THE THERMAL EFFECT OF THE SUPERHIGH FREQUENCY ELECTROMAGNETIC FIELD

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As a result of the widespread introduction of radio engineering into the national economy, the human organism has begun to be subjected, not infrequently, to the action of a new stimulus to which it is not accustomed—radio waves. These occupy that portion of the electromagnetic spectrum having waves from millimeters to tens of thousands of meters in length. The part where the waves are shortest— the super-high-frequency region (SHF), covering the band from millimeters to tens of centimeters— has been the least studied. One of the differences between the SHF field and the UHF field is the ability of the former to be concentrated in a directed beam, which can exert its effect at a given distance. The most pronounced effect of the SHF field on the organism is its thermal effect.

Temperature changes in the organism, under the influence of UHF as well as of SHF, have been studied before [1, 2, 3, 4, 5, etc.] but without taking the intensity of the action into account, so that it is difficult to compare the results so obtained. Several investigations [6, 7, 8, etc.], and also our own data (1955-1957) indicate that the temperature increase under the influence of these waves depends on their length, on the time and intensity of irradiation, and on electrical and thermal constants.

In the present study, data are presented on the characteristics of the temperature rise in certain types of animals under the influence of the SHF field which will be of definite interest for the clarification of the mechanism of its thermal action and for working out the doses for the use of microwaves as a therapeutic agent, and also for the solution of certain professional problems of preventive medicine.

To accomplish this task, thermometry was carried out at points directly within the SHF field on dogs, cats, rabbits, rats, and frogs (170 animals in all). Temperature was recorded with the aid of an EPP-09 potentiometer, with Chromel-Copel needle thermocouples.

In this work, allowance was made for the special features of the arrangement of thermocouples perpendicularly to the direction of the electric field vector E [4]. Instrumental measurements of radiation intensity were carried out by engineers.

EXPERIMENTAL RESULTS

In an investigation of the thermal effect of the SHF field at an energy flux of 0.1-0.3 watt/cm^2, the rectal temperature increased more markedly and more abruptly in small animals than in large ones (Fig. 1).

In small animals, the rectal temperature began to rise at the beginning of irradiation; in larger animals, after 1-5 minutes or more, depending on their size.

The character of the warming curve also depended on the energy flux: with reduction in radiation intensity, a decrease in the temperature rise was observed. In the rat, for example, at an energy flux of 0.1 watt/cm^2, the magnitude of the increase in rectal temperature was less than in a field of greater intensity (Fig. 2). The time required for the temperature to return to the initial level after irradiation is stopped also depends on the dimensions of the animal. The temperature curves followed the law of ascending (in warming) and descending (in cooling) exponentials.

When different animals were irradiated in fields of different intensity, the survival time was not the same. Thus, at an energy flux of 0.3-0.2 watt/cm^2, the rats died after 12 minutes, on the average; rabbits, after 25-35 minutes; cats, after 45-60 minutes. Under these conditions, a large dog still remained alive even after 2 hours.

At lower intensities of radiation, the survival time of the animals was correspondingly prolonged.

In all types of experimental animals, no rise in rectal temperature was observed at an energy flux of 0.01 watt/cm^2 (Table 1).

From data on the distribution of heating according to depth, one can form an idea of the mechanism of action of waves of different lengths.

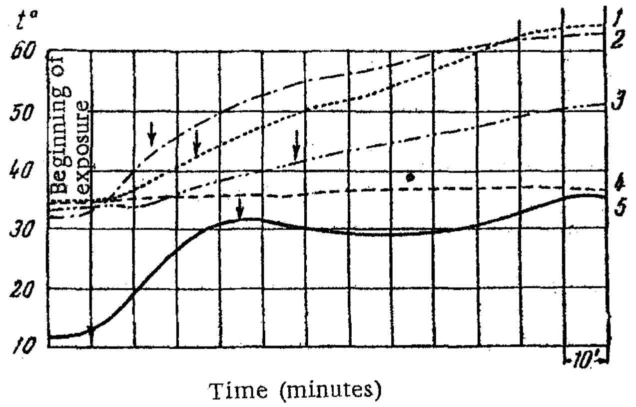

Fig. 1. Variation in rectal temperature of different animals. 1) Rabbit; 2) rat; 3) cat; 4) dog; 5) frog.

In dogs, cats, rabbits, and rats, the greatest temperature rise was observed under the skin; for example, at the time of death of a rat in an intense field (energy flux 0.3 watt/cm^2), the subcutaneous temperature was 46-50°. Thus, the temperature rose 10-14°. The increase in temperature began simultaneously with irradiation and was considerably greater than the rise in rectal temperature. In dogs, the temperature under the skin rose 3.5° (while the rectal temperature rose 1.5°).

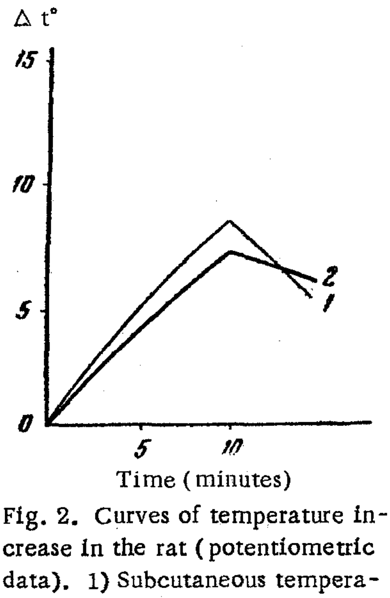

Fig. 2. Curves of temperature increase in the rat (potentiometric data). 1) Subcutaneous temperature; 2) rectal temperature.

With reduction in radiation intensity the subcutaneous warming decreased (see Fig. 2); even in rats, it was not observed at an energy flux of 0.01 watt/cm^2.

Deep in the thigh muscle and in the brain of the rabbit at a depth of 1-1.5 cm, during irradiation in an SHF field (energy flux 0.3 watt/cm^2) the rise in temperature did not begin immediately, but 1-3 minutes after the beginning of irradiation, and reached 7.6° (Table 2).

Thus with equal energy fluxes and irradiation time, the energy entering per unit weight is less in the large and greater in the small animal. In large animals, more superficial warming was observed. This is related to the fact that the vital organs in larger animals are more deeply situated and are consequently less strongly heated than in small animals. This also determines the degree of overheating, in a certain measure, and the times of death. The total heating of the body of the animal is determined by the wavelength of the SHF field; on account of heat conduction and circulation of the blood, heat is carried from parts of the body heated more to those heated less. The circulation simultaneously plays the role both of a warming and of a cooling factor. In view of the fact that under irradiation in an SHF field warming takes place unequally, the role of the circulation, along with heat conduction, probably predetermines the ultimate magnitude of the general overheating, and, therefore, the death of small animals as well.

TABLE 1

Dependence of Rectal Temperature in Various Kinds of Animals on Energy Flux and Exposure Time

Energy flux in watt/cm²	Dog	Cat		Rabbit		Rat	
	temperature rise after 2 hours	exposure time in minutes	temperature rise	exposure time in minutes	temperature rise	exposure time in minutes	temperature rise
0,2—0,3	1,5°	60	7,0°	25	7,5°	12	10,0°
0,05—0,1	0,5°	120	6,0°	120	6,6°	19	7,8°
0,02—0,04	0°	120	1,2°	120	1,5°	120	3,4°
0,01	0°	120	0	120	0°	120	0

One of the important factors causing a difference in the extent of temperature increase in individual types of animals is the efficiency of temperature regulation by the nervous system. Thus, when exposed to an SHF field (energy flux 0.05 watt/cm²) that will cause the death of a rabbit after 1-1½ hours, with 6° of overheating, a cat of the same weight dies after a 2-hour exposure, and a dog (of approximately the same weight) generally does not die.

TABLE 2

Dependence of Temperature in Rabbit Organs on Energy Flux, and Survival Time in Exposure to SHF Field

Energy flux in watt/cm²	Temperature				Exposure time in minutes
	rectal	in muscle	in brain	subcutaneous	
0,2—0,3	7,5°	7,6°	7,6°	12,5°	35 (died)
0,1—0,05	6,6°	7,0°	7,1°	8,1°	115 »
0,02—0,04	1,5°	1,5°	—	2,5°	420 (survived)
0,01	—	—	—	—	420 » »

In spite of the fact that dogs can be irradiated longer than other animals, exposure cannot be considered harmless even for them. Maintenance of body temperature at an approximately normal level under such conditions requires considerable effort on the part of the neuroregulatory apparatus, which, under prolonged and repeated exposures, may be not without consequences for the organism. Evidence for this is found in our investigations of cardiac activity by the electrocardiographic method [8], and the studies of other authors.

The data obtained permit us to divide the effects of the SHF field into thermal and extrathermal effects. The thermal action in turn can be divided (for small animals, including cats) into lethal effects, leading to death of the animals after a certain period of exposure (up to 2 hours at an energy flux of 0.05 watt/cm²), and sublethal effects, which do not cause death of the animals even after a longer period and are at a lower radiation intensity.

We regard as "extrathermal conditions" the maximum energy flux at which prolonged exposure (more than 2 hours) causes neither general nor local increase in temperature, as far as can be detected by methods available to us. This limit occurs at an energy flux of 0.01 watt/cm^2; respiration, blood pressure, and cardiac rhythm are not noticeably altered under these conditions [6].

This limit varies depending on the size of the animal: for large animals (dog) it lies within the limits stated above; for small animals it is somewhat lower.

SUMMARY

Rectal and subcutaneous temperatures were studied in experiments on 170 animals—dogs, cats, rabbits, rats, and frogs—by the method of continuous thermometry in super-high-frequency electromagnetic fields of different intensities. In addition, thermometry was carried out in muscles and brain of rabbits. The survival time of various animals was determined, as well as the temperature increase. The characteristics of heating and cooling were investigated. The temperature curves followed the law of ascending and descending exponentials in heating and cooling, respectively. The heating effect was greatest in the subcutaneous tissue, less in the brain and deep in the muscles of the thigh, and even less in the rectum. The thermal effect, in the super-high-frequency field, depends on the energy flux, the exposure time, and the size and species of the animal. The lower limit of the "thermal conditions" which cause the death of small animals, including cats (lethal effect), is 0.05 watt/cm^2. The lower limit of the "thermal conditions", at which there is no heating effect on tissues, is 0.01 watt/cm^2.

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