Changes in the state of water, induced by radiofrequency electromagnetic fields

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Abstract **Microwave irradiation (f = 36 GHz) changes the properties of distilled water within the first 1–10 min. The new state is retained for at least tens of minutes and manifests itself as changes in power density spectrum of periodic fading voltage fluctuations that are generated during discharge of a capacitor in which water is used as a dielectric. It is assumed that long-term changes in water properties mediate the effect of electromagnetic fields on biological systems.**

Key words: Water; Cluster; Irradiation; Millimeter microwave

1. Introduction

Currently it is believed that electromagnetic fields EMF of nonthermal power – static, or low to high frequency – elicit various effects in biological systems, including changes in Ca^{2+} regulation [1,2], channel activity [3], enzyme activity [4], in RNA and DNA synthesis [5–7] as well as in growth behaviour [7], etc. (for reviews, see [8,9]). Two points deserve particular attention: first, a great diversity of effects induced by electromagnetic radiation, and second, a wide range of frequencies (from 0 to hundreds of GHz) and irradiation power densities (from a few pW/cm^2 to several mW/cm^2) within which these effects are observed. It seems hardly probable that biological systems have special receptors for each type of electromagnetic radiation, which are able to absorb the energy of the field and induce the corresponding response. It is more likely that in many cases, the effect of the field is mediated via some primary receptor, which is capable of absorbing the energy of the electromagnetic field in a wide range of frequencies and inducing one or another response, depending on the object and on its state at the moment of irradiation. Analysis of our own data and the results reported in literature led us to propose that this primary receptor may be water, which plays a unique role in the functioning of biological systems. To verify this proposal, we undertook experiments along two lines. In one set of experiments, we studied the effects of preliminary irradiation of water on the properties of Ca^{2+}-activated K^+ channels in cultured kidney cells (Vero), which have been shown previously by patch-clamp experiments [3] to respond to millimeter electromagnetic radiation by considerable changes in channel open state probability. It was found that replacement of unirradiated water solution by irradiated solution in experimental chamber causes similar qualitative changes in activity of K^+ channels as the irradiation of water solution immediately in the chamber [10]. This finding appeared to be a strong argument for the key role of the water solution in mediating the effect of field.

In experiments of the other line we attempted to choose a physical method that could provide independent and direct support for the hypothesis that the properties of water (not an aqueous solution of biologically important ions) can change in response to irradiation. A method proposed by one of the authors of this paper was used [11]. The method is based on the following experimental fact. A discharge of capacitor in which water or an aqueous solution serves as a dielectric, is accompanied by periodic fading voltage fluctuations the power density spectrum of which characterizes the state of water and depends on the composition of the examined solution. Actually, we are dealing here with the spectrum of the voltage noise component, which is entirely determined by the properties of water as a dielectric and of conducting medium. The origination of these fluctuations in water and aqueous solutions may be attributed to the occurrence of ice-like clusters containing a large number of water molecules [12,13]. In the present paper we showed that the power density spectrum of the fluctuations, which characterizes the state of water, is influenced by millimeter electromagnetic waves, and a new, irradiation-induced, state of water is maintained for at least tens of minutes after termination of irradiation.

2. Materials and methods

Distilled water at 21°C was used. The pH value of water was 6.0.

The diagram of the experimental set-up is presented in Fig. 1. It consists of a measuring unit and a unit for irradiation of samples with millimeter electromagnetic waves.

The measuring unit comprises a rectangular pulse generator an amplifier, a set of active second-order Butterworth filters with a cut-off frequency of 500 Hz, a double-beam oscillograph, an analog-to-digital converter, and a computer.

The experimental cell consists of a polyethylene capillary 1 mm in inner diameter into which gold-plated electrodes are inserted. The interelectrode distance is 2 mm. The volume of water sample in the cell is 15 μl.

The experimental arrangement for irradiation comprises a generator of millimeter electromagnetic radiation and a 7.2 × 3.4 mm waveguide. In the vertical plane of the waveguide, a through channel 1.2 mm in diameter is done into which the experimental cell is placed. Using a sliding plunger set at a free end of the waveguide, the system waveguide-cell is tuned so that the cell is in the antinode of the EMF field. The exposure of samples to millimeter EMF is carried out at a frequency of 36 GHz at two powers, 50 μW and 5 mW. The absorption of radiation power in the cell is approx. 95%. The experimental procedure was as follows. Rectangular unipolar voltage pulses (18 V, 1 ms, duty 1000) were applied from the pulse generator to the cell. The curves of cell capacitance discharges were recorded and summed synchronously to about 50 times. As a result, the signal-to-noise ratio increased 7-fold.

After the registration of the control discharge curve, the cell was exposed to EMF for 10 min. During exposure, the curves of cell capac-

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itance discharge were recorded at 1 and 10 min. To reveal eventual late effects, the curves were taken 20 and 60 min after termination of microwave irradiation.

The curves were then digitized and filtered to remove the exponent. This made it possible to discriminate periodic voltage fluctuations.

Analysis of voltage fluctuations was carried out by using the Fourier transform. The length of data array after digitizing was 1024 points, and that of power spectrum was 512 points. The scale factor of the spectrum was 1.8 Hz per point.

In control experiments, the curves of cell capacitance discharge were recorded at the above indicated times but without EMF exposure.

3. Results and discussion

A typical curve of cell capacitance discharge is presented in Fig. 2A. It is clearly seen that the discharge process is accompanied by periodic fading voltage fluctuations. Fig. 2B shows the same fluctuations after the subtraction of the model exponent from the capacitor discharge curve. The fluctuation amplitude reaches 10–15 mV. Analysis of these data using the Fourier transform gives the power density spectrum for voltage fluctuations on cell electrodes (Fig. 3A,a). Under conditions of these experiments, the spectrum has two distinct bands with the maxima at 5.25 Hz and 46.8 Hz. In the absence of millimeter EMF, the spectrum remains unchanged at least throughout the experiment (1–2 h). However, even after the first minute of irradiating the sample with a 50 μW field, marked changes in the spectrum are observed: the amplitude of the band at 46.8 Hz is sharply reduced, whereas that of the low-frequency band with a maximum at 5.25 Hz increases slightly (Fig. 3A,b). Further irradiation of the sample leads to a nearly complete disappearance of the band at 46.8 Hz by 10 min and some broadening of the band at 5.25 Hz (Fig. 3A,c). By 20 and 60 min after termination of exposure, the spectrum continues to change. In this case, the band at 46.8 Hz is not restored, and the maximum of the low-frequency band shifts from 5.25 Hz to 6.75 Hz (Fig. 3A,d and e).

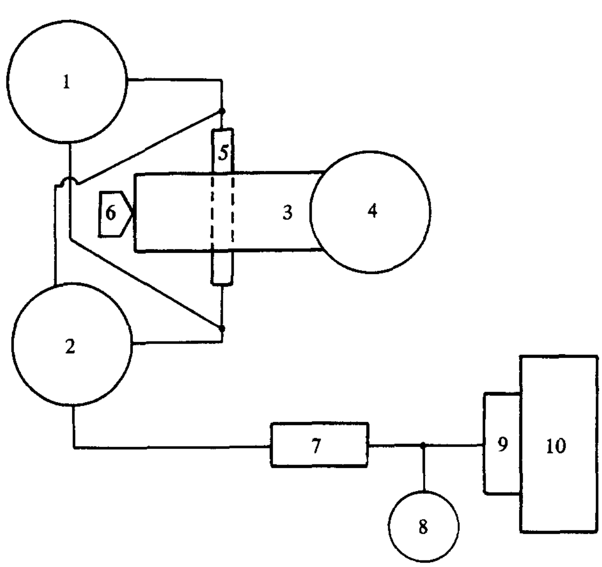

Fig. 1. Block diagram of the experimental set-up. 1, Г5-82 generator of rectangular pulses; 2, у5-10 amplifier; 3, waveguide (7.2 × 3.4 mm); 4, Г4-156 millimeter radiation generator; 5, experimental cell; 6, sliding plunger; 7, filter; 8, CI-55 double-beam oscillograph; 9, analog-to-digital converter; 10, computer.

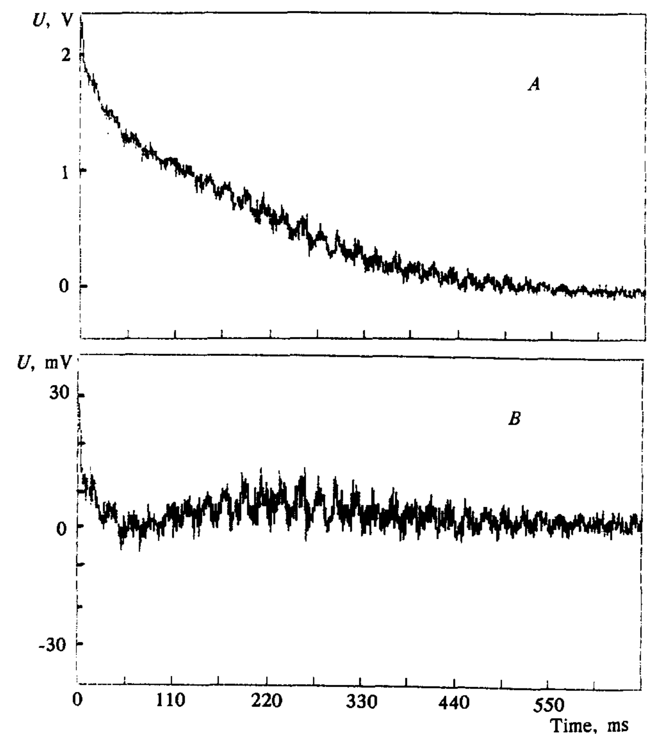

Fig. 2. (A) A curve of cell capacitance discharge; (B) voltage fluctuations on electrodes of experimental cell during capacitance discharge.

One might expect that an increase in power density would accelerate the onset of spectral changes. However, this did not take place. With a generator power of 5 mW, i.e. 100 times as great as in the preceding experiment, the spectrum changed much more slowly (Fig. 3B). Thus, noticeable changes in the band at 46.8 Hz occurred only by 10 min of irradiation. Its complete disappearance was observed by 20 min after the termination of exposure (Fig. 3B,c). As in the preceding experiment, a minor increase in the band at 5.25 Hz was noted. By 60 min, a partial restoration of the band at 46.8 Hz was observed (Fig. 3B,e).

Thus, surprising as it may seem, at a higher radiation power, the spectral changes occur more slowly, and the restoration of the original state of water proceeds much more rapidly.

Whatever the interpretation of the periodic voltage fluctuations on cell electrodes may be, it is very important that the power density spectrum appears to be a parameter that characterizes the state of water. The results of this study indicate that the state of water can be changed by millimeter EMF. It is remarkable that a new, irradiation-induced, state is maintained for an extended time after termination of exposure. This suggests that water possesses a 'structural memory'. It would be more correct to apply the term 'structural memory' in relation to the system water–gases dissolved in water, since it is not ruled out that irradiation changes the concentration of dissolved gases, which in turn leads to changes in water structure. If this is the case, the changes in concentration of gases and in water structure must occur very rapidly, within one or several minutes, as demonstrated by our experiments.

The presented findings suggest that in addition to the well known anomalous properties [14], water has one more unusual feature: it comes in quasi-equilibrium states, the transition be-

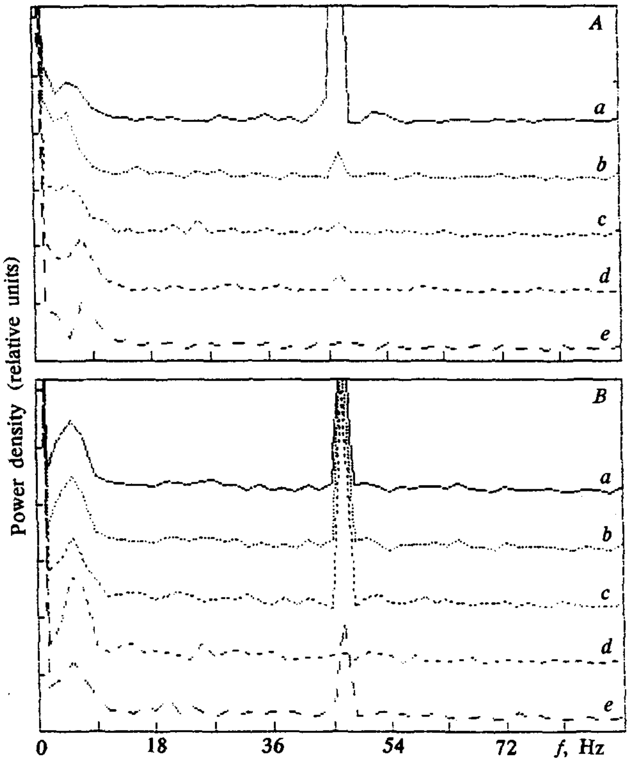

Fig. 3. (A) Power density spectrum of voltage fluctuations on cell electrodes at an EMF power density of 50 μW: a, prior to irradiation; b, 1 min after onset of irradiation; c, 10 min after onset of irradiation; d, 20 min after termination of irradiation; e, 60 min after termination of irradiation. (B) Power density spectrum of voltage fluctuations on cell electrodes at an EMF power density of 5 mW: a, prior to irradiation; b, 1 min after onset of irradiation; c, 10 min after onset of irradiation; d, 20 min after termination of irradiation; e, 60 min after termination of irradiation.

tween which may be triggered by various external factors. Apart from the high-frequency electromagnetic field, such factors may be DC and AC low-frequency magnetic fields, which were reported to change the physical characteristics of water, for example, surface tension, wetting angle and others [15–17]. Unfortunately the research along this line was not continued.

What is the nature of structural distinctions between irradiated and unirradiated water samples? We have no data that could provide an unambiguous answer to this question. It would be tempting to suppose that they differ in size and concentration of water clusters, which probably represent relatively stable structures the equilibrium between which may change under the influence of physical and chemical factors. The idea of clusters in water medium was first advanced in [12] where it was postulated that hydrogen bonding between water molecules is a cooperative process so that the formation of hydrogen bond dimer of two water molecules makes it easier to form additional bonds with other molecules. Based on this assumption, it is easy to explain the appearance of periodic voltage fluctuations in the process of cell capacitance discharge [11]. It is apparent that if clusters do occur and if they can change in response to external agents, this should be of great importance for various biological processes. In the light of the obtained results, it cannot be excluded that water was one of the targets (if not a single) in many experiments in which the effects of magnetic and electromagnetic fields on chemical and biological systems were observed in a wide range of frequencies and intensities. Noteworthy here is the fact that irradiation at 50 μW produces a stronger effect than irradiation at 5 mW. This fact suggests a nonlinearity of internal processes that lead to changes in water state, which seems also to be inherent in some biological effects of electromagnetic waves [9].

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