CHARACTERISTICS OF THE ELECTRICAL IMPULSE APPLIED TO STOP CARDIAC ARRHYTHMIAS

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The application of a powerful electrical stimulus to the heart was regarded until recently as an extraordinary method, usable only after the development of ventricular fibrillation. In 1956 it was shown experimentally by B. M. Tsukerman and N. L. Gurvich [10], and in 1959, clinically, by A. A. Vishnevskii, B. M. Tsukerman, and S. I. Smelovskii [2] that the application of such a stimulus could also abolish a chronic disturbance of the cardiac rhythm—auricular fibrillation. The treatment of cardiac arrhythmias by electrical impulses is widely used nowadays both in the Soviet Union [3, 6-9] and elsewhere [11].

As a result of previous experimental investigations [3, 5], satisfactory parameters for the impulse with respect both to effectiveness and to minimal traumatizing effect on the heart were determined. However, the form and magnitude of the impulse generated by the defibrillator are largely dependent on the external load in the circuit of the discharge current. This load is determined by the resistance of the chest wall to the defibrillating current, and this has not been studied in man. Because of the great dependence of the resistance of biological objects on the characteristics of the current flowing through them, the magnitude of the external load can be measured only by applying a defibrillating impulse.

The object of the present investigation was to study the voltage and strength of the electrical impulse capable of abolishing a cardiac arrhythmia, and also to determine the resistance of the patient's chest wall to this impulse.

EXPERIMENTAL METHOD AND RESULTS

Measurements were made during 40 attempts to treat 37 patients by means of electrical impulses for various cardiac arrhythmias: in 35 patients the current was applied transthoracically, and in 2 directly to the heart during mitral commissurotomy.

In the transthoracic method electrodes 12 cm in diameter were applied anteriorly to the left subclavicular region and posteriorly to the left scapula. The skin in these regions was first freed from fat with alcohol and ether. Where the current was applied directly to the heart, one of the electrodes was applied below the patient's chest wall and the other was pressed firmly to the heart. Treatment was given with a pulse defibrillator working on N. L. Gurvich's system, containing a condenser with a capacitance of 16 μF, and a coil with an inductance of 0.25 H and an active impedance of 25 Ω.

The voltage and strength of the current were recorded by a type OK-21 twin beam cathode-ray oscillograph. The voltage at one input of the oscillograph was taken directly from the electrodes of the defibrillator; at the other input the voltage was taken with a very small resistance, included in series in the discharge circuit. Hence, one beam recorded the voltage pulse, the other the current pulse. During the subsequent analysis of the oscillograms, the electrical resistance of the patient's chest wall to the pulse passing through it was also calculated. The energy of the discharge (W) was calculated from the formula:

$$W = \frac{CV^2}{2},$$

where C is the capacitance of the condenser (in F) and V the voltage of its discharge (in V).

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Physical Parameters of the Electrical Impulse Stopping Arrhythmia When Applied through the Closed Chest Wall

No. of patients	Voltage of condenser discharge (in V)	Voltage at electrodes* (in V)	Current* (in A)	Energy of discharge (in J)
1	3500	750	19	98
10	4000—4400	750—1200	20—25	128—155
13	4700—5000	800—1300	26—29	176—200
8	5200—6000	1000—1500	29—33	218—288
2	6300—7000	1100—1900	33—37	320—392
1	7800	2200	41	490

* The voltage and strength of the current were measured in the 1st half-wave. The 2nd half-wave amounted to 30-50% of the 1st.

The 37 patients included 13 women and 24 men. In 31 a diagnosis of chronic auricular fibrillation was made, in 1—a prolonged attack of paroxysmal tachycardia, and in 5—atrial flutter.

Depending on the character of the underlying disease, the patients were subdivided into the following groups: those with heart disease of rheumatic etiology (21), those with atherosclerotic and myocarditic cardiosclerosis (13), those with thyrotoxicosis (1), and with arrhythmias of unknown origin (2).

The duration of the arrhythmias varied from 1 month to 12 years. The ages of the patients ranged from 13-14 to 67 years. The patients differed in build and body weight (84-106 kg).

Voltages of the Condenser Discharge and Immediate Results of Treatment. For the initial application of the current, in order to abolish the arrhythmia the condenser of the defibrillator was charged to not less than 4 kV (for adults) and 3 kV (for adolescents). Lower voltages were not used to avoid ventricular fibrillation [1].

An immediate positive effect was observed in 35 of the 38 attempts at transthoracic electrical impulse therapy (three patients were treated twice). In 3 patients, despite the use of high voltages, the arrhythmias could not be stopped; 2 of these patients had auricular fibrillation of 1 and 5 months' duration, developing against the background of myocarditic and atherosclerotic cardiosclerosis. In the third patient, a boy 14 years old, a prolonged attack of paroxysmal tachycardia of supraventricular origin was present.

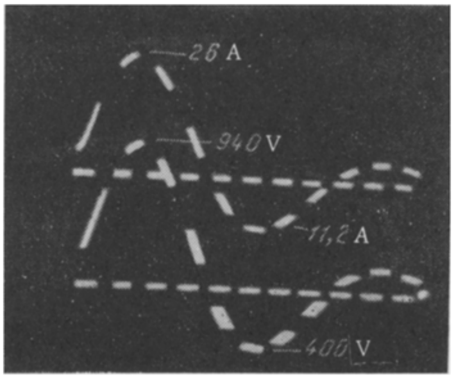
In 1 of the 2 patients treated for auricular fibrillation by direct application of the discharge to the heart during surgical operation, success was obtained.

After abolition of the arrhythmia, even of its bradysystolic form, all the patients felt better and, in particular, they noted that breathing was easier and that the palpitations had disappeared.

Parameters of the Electrical Impulse and Resistance of the Patients' Chest Wall. The records of the current and voltage showed that the impulse, consisting of a damped oscillatory discharge (see figure), had a marked 2nd half-wave and the half-period was 6.8 msec. The voltage (measured by the amplitude of the 1st half-wave) varied in the different patients from 750 to 2200 V, and the strength of the current from 19 to 4.1 A. The voltage of the discharge, its energy, and also the values of the current strength and voltage measured at the patient are given in the table.

The arrhythmia in 1 of the 2 patients was stopped by the discharge applied directly to the heart. The voltage of the discharge at the condenser was 3.2 kV, the voltage at the patient was 675 V, and the strength of the current was 17.4 A.

The electrical resistance of the patients' chest wall to the discharge current was calculated by dividing the voltage by the strength of the current. The resistance of the chest wall varied in the different patients from 27 to 53 Ω. The lowest resistance was found in a patient weighing 70 kg, the highest (53Ω) in a patient weighing 78 kg. In the heaviest patient (106 kg) the resistance of the chest wall was 46 Ω, and in an adolescent (34 kg) it was 37 Ω. Hence, no direct relationship could be observed between the ohmic resistance of the patient's body and his weight. When the discharge was applied directly to the heart (the other electrode below the left scapula) the resistance in the two patients was 30 and 40 Ω respectively.



Oscillograms of current (top) and voltage (bottom) during a discharge with a voltage (at the condenser) of 4800 V, abolishing auricular fibrillation in patient B. Amplitude of voltage (1st half-wave) at the patient 940 V, amplitude of current 26 A. Time marker (between beginnings of adjacent dashes) 1.6 msec.

Depending on the voltage of the discharge, the energies of the discharges restoring the sinus rhythm were distributed as follows: 1 patient received less than 100 J, 10 received 128-155 J, 13 received 176-200 J, 8 received 218-288 J, 2 received 320-392 J, and 1 patient received 490 J. About one-third of the energy was dissipated by the active impedance of the induction coil.

The results of this investigation helped to explain the relationship between the voltage of the condenser discharge and the true value of the voltage applied to the patient's chest. It was found that the voltage applied to the chest was in fact only 20-33% of the voltage indicated on the kilovoltmeter of the defibrillator. In addition, neither the resistance of the patient's body nor the voltages necessary for abolishing the arrhythmias bear a precise relationship to the patient's weight (or the dimensions of his chest). Evidently other causes are responsible for the observed scatter of the parameters of the essential electrical stimulation, possibly associated with individual differences in the course of the arrhythmia.

The measurements of the voltages applied during discharge of the defibrillator to the patient's chest could be compared with the voltage of an alternating current used for the same purpose [12]. The investigation cited showed that for transthroacic defibrillation of the heart by an alternating current, not kilovolts, but only 440-720 V need be applied. This considerable reduction of the essential voltage when an alternating current is used is apparent, and it is determined by the method used to measure it (the effective value of one half-period). In fact the effectiveness of an alternating current in relation to arrhythmias is determined not by one, but by the sum of 2 half-periods: after rectification of the alternating current the voltage required for defibrillation has to be doubled [4]. In addition, to obtain comparable results by the two methods, the amplitudinal and not the effective values of the alternating current must be used.

Hence, for a correct calculation, the voltage of the alternating current must be multiplied by $2\sqrt{2}$ (by 2.82). In this way it is found that in fact not 440-720 V, but 1240-2020 V is required for transthoracic defibrillation, i.e., the same values as during abolition of arrhythmias by the electrical discharge method.

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