Contraction of Frog Myocardium in Non-uniform Electromagnetic Field

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Abstract. Tension of the frog heart irradiated by nonuniform electromagnetic field was investigated. Tension changes up to 50 % of initial values were observed. The presence of a.c. field gradient is viewed as a possible reason for such alterations.

Key words: Microwave electromagnetic field — Myocard tension — Field gradient

Introduction

Recent investigations of the effects of electromagnetic oscillations on biologic objects have become very numerous. Experiments have been carried out over a wide frequency range: from fractions of unit cycles per second to hundreds of gigacycles per second. Effects of electromagnetic field on biologic objects at some power levels which have no noticeable thermal effects get to the centre of interest. It usually concerns a power flow not exceeding several mW/cm^2. At similar levels and at a frequency of 147 MHz modulated by 6 to 25 Hz, an acceleration of the Ca ion yield from the cerebrum of chicken or cat is observed (Adey 1980). A field of a frequency of 240 MHz modulated by 16 Hz increases the yield of labeled calcium from frog heart by 19 % (Schwartz et al. 1983). In a frequency range from 40 to 80 GHz electromagnetic oscillations effect division processes of the microorganism cell, the functional activity of systems and proteins in bacteria, and multicellular organisms (Smolyanskaya et al. 1979; Devyatkov et al. 1981).

Examples presented in the present paper as well as a number of other facts bring convincing evidence for the influence of electromagnetic oscillations on the functions of biologic objects. The mechanisms of these effects have not yet been understood.

The aim of the present paper was to study the effects of non-uniform microwave electromagnetic field on contraction of the frog myocardium.

Materials and Methods

Evoked contraction of heart muscle strips of the frog *Rana temporaria* was studied. The strips were placed in physiological solution containing (in mmol/l): NaCl 110; KCL 2.5; $CaCl_2$ 1.8; Tris-HCl 10; glucose 40 % 2.5 ml/l, pH = 7.4—7.5. A schematic representation of the equipment used is shown in Fig. 1. One end of the muscle preparation was fixed to the wall of the chamber, the other one to mobile electrode of a mechanoelectric transducer. Amplified signals were recorded. Contractions were evoked by 15 ms pulses of amplitudes of 20—30 V and a frequency of 0.3 Hz. The tension of the contracting muscle was considered to be optimal when the leading front of a single contraction mechanogram plotted by a control recorder became equal to relaxation.

The quantity of the solution flowing through the chamber was regulated so as to keep the tension constant at the lowest flow rate of the solution.

Measurements were made at solution temperatures varying from 17 to 19 °C. During a single measurement cycle (heating-cooling) the temperature of the bathing solution was kept constant within ±0.1 °C.

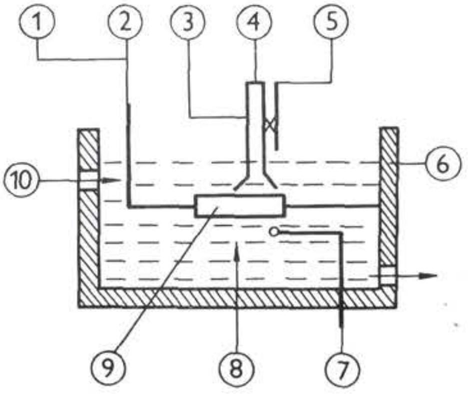

Fig. 1. Layout of the equipment 1 — measuring graphplotter, 2 — converters, 3 — antenna, 4 — microwave generator, 5 — falling and reflected power meter, 6 — thermostatic chamber with solution, 7 — temperature gauge, 8 — stimulator, 9 - muscle, 10 — reservoir with the physiological solution.

The temperature was measured by an electronic thermometer with a low thermal-capacity dot transducer. The error of the measurement did not exceed ±0.1 °C. The experiments were carried out at a wave range of 8 mm and a frequency of 11 MHz. In the microwave region dielectric emitters were used as the irradiation source. At the frequency of 11 MHz, a pair of electrodes was used, one needle-shaped and another plate-shaped, with an area considerably larger than that of the muscle preparation. Emitters and electrodes were submerged in the bathing solution and fixed in immediate proximity to the muscle. During the experiment, the power flow was determined by measuring the decrement in the reflected microwave power; at all the frequencies used the power flow was $5\,mV/cm^2$.

Results

Fig. 2 illustrates power changes of the frog heart muscle tension during irradiation by a nonuniform electromagnetic field. Percentual changes in the tension as compared to pre-irradiation values are plotted. Curve *a* was obtained at 28.26 GHz, curve *b* at 11 MHz.

During the initial irradiation stage, the tension decreased reaching a minimum (−6 %) within 1—2 min. The extent and the duration of the decrease depended on the microwave power flow applied. Both the decrease and its duration were inversely proportional to power flow.

The tension continued decreasing until a thermodynamic equilibrium between the solution and the muscle has been reached. Subsequently the tension began increasing up to a new stationary level; the new stationary level was reached within approximately 10 min.

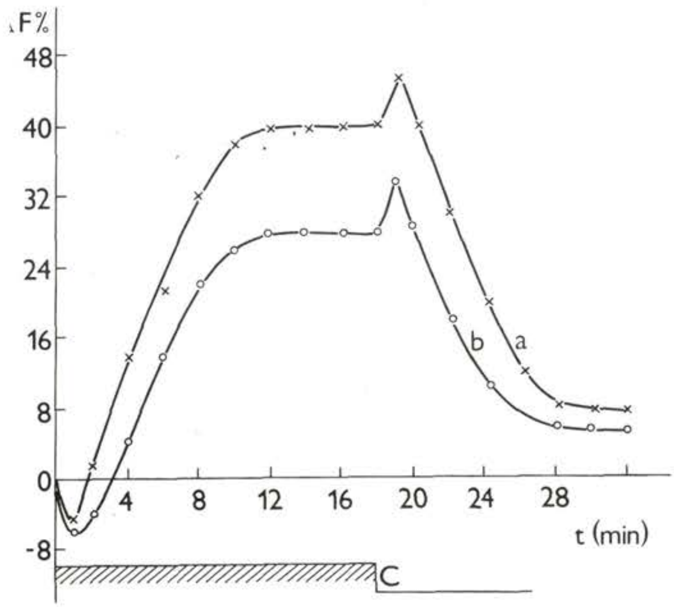

Fig. 2. Tension changes ΔF (in percents of the control values) during irradiation: *a* — at 28.86 GHz, *b* — at 11 MHz, *c* — irradiation time. Power flow $W = 5\,\mathrm{mW/cm^2}$.

Measurements on almost 150 samples showed that the initial level increment made up 20 to 50 per cent.

After the irradiation had been switched off, an additional increase in the tension and a subsequent decrease to initial levels were observed.

The additional increase as well as the initial decrease in tension are associated with changes in the muscle temperature. This follows from a plot shown in Fig. 3; the curve shows the relationship between the tension and muscle temperature. An increase in temperature, e.g. from 17 °C to 18 °C, is followed by an 8—10 % decrease in tension. Cooling thus would result in an increase in tension.

When the muscle was exposed to electromagnetic field of lower frequency (11 MHz), with nonuniformity being produced by a needle-shape electrode, a change in the tension power was also observed (Fig. 2, curve *b*).

In analogous experiments with the muscle fixed between two plates insignificant contraction changes were observed. No change at all could be observed when the preparation was exposed to microwave irradiation using large area horn-type emitters.

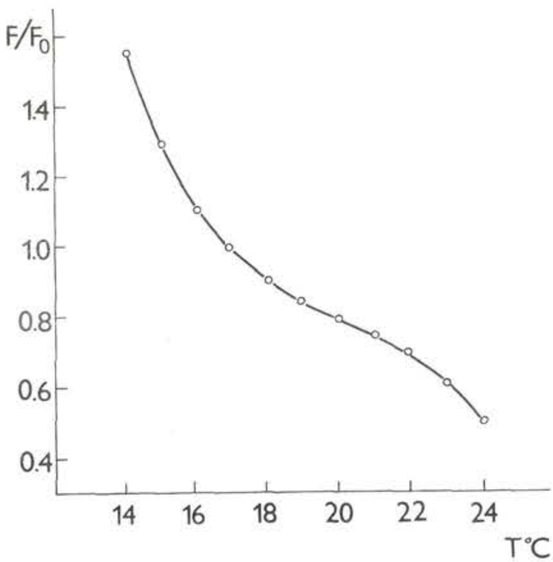

Fig. 3. Temperature-tension relationship. *F/Fo* — tension ratio at a given temperature to the value at 17 °C.

In a series of preliminary measurements at 27—58 GHz and 10—20 MHz, no frequency-tension relationship was observed.

Repeated exposure of the muscle to nonuniform electromagnetic field resulted in identical changes during identical cycles; this could be observed following 10 or more subsequent exposures of a single sample.

Conclusions

Heart muscle cell generates tension following depolarization by action potential. The tension amplitude is a function of intracellular free Ca^{2+} concentration, and it consists of two components (Coraboeuf 1974): a "phasic" one, controlled by the slow inward calcium current, and a slow one, "tonic", controlled by sodium-calcium exchange (Horackova and Vassort 1979). Short-term (transitory) alternations in tension, as shown in the plots (Fig. 2) seem to be due to the effect of temperature on the "phasic" component (Goto et al. 1978).

However, major changes in muscle response to irradiation develop after the temperature regime has been stabilized and these cannot be explained in terms of thermal effects. As the plots show (see Fig. 2 and 3) tension changes are inversly proportional to temperature changes.

The measurements showed that major tension growth could be observed only at high nonuniformity of the electromagnetic field in the vicinity of the muscle preparation.

It is well known that the millimeter irradiation is rather strongly absorbed by water solutions. A local temperature increase may therefore occur due to the microwave energy absorption. This may be enough to produce thermoconvective phenomena (Betskij et al. 1983) occurring at the solution-muscle border, and resulting in enhanced muscle metabolism. On the other hand, a direct influence of the electromagnetic field gradient should also be taken into account. Under the influence of Coulomb forces, ions may move towards the charged surface thus leading to an increased premembrane concentration.

However, the majority of molecules are not charged, though they, as a rule, are dipoles with an electric momentum $p = q \cdot d$, where q is the charge, d is the distance between the dipole charges. Dipoles do not move under the influence of a uniform electric field. In a nonuniform field, the dipole formations will mix intervening into the area of higher voltage whereas the charged ions will only oscillate around the equilibrium. The drawing force will be

$$\vec{F} = \vec{p} \cdot \operatorname{grad} \vec{E}$$

This spatial drift of the dipole formations can stimulate metabolism processes on the muscle surface. We believe that this is one of the possible reasons for the increased contraction power in frog heart under the conditions of irradiation by nonuniform electromagnetic field.

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