ELECTRICAL RESISTANCE OF BIOLOGICAL OBJECTS TO THE DEFIBRILLATOR DISCHARGE CURRENT

B. M. Tsukerman and N. A. Len'kova

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A relationship was found between the electrical resistance of biological objects and the defibrillator discharge voltage. This resistance and the pulse parameters of the defibrillator were found to be mutually dependent.

The action of a defibrillator pulse on the heart must evoke excitation of all the excitable elements of the heart. As a result, the continued circulation of excitation becomes impossible, and the arrhythmia due to this process is stopped.

When evoking excitation, the defibrillator current must not damage the heart. This condition determines the choice of its most suitable parameters. The best type of therapeutic effect has been shown to be given by a pulse consisting of the rapidly attenuating wave discharge of a capacitor containing both the first (positive) and a second (negative) half-wave [1]. The biological effect of stimulation of the heart is determined by the sum of the amplitudes of the first two half-waves, while the traumatic action of the discharge decreases with an increase in the second half-wave (within certain limits) [2, 3].

To obtain the necessary pulses, defibrillators are used. In these instruments the discharge of a capacitor (with capacitance C), to produce the required pulse, passes through a coil (with inductance L and ohmic resistance (R_L). During discharge of the defibrillator through the patient's body (resistance R_b), the voltage on the electrodes is determined by the ratio between R_L and R_b. Accordingly, if the capacitor discharges to the same voltage (V_c), with different values of R_b, the voltage on the patient's body (U) will differ. In addition, the type of pulse also depends on R_b: with an increase in R_b the amplitude of the second half-wave diminishes and the discharge may even become aperiodic.

The resistance of the body – for example, of the human chest – can very considerably [4]. It also is known to depend on the current by which it is measured.

This problem with respect to the effect of defibrillating pulses has not been studied and is the subject of the present investigation.

EXPERIMENTAL METHOD

Discharges of an N. L. Gurvich defibrillator (parameters: C 15 μF, L 0.27 H, and R_L 24 Ω) were passed through the thorax of dogs anesthetized with morphine and thiopental. The electrodes were wrapped in 4 layers of gauze soaked in physiological saline and applied to areas of the skin free from hair. The defibrillator was charged to 500-6000 V. The discharge current was measured at the peak of the first (J') and at the peak of the second (J") half-waves, and the voltage on the animals's thorax was measured at the peak of the first (U') and at the peak of the second (U") half-waves, and the resistance of the thorax was calculated. The instrument used for the measurements consisted of a dual-beam CRO and voltage divider. The records of current and voltage were photographed. The relative error of the measurements was ±7.7%.

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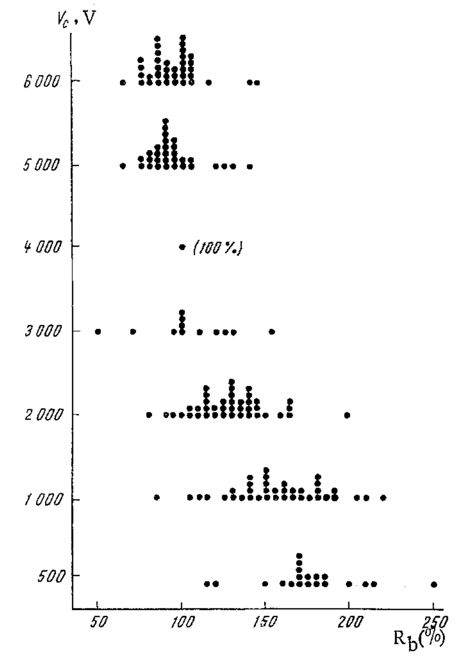

Fig. 1. Relationship between electrical resistance of animals' body (abscissa) and voltage (ordinate) of defibrillator discharge. Resistance given in relative units. Value of R_b when V_c = 4000 V taken as 100%.

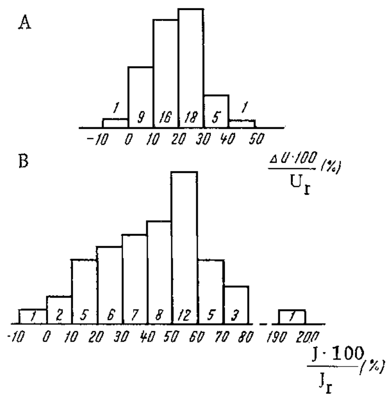

Fig. 2. Comparison of parameters of defibrillator discharge through biological and stable resistors with an increase in V_c from 500 to 6000 V (distribution of results of 50 experiments on 14 dogs): A) decrease in voltage of defibrillator discharge on biological resistor (U) compared with voltage on stable resistance (U_r); B) amount by which discharge current through biological object (J) exceeds current through stable resistor (J_r).

EXPERIMENTAL RESULTS

Measurements were made during 277 discharges in experiments on 14 dogs. The resistance of the thorax was found to be highly dependent on the voltage of the capacitor discharge. As V_c changed from 500 to 6000 V, R_b in the same experiment (with the same distance between the defibrillator electrodes) was reduced as a rule by 2-3 times. Repeated application of discharges of the same voltage produced no change in R_b. The relationship between the resistance of the object and the voltage of the defibrillator discharge is illustrated in Fig. 1.

If the defibrillator was discharged through a resistor with stable resistance, the voltage drop U_r on this resistor was strictly proportional to V_c. If the parameters of the discharge circuit of the defibrillator were unchanged, the value of U_r/V_c was always constant. The resistance of a biological object to a defibrillating pulse is a variable and it depends on the voltage of the defibrillator discharge, and under these circumstances U/V_c changes. The value of U also changes, but not in the same way, because in the same interval of fluctuations in V_c, the value of U_r also changes.

A histogram reflecting differences in the changes in U compared with U_r, based on the results of 50 experiments on 14 dogs in which V_c was changed from 500 to 6000 V, is shown in Fig. 2A. The values of U were measured in the experiments, and those of U_r were calculated in accordance with the theory of an oscillatory circuit for V_c = 6000 V. It is clear from Fig. 2 that with an increase in V_c from 500 to 6000 V, the voltage on the thorax in most experiments changed by 10-30% less than if R_b had been stable.

The facts described above show that the defibrillator and biological object behave as if connected into a single system with the properties of a voltage stabilizer. It can be considered that similar interaction takes place during discharge of the defibrillator, during which the voltage on the animal's or human body varies from its maximum to zero.

Calculations carried out in a similar way for the current showed that, on the contrary, an increase in the discharge voltage in the experiments with the biological object led to a much greater increase in current (J) than the discharge of the defibrillator through a stable resistor (J_r). It is clear from the histogram

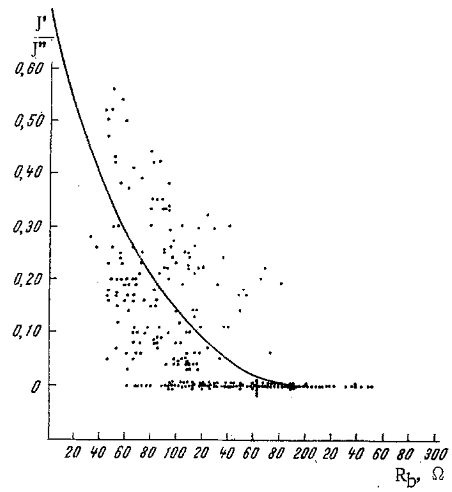

Fig. 3. Ratio between amplitudes of two half-waves of defibrillator pulse with different resistances of the animal body. Resistances measured at peak of first half-wave. Each point is the result of a separate measurement. Curve reflects this same relationship for a stable load resistance.

in Fig. 2B, reflecting differences in the changes in J, compared with J_r with an increase in V_c from 500 to 6000 V, that this increase in relative values amounted to 50-80%. It thus follows that, whereas the defibrillator—biological object system behaves relative to voltage as a stabilizer, relative to current it behaves in the opposite way: changes in current arising during a change in load resistance are considerably increased.

A graph showing the relationship between the ratio between the amplitudes of the second and first half-waves (J''/J') and the value of R_b measured at the peak of the first half-wave is given in Fig. 3. The curve reflects the same relationship calculated for a stable resistance. Comparison of the calculated and experimental data shows that the points, which are results of separate experiments on animals, are distributed irregularly, with only a slight tendency to be arranged around the theoretical curve. Under the experimental conditions used, this could only be the result of instability of the resistance of the animal's body, which changed during discharge of the defibrillator. The results showed that in half of all the cases the body resistance rose sharply during the discharge, leading to a decrease and, often, to total disappearance of the second half-wave. In one-quarter of all cases the resistance was reduced and the second half-wave was greater than the theoretical. Finally, in one-quarter of cases the body resistance of the body during the discharge: polarization, a decrease in pulse voltage during the discharge, and heating of the body tissues by the current passing through them. The first two factors increase, the third decreases the resistance of the object. The marked dispersion of the experimental results (Fig. 3) can evidently be explained by predominance of certain processes which could not be predicted beforehand.

Hence, the defibrillator and biological object constitute a system linked by complex relationships between its two components. A change in the parameters of one component of this system inevitably causes changes in the parameters of the other component. The output pulse of the defibrillator under these circumstances varies considerably in amplitude, duration, and attenuation rate, and deviates from the optimal form. This is a defect of modern pulse defibrillators.

The results of this investigation indicate the marked variability in electrical resistance of biological objects when exposed to the action of a powerful pulsed current. The biophysical nature of this phenomenon is interesting and requires investigation on its own account. Another conclusion to be deduced from the present investigation is the practical one that a defibrillator whose output pulse should be as independent as possible of the load resistance must be designed.

LITERATURE CITED

1. N. L. Gurvich, Fibrillation and Defibrillation of the Heart [in Russian], Moscow (1957).
2. N. L. Gurvich and V. A. Makarychev, in: Current Problems in Resuscitation and Hypothermia [in Russian], Moscow (1964), p. 14.
3. V. A. Makarychev, Byull. Éksperim. Biol. i Med., No. 6, 27 (1966).
4. V. A. Makarychev, B. M. Tsukerman, and N. L. Gurvich, Byull. Éksperim. Biol. i Med., No. 11, 32 (1966).