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ELECTRICAL INDUCTION OF VENTRICULAR FIBRILLATION IN THE HUMAN HEART

A study of Excitability Levels with Alternating Current of Different Frequencies

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Abstract. An experimental study was made on induction thresholds for ventricular fibrillation with alternating currents at frequencies ranging between 6 and 1 600 c/s. The tests were performed on experimental dogs and on patients in association with open-heart surgery. The most vulnerable range was found to be between 12 and 60 c/s. A close similarity was demonstrated between canine and human hearts. The induction of ventricular fibrillation during open-heart surgery is discussed. Ventricular fibrillation, caused by electricity, is either accidental or deliberately induced for medical purposes. The myocardial threshold of excitability towards alternating currents is dependent on two parameters, current and frequency. The vulnerability of the heart towards current has been thoroughly investigated by several authors (Walter, 1969; Dalziel & Lee, 1969; Nickel & Spang, 1965; Kugelberg, 1975). A frequency of 50–60 c/s was utilized in all these determinations, as this is the one of choice in networks for distribution of electric power all over the world. Thus, accidental ventricular fibrillation is most likely to occur with currents of this frequency, and inductions for medical purposes, i.e. during open-heart operations, are achieved in the easiest way with simple transformers delivering the same frequency.

The myocardial excitability threshold as a function of frequency has not been systematically investigated in man, ventricular fibrillation being a too dangerous condition. Determinations are made on skeletal muscles as "let go" tests in man. The highest excitability for the muscles in these experiments was found to be in the range 10–150 c/s (Hopps, 1969; Dalziel & Lee, 1969). Different frequencies as a threshold for sensation have also been tested in man and the range 30–100 c/s proved to be the most vulnerable (Geddes, 1969).

In dogs, the excitability of the heart against currents of changing frequency has been measured as regards ventricular fibrillation. The test currents were delivered from electrodes placed on the outside of the thorax and the sensitive range was 30–150 c/s (Geddes, 1969). With higher frequencies, the risk diminishes and it should be mentioned that currents up to 3 Amps have been passed through the human body without inconvenience, provided that the frequency was in the range 0.5–1.0 Mc/s (d'Arsonval, 1893).

The present investigation was made on dogs and in man, testing the vulnerability of the myocardium to ventricular fibrillation using sinusoidal, alternating currents in the frequency range 6–1 600 c/s. The problem concerns both electrical hazards and the optimal method for creation of fibrillation for medical purposes.

METHODS

Experiments on dogs

Determinations were made on 2 mongrel dogs weighing 25 and 10 kg, respectively. Anaesthesia was induced intravenously with pentobarbital and maintained with an Elema Servoventilator on 50% oxygen and 50% nitrous oxide. No other drugs were used. Arterial pressure and

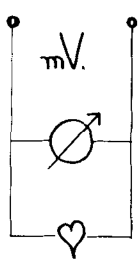

Fig. 1. Determination of voltage.

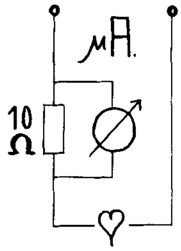

Fig. 2. Determination of current.

ECG were recorded. Test currents were delivered from a Sine Wave Generator, Exact Mod 126. Current and voltage were measured according to standard electrical principles (Figs. 1 and 2). The electrodes were made of stainless steel. They had a circular shape with a surface of 3.1 cm^2 and were sutured directly to the myocardium, one over each ventricle. Implantation of the electrodes was made at an earlier stage and the cables were placed with their terminals subcutaneously, ready for easy exposure. The current was slowly increased in each test up to the point of fibrillation, at which voltage and current were noted. Separate measurements were performed at the following frequencies: 6, 12, 25, 50, 100, 200, 400, 800 and 1 600 c/s. When the experiment resulted in full ventricular fibrillation, it was defibrillated with a double square-pulse via the cables over the electrodes (Kugelberg, 1967, 1975).

Four random measurements were made at each frequency and their mean value was utilized as the final result. The differences within each set of values were insignificant.

Determinations in man

The tests were made on 3 patients undergoing open-heart surgery. They were chosen for the experiments because their expected perfusion time was short. Fifteen minutes of their time on the pump-oxygenator were used exclusively for this purpose. As soon as a satisfactory perfusion was established, the measurements were made with the same technique and equipment as in the previously described experiments on dogs. The epicardial electrode consisted of a circular teflon plate on which two 4 mm platinum knobs were places 42 mm apart (Kugelberg, 1975). Blood gases, electrolytes and myocardial perfusion at the moment of testing were satisfactory. Brief data concerning the patients are presented below (Table I).

Table I

Patient no.	Sex	Weight (kg)	Diagnosis	Total heart volume (ml)
1	Male	22	Ao-stenosis	230
2	Female	29	ASD	530
3	Female	61	ASD	1 410

Table II. *Induction thresholds for ventricular fibrillation in 2 dogs and 3 patients*

Frequency c/s	12	25	50
Dog 1	200	200	260
Dog 2	260	230	250
Patient 1	440	460	480
Patient 2	160	160	190
Patient 3	320	200	200

RESULT

As a function of frequency, the excitability thresholds are presented in the diagrams of Figs. 3, 4, 5 and 6. Both current and voltage over the heart muscle at the moment of onset of fibrillation are given. The most sensitive range was between 12 and 50 c/s. The values for these frequencies are presented for each heart separately in Table II.

DISCUSSION

The frequency response to alternating, sinusoidal currents over different biological tissues seems to be rather homogeneous. Studies of "let go" current levels (Hopps, 1969; Dalziel & Lee, 1969) show that

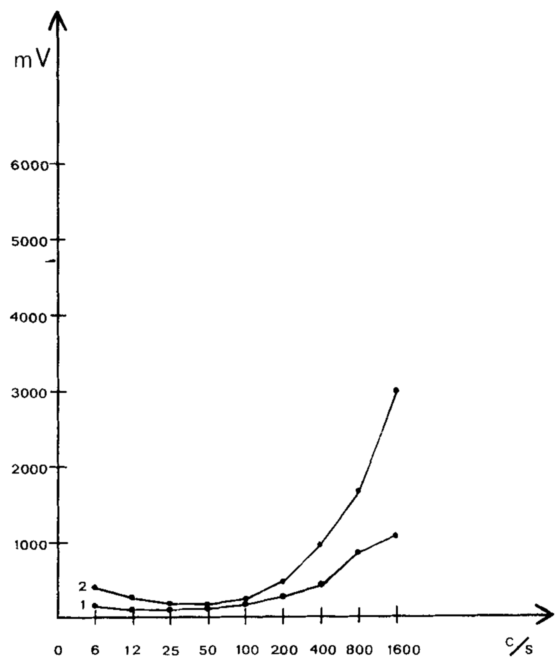

Fig. 3. Induction thresholds as voltages over the given frequencies in 2 dogs.

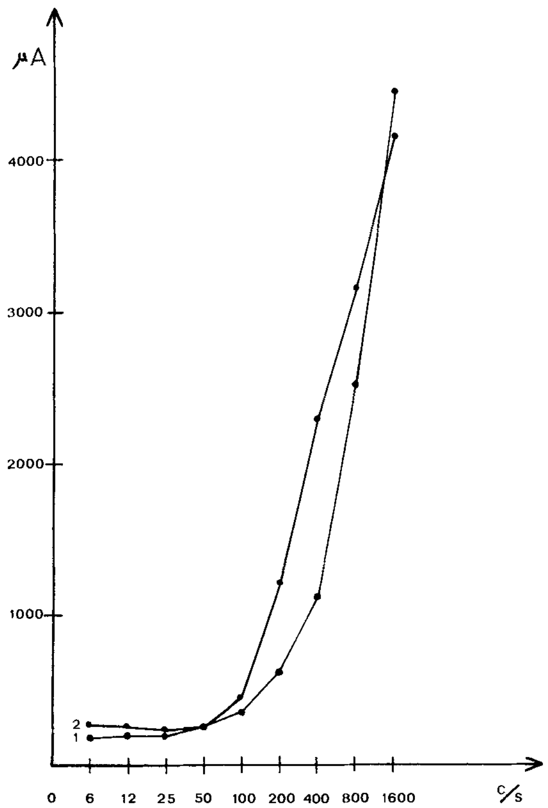

Fig. 4. Induction thresholds as current flow over the given frequencies in the two dogs.

the most sensitive range is 30–70 c/s. Similar conditions are found in determinations of sensation-thresholds in man and both thresholds for induction of ventricular fibrillation and vagal stimulation in different animals. (Geddes, Baker, Moore & Coulter 1969; Geddes, Cabler, Moore, Rosborough & Tacker 1973; Geddes & Baker 1971). A comparison of the results presented in Figs. 3, 4, 5 and 6 shows a striking similarity between dogs and man, from which it seems justified to conclude that the canine heart permits a certain degree of comparison with the human myocardium in electrical experiments. The relation between current and voltage in the two pairs of curves shows a congruent form. Thus, within the given limits, the impedance of the hearts is independent of frequency.

Ventricular fibrillation, induced by a.c. current during open-heart surgery, has several advantages. It diminishes the hazards of air embolism and it facilitates surgery. The ideal frequency, according to the determinations made in this work, is about 40–60 c/s. A minimum of electrical energy will then be distributed to the heart. An earlier investigation has, however, demonstrated disadvantages with ventricular fibrillation during surgery, particularly when it is electrically maintained. (Hottenrott, Maloney & Buckberg, 1974). Three factors are given as causes of injury: (1) The continuous presence of the induction current (1.5–4.5 V a.c. 60 c/s) causing a ventricular fibrillation "under contraction". (2) Distension of the heart, which impairs the postoperative function of the myocardium, particularly after electric fibrillation. (3) Oedema of the fibrillating heart muscle as a result of ischaemia.

I have used electrical ventricular fibrillation during open-heart surgery in more than 500 cases. They have not demonstrated any decrease of myocardial function as a result of the method. Nevertheless the results is not contradictory to the observations of Hottenrott et al. In this connection, it is pointed out that induced ventricular fibrillation should be used with respect to the following four aspects:

(1) The induction current should not exceed the threshold needed. This means a current flow of approximately 400 μA, which is usually achieved with a voltage of about 0.200 V (50–60 c/s a.c.).

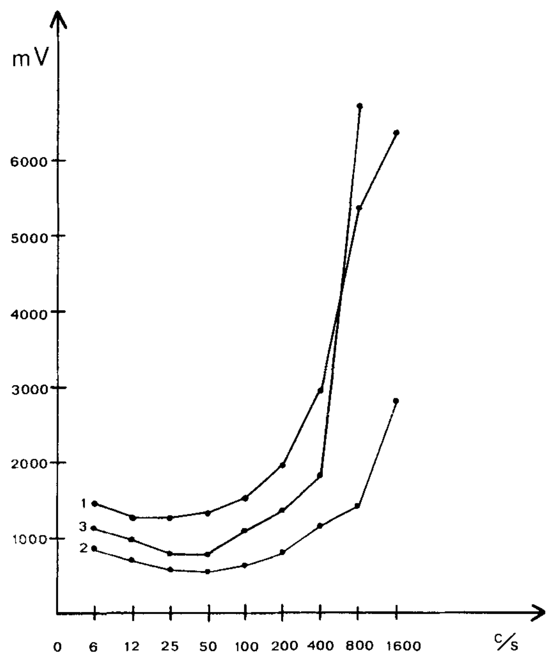

Fig. 5. Induction thresholds as voltages over the given frequencies in 3 patients. Numbers of patients correspond to previous text.

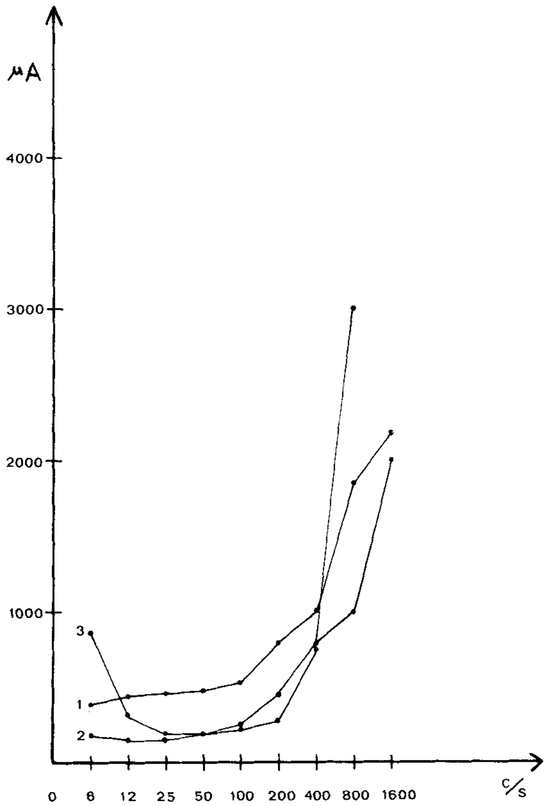

Fig. 6. Induction thresholds as current flow over the given frequencies in the three patients. Numbers of patients as in previous text.

(2) When the induction is performed, the current may very well be switched off after a few minutes. A spontaneous defibrillation rarely occurs, but if it does, re-fibrillation can be made immediately.

(3) Distension should be avoided under all circumstances by continuous or intermittent clamping of the aorta.

(4) Ischaemic injury should be prevented by intermittent perfusions of the coronary arteries (release of the aortic clamp) or by hypothermia of the myocardium (Kugelberg 1971). Such a hypothermia, however, may probably be replaced by a normothermic infusion of Cardioplegin (Kirsch 1970; Kirsch, Rodewald & Kalmár 1972).

All currents and voltages are given in RMS-values.

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