.* During the attempt to make separate recordings of the active and reactive components of the impedance, difficulties arose on account of the rapid pulse waves of vascular filling. Hence, the use of balanced bridges with a separate manual balancing at X and R is impracticable. Bridges with both components unbalanced and with a wide range of measurements are at the present time a technically complex problem.

We give below a description of the measuring bridge with partial balancing in respect of the active component. A block diagram of the recording apparatus is given in Fig. 1. The power section consists of a power transformer, a rectifier with D7E diodes, a ripple filter and a stabilizer with a stabilitron tube SG2S. The generator was assembled in accordance with an LC scheme with a back transformer coupling, incorporating a power amplifier with a 6Zh2P tube and a voltage stabilizer.

The measuring system consists of an alternating current bridge, partially balanced in respect of its active component, with a close inductive connection between its arms. The bridge is supplied with power from a master oscillator through a transformer. To ensure more reliable insulation of the subject to be investigated from the oscillator, the primary and secondary winds of the transformer are spaced. The core of the transformer consists of a ferrite ring.

In order to widen the range for the capacitive component, the region of best separation of R and X was found experimentally to correspond to different values of the ohmic component. Partial balancing in respect to R was carried out to give the optimal value of the active impedance for separation of the components of the impedance. This can be done conveniently by regarding the object as a series coupling of ohmic impedance and capacitance. This method enabled the capacitance to be measured within limits of 0.003 and 0.5 μF, and the error in respect of R at any value of the capacitance did not exceed ±0.25% within these limits. The range of measurements of the ohmic impedance was between zero and 6000 Ω when the electrodes were constructed in this manner. The error in respect of X under these conditions was determined by the accuracy of the readings. The apparatus provides for calibration signals for both components.

An amplifier with a deep feedback, assembled around 6Zh1P tubes, amplified the signal of bridge imbalance. Two identical cathode repeaters were located at the output of the amplifier. Phase-sensitive detectors separated the signal into active and reactive components. Both were assembled around diodes and had a symmetrical output. An arrow indicator was included in the output of the detector for the active component, for partial balancing of the

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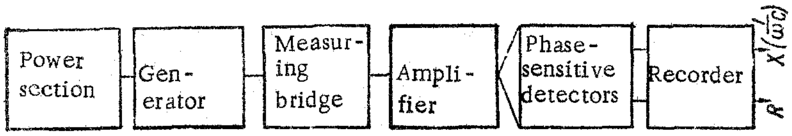

Fig. 1. Block diagram of recording apparatus. For explanation see text.

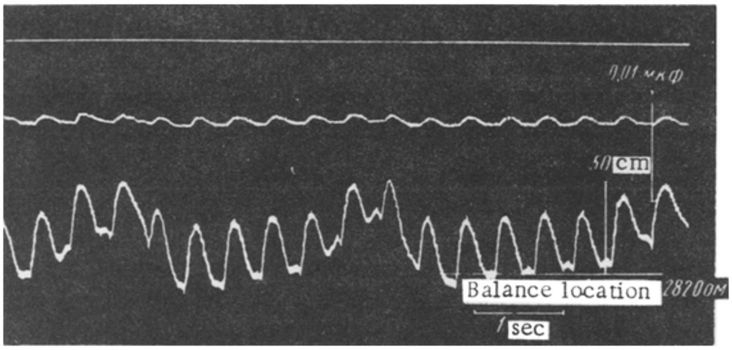

Fig. 2. Separate recording of the capacitive (top) and ohmic components of impedance. Recording made during bronchography by means of a catheter introduced through the respiratory tract into an intact lobe of the lung. Partial balancing of the bridge is shown by the horizontal straight line on the right. Also on the right are shown the calibration scales in microfarads for the capacitive component and in ohms for the pulse waves of ohmic impedance. Tracing made at a velocity of movement of the paper of 25 mm/sec and with slight amplification.

bridge. The separated signal was led to two channels of an ink-recording oscillograph and could be recorded synchronously with the ECG, the phonogram, etc. (Fig. 2).

Measurements of the electrical impedance were made during diagnostic bronchography, during operation or during catheterization. The catheter with the detector was introduced either through the respiratory passages as far as their ramification into small bronchi, or through a vein in the arm as far as the terminal ramification of the pulmonary artery, as is done when measuring the pulmonary capillary pressure. The position of the catheter was checked visually through the bronchoscope or by fluoroscopy.

Among the patients with various lung diseases but without signs of a cardiac lesion we selected a group in which, according to the clinical and roentgenological findings, the second lung was intact. Measurement of the ohmic component of the electrical impedance showed that its value varies within fairly wide limits (1000-3400 $\Omega \cdot$ cm). The wide range of variations of the ohmic impedance is mainly due to differences in the degree of aeration and vascular filling of the lungs.

When the impedance was measured in a collapsed lung (7 persons) values of between 250 and 1000 $\Omega \cdot$ cm were obtained, indicating that the impedance is considerably dependent on the volume of air in the lungs. Experiments on isolated lungs showed that the ratios between the specific impedances of a lobe of the lung, dependent on changes in the volume of air, may be taken approximately as the volume ratios of the organ provided that the latter are not too great.

The resulting curve of ohmic impedance, reflecting the pulse variations in vascular filling of the lungs, may be interpreted from the point of view of the time relationships between the individual elements of the curve of the electroplethysmogram and the other indices of the state of the cardiovascular system (ECG, phonocardiogram, pressure inside the chambers of the heart and great vessels, and so on). The shape of the curve and amplitude of its peaks may also be analyzed.

The changes in vascular filling of the lungs resulting from the action of the heart were studied in the intact lower lobes of the lungs of 39 patients with no heart lesion and of 10 patients with mitral stenosis (Fig. 3). The

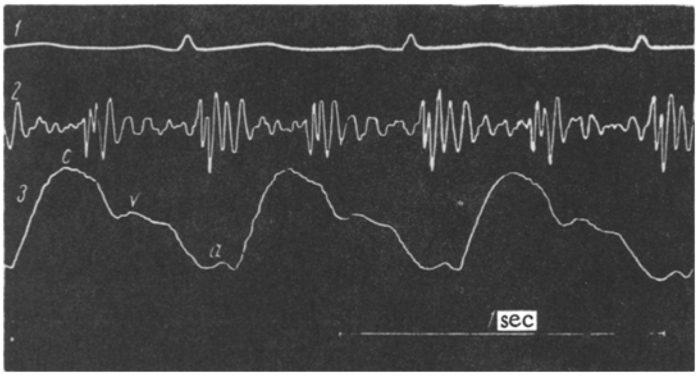

Fig. 3. ECG (1), phonocardiogram (2), and ohmic component of impedance – electroplethysmogram (3). Velocity of movement of paper – 100 mm/sec.

simultaneous recording of other indices of the state of the cardiovascular system enabled the origin of the principal waves of the electroplethysmogram to be established. As might have been expected, the C and V waves were analogous in nature to the C and V waves observed on the plethysmograms reflecting the activity of the left ventricle. The a wave was less constant in normal conditions (in 14 of 39 subjects), but it was recorded in all 5 patients with increased function of the left atrium (mitral stenosis with sinus rhythm) and was always absent in the patients with mitral stenosis complicated by atrial fibrillation. These findings indicate that a retrograde blood flow may take place during atrial systole, and not just a retrograde transmission of pressure from the left atrium.

Interpretation of the reactive component is evidently more complex. Changes in the vascular filling of the lungs leads to a change in the dielectric permeability of the medium and to a corresponding change in the outline of the curve (see Fig. 2), although the absolute value of the reactive impedance in our observations often differed considerably in different patients while the value of the ohmic impedance (the vascular filling) remained approximately constant, which is undoubtedly interesting and deserves further study.

These observations showed that the suggested method of graphic recording of the components of the impedance is safe, is not followed by complications, gives information, not only concerning the dynamics of the changes in the electrical impedance, but also of its absolute value, and may be used to evaluate the functional state of the lungs and the pulmonary circulation in clinical conditions.

SUMMARY

With the aid of electrodes located at the end of a catheter introduced into the lungs through the bronchi or blood vessels, a measurements was made of the electric resistance of the lungs with a subsequent separation of the useful signal into the ohmic and capacitance components. A block diagram is presented and a brief description is given of the main elements of the instrument. Some problems concerning the equivalent electric circuit diagram of the object, as well as of the accuracy and the range of measurements are discussed.

Some practical results concerning the clinical use of this method are presented.

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