Some debatable problems on electroimpulse therapy of cardiac arrhythmias

by

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The possibility of terminating atrial fibrillation with an electric discharge was reported in 1956, by Tsukerman and Gurvich.[20] In this article the authors described the results of experiments which proved that atrial fibrillation provoked in dogs by various means can be terminated delivering to the animals heart a discharge from a defibrillator.

In Gurvich's defibrillator used for this purpose, a single discharge of the capacitor included the inductance coil in the discharge circuit. This type of defibrillator [1] has been widely used in the Soviet Union and has proved an excellent mean for ventricular defibrillation.

It appears to us, that as long as the reserchers follow in the steps of Kouwenhowen [7] and continue to use alternate current defibrillators, electric therapy of cardiac arrhythmias cannot be fruitfully developed. This has been proved by the unsuccessful attempts of Lown,[11] Zoll [23] and Paul [16] to cure certain types of tachycardia with external countershock using alternate current. It has been also proved by the comprehensive experimental work of Lown *et al.*[10] who observed severe complications resulting from such treatment of a normally pulsating heart.

We started our studies on the therapeutic effect of the electric stimulation in patients suffering from persistent atrial fibrillation. We used an impulse defibrillator with a good form of discharge current. Prior to the clinical experiments we studied morphological changes in the dog's heart under the influence of such an impulse. It has been established [9] that with a capacitor charge of 500 to 6000 V, discharges applied both, across the intact chest and directly, to the heart did not cause disturbances that could have substantially affected the contractile function of the myocardium. Naturally in the past this problem was not paid sufficient attention because electric shock was used only for ventricular defibrillation in order to save the patient's life. In this case the deleterious effect was acceptable. In February 1959, since we were convinced that the impulse delivered by Gurvich's defibrillator was relatively innocuous we used it for the first time, to stop atrial fibrillation. We applied the discharge directly to the heart of a patient during mitral commissurotomy.[22] As a result auricular fibrillation, which the patient had for a number of years, was immediately stopped and a regular sinus rhythm was restored (Fig. 1). This apparent and striking effect was later observed in the majority of our patients.

In 1961 we reported the results of electroimpulse therapy of the chronic and paroxysmal forms of atrial fibrillation and flutter in 20 patients with rheumatic heart disease.[21] Eleven of them had the discharge applied through the intact chest.

In 1957 Peleska (Czechoslovakia) offered his type of defibrillator using the scheme of Gurvich; in 1962, another one was made in the U.S.A. by Lown *et al.*[11] Thus the possibilities were created for extensive studies of the electroimpulse therapy of cardiac arrhythmias. The works of other investigators confirmed—to our greatest satisfaction—our main conclusion. Dr. Lown has undoubtedly done very much for studying and propagating this method. Greatly due to his efforts electroimpulse therapy of cardiac arrhythmias has been winning ever wider acclaim in various clinics all over the world.

However, some problems have arisen which must be elaborated. The most important of these are:

1. Is it necessary to use a cardiosynchronizer?

2. What are the optimal parameters of the impulse which stops the circulations of the heart's excitation.

Is it necessary to use a cardiosynchronizer?

Lown's instrument, which he named "cardioverter", includes a cardiosynchronizer besides the defibrillator. At first glance, the synchronizer which makes it possible to supply an electric discharge during the absolute refractory period seems very advisable. In fact, it prevents the discharge from hitting the vulnerable period of the cardiac cycle which, according to widespread opinion, very often causes ventricular fibrillation.

Lown, as well as many other researchers, consider the cardiosynchronizer essential for a large use of the electroimpulse therapy.

From our point of view this opinion is not quite justifiable. Let us consider, for example, the possibilities of hitting the vulnerable period of the cardiac cycle with random shocks. The percentage of such a possibility is: $i = \dfrac{0.03 \times 100}{RR}$, where 0.03 is the duration (in seconds) of the vulnerable period of the cardiac cycle,[12] and RR the length of the cardiac cycle (on the electrocardiogram) in seconds. Evidently "i" depends upon the heart rate. The heart rate of dogs varies (depending upon the conditions of the experiment and the type of narcosis) between 80 and 130 per minute, that is RR is between 0.75 and 0.50 seconds. Therefore, "i" will vary from 4 to 6.6 per cent, the mean value will be 5 per cent. According to Lown,[13] ventricular fibrillation occured in about 2% of dogs under penthotal narcosis. The reason for this is that not every shock hitting the vulnerable period of the cardiac cycle causes ventricular fibrillation.

Our statement can also be proven by the old work of Ferris *et al.* They showed that the short electric shock administered transthoracically during the T phase of the electrocardiogram caused numerous cases of ventricular fibrillation only when the current intensity was relatively low. If the intensity was increased to 24A, ventricular fibrillation would not occur. In other words, in certain conditions electric stimulation of the normally pulsating heart may cause ventricular fibrillation. However, the appearance of fibrillation depends not only on the moment when the shock is applied but also on its intensity. If the electric shock is sufficiently high no ventricular fibrillation will occur at all. While we were studying the characteristics of our defibrillator we arrived at the same conclusion. Our experiments were carried out on narcotized dogs. The thoracotomy was performed and one of the electrodes of the defibrillator was placed directly on the heart. The other electrode was put under the animals' shaved shoulder blade. If the capacitor was charged at 500 V the shock applied at a random period of the normally pulsating heart caused ven-

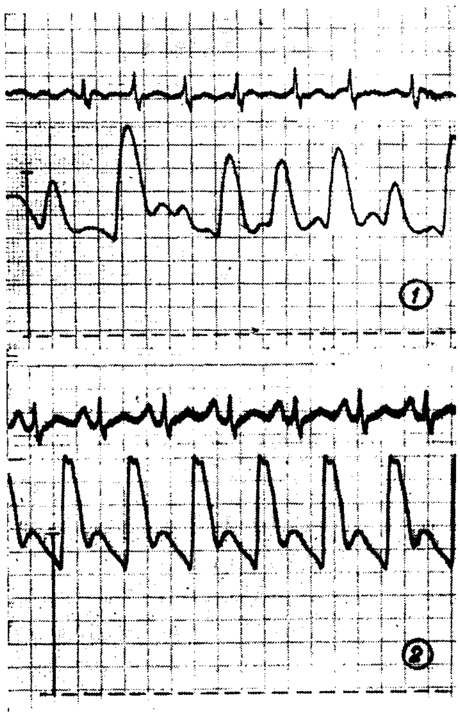

Fig. 1.—Electrocardiogram (above) and blood pressure in the posterior tibial artery (below) of patient L. (February 1959). (1) Atrial fibrillation. (2) Sinus rhythm immediately after atrial defibrillation with a 2,000 V discharge through the open chest.

tricular fibrillation once out of 30 discharges. At 750 V it occured still more rarely while at 1000 to 4000 V it was not observed at all.

Finally, we should like to report here the cases of electroimpulse therapy in various arrhythmias without cardiac synchronization. Our Clinic and the Republican Clinic Hospital, sponsored by the Kaunas Medical Institute (Dr Lukosevicute), admitted 288 patients with atrial fibrillation and paroxysmal tachycardia. These patients were treated with 700 discharges (in toto). The capacitor was charged and 3 to 6 kv administered transthoracically and 2 to 3 kv directly to the heart.

Of all these discharges only one caused ventricular fibrillation (less than 0.15%). Using the above mentioned formula we can calculate the number of cases when we must hit the vulnerable period. The heart rate varied in different patients between 80 and 140 per minute; neutralized intervals (RR) varied, correspondingly, from 0.75 to 0.43 sec. Therefore "i" varied between $\frac{0.03\times100}{0.75} = 4\%$ to $\frac{0.03\times100}{0.43} = 7\%$; with an average not lower than 5.5%. This means that we hit the vulnerable period of the cardiac cycle not less than 38 times.

At present it is impossible to explain why ventricular fibrillation did arise in one case, just as it is impossible to answer the question why this complication is observed sometimes when the "cardioverter" is used.[8 15 19]

Optimal impulse parameters

We believe that Lown's defibrillator caused ventricular fibrillation when used without the cardiosynchronizer because his defibrillating impulse parameters were not very well chosen.

Electric stimulation of the heart used to suppress pathological rhythms must satisfy the following requirements:

1. The stimulus must have the maximum effect in terminating arrhythmias;
2. It must cause the least possible damage;
3. It must not cause ventricular fibrillation.

Let us analyze (from this point of view) the four forms of current which have been used by different authors to stop ventricular fibrillation: 50-60 hz AC (Fig. 2A); the unmodified capacitor discharge (Fig. 2B); the capacitor discharge through the inductance coil (with a ferric core) (Fig. 2C) and the capacitor

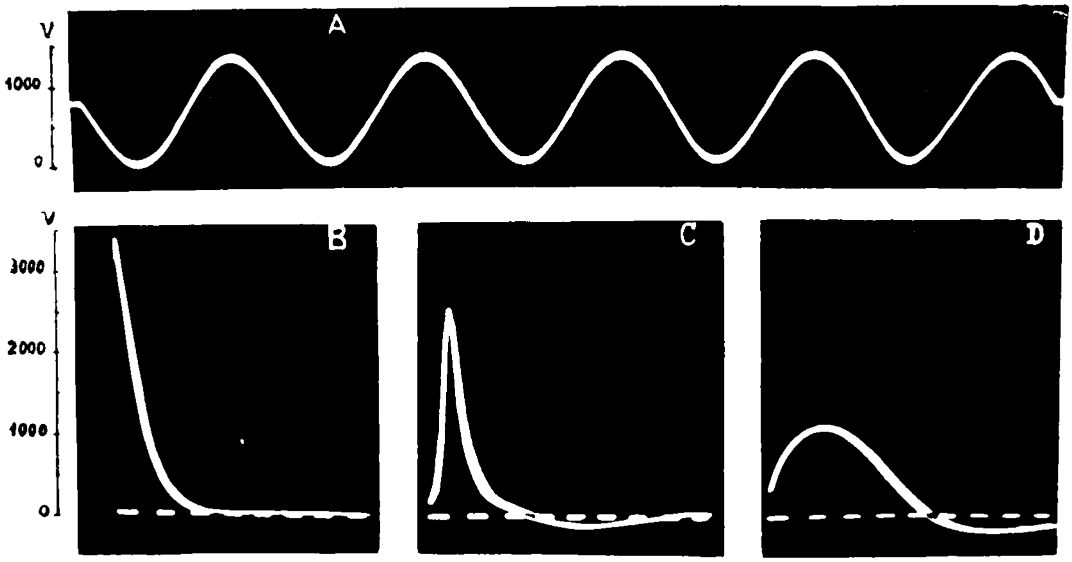

Fig. 2.—Oscillograms of various kinds of defibrillating current. (A) 50 Hz A.C. during 0.1 sec. (B) 16 μF capacitor discharge. (C) 16 μF capacitor discharge through 0.3 H inductance coil with a ferric core (Prema defibrillator, 1957). (D) 16 μF capacitor discharge through 0.38 H inductance coil without a core (Gurvich's defibrillator). Amplitudes of the curves correspond to the "threshold of defibrillation" (in volts) for each kind of current. The time scale: the distance between the left ends of the dots corresponds 1.7 msec.

discharge through the coil without a core (Fig. 2D).

The alternate current, as stated above, proved unfit for suppression of supraventricular arrhythmias, as it damages substantially the myocardium and causes ventricular fibrillation. Discharge of the capacitor is more effective for defibrillation and causes less damages than AC,[6 14] still it injures the heart to a great extent and ventricular fibrillation of the normally beating heart arises both at low and high discharge voltage.[17] The ferric core inductance (Prema defibrillator of Peleska system, 1957) reduces these effects but does not eliminate them. Of all tested impulses the best one proved to be that proposed by Gurvich, which was obtained from a capacitor discharge with an inductance without a core.[4 18] However, the latter impulse may have different properties, the differences depending on the duration of the impulse, namely a capacity and inductance value.

Gurvich ascertained,[1 5] that the same relation existed between the duration and intensity of the defibrillating impulse as the one discovered by L. Hoorweg and G. Weiss for electric stimulation of muscles and nerves (Fig. 3). Analyzing this curve, Gurvich proposed to consider as optimal that impulse length, which corresponds to the utilization time of the heart, that is 8 to 10 msec. It is inconvenient to shorten the impulse length considerably, because this would require a substantial increase of the discharge voltage necessary for defibrillation. It is also improper to lengthen the impulse to more than 10 msec, because the discharge energy grows much quicker than the drop in the voltage necessary for defibrillation.

Peleska[18] studied the influence of the electric impulses of various duration and amplitude upon the heart. He proved statistically in a great number of experiments, that if an impulse (of a kind

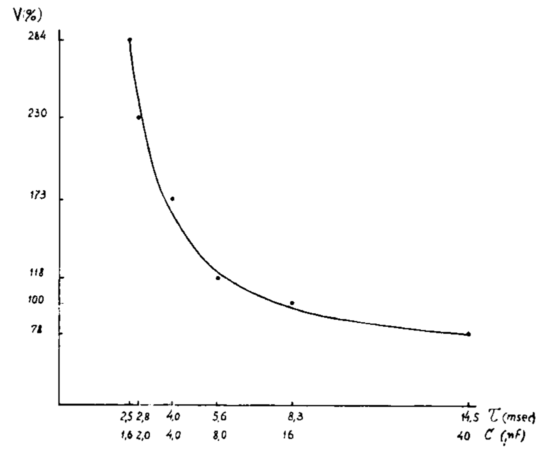

Fig. 3.—Dependence of the impulse duration (τ) and the threshold of defibrillation voltage (according to the data kindly presented by N. Gurvich and V. Makarychev). Discharge through 0.25 H. inductance coil without a core. Abscissa axis: τ (msec) and the corresponding values of the capacitor (μF). Ordinate axis: "defibrillation thresholds" in per cent where 100% in the "defibrillator threshold" for the impulse where τ=8.3 msec.

shown in Fig. 2D) hits the heart during the vulnerable period, ventricular fibrillation does not occur with 10 msec—impulse duration, even if the discharge voltage is comparatively low.

The above evidence gives us reason to consider that:

1. Of all mentioned forms of electrical stimulation the best is the capacitor discharge with an inductance (without a core) when the impulse duration is 8 to 10 msec. Such an impulse satisfies all three of the above stated requirements.

2. If a defibrillator generates such impulses it can be used to treat cardiac arrhythmias without a cardiosynchronizer.

3. Comparatively frequent cases of ventricular fibrillation which occured when Lown's defibrillator was used without the cardiosynchronizer may be explained with the inadequacy of the impulses generated by this instrument.

The problem of choosing an optimal type of current for defibrillation is not yet solved. Probably the impulse with a second, negative half-wave[6] will prove the best—that is, the least deleterious. One thing is evident: that it will be an impulse and possibly a biphasic one. Therefore we propose to reject the widely used term "DC countershock or electric shock" and replace it with another one: "electroimpulse therapy of arrhythmias".*

Summary.—The reported experimental and clinical data show primarily that electric stimulation during the vulnerable period of the cardiac cycle does not in all cases cause ventricular fibrillation. This occurs mostly when the intensity of stimulation is comparatively low. The form of impulse plays an important role. Of all tested forms the best impulse proved to be the capacitor discharge with an inductance without a ferric core and an impulse duration of 8 to 10 msec. With such an impulse and a sufficiently high amplitude (4 to 6 kv capacitor discharge when applied to the intact chest of an adult man) ventricular fibrillation occurs not more frequently than when the cardiosynchronizer is used. Therefore, we consider the cardiosynchronizer superfluous.

*The name was adopted at the Symposium on profound hypothermia (Moscow, September 1964).

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