Presented at: International Microwave Power Institute (IMPI) 1977
Symposium, Minneapolis, Minnesota, May 24-7, 1977

Glaser

BIOLOGICAL EFFECTS OF ~~SHORT-TERM INFLUENCE OF~~ Short Exposure to MICROWAVE LOW-INTENSITY ELECTROMAGNETIC FIELDS

M.G.Shandala, Yu.D.Doumanski, A.M.Serdjuk, N.G.Nikitina,
I.P.Los, L.K.Ershova, L.A.Tomashevskaya

Kiev Research Institute of General and Communal Hygiene,
USSR

The development of the modern science and technology is inseparably linked with the application of the technological process devices utilizing the energy of electromagnetic waves. At the present time, as we already know, technological devices and equipment, whose principle of operation is based on the use of the energy of microwave electromagnetic field are widely applied in many fields of industry, everyday life and medicine. This resulted in the fact that the human being became more and more often subjected to the influence of the microwave electromagnetic field. In this connection the investigators in various countries of the world are becoming interested in the problem of deciding how important is the influence of this factor on a human organism, and what are its consequences. This problem, in spite of a considerable number of publications in the world literature, remains an urgent problem right up to the present moment.

Our report deals with the study of the biological effect of the low-intensity microwaves at a relative short-term exposure.

In order to determine the bioeffects of the microwaves we have carried out experimental researches on animals. A magnetron oscillator, operating on a 2370 mHz frequency, has been used as the

microwave source. The value of the energy flux density (EFD) has been monitored with the help of the instrument "MEDIC-1" (МЕДИК-I). The experiment consisted of two series of investigations on various species of animals: series I on 175 young unisexual (male) white rats and series II on 42 rabbits. The animals in the first series of investigations were subjected, in the course of four months and in the second series in the course of two months, to the influence of microwaves with intensities of 1000, 500, 100, 50, 25 and 10 $\mu W/cm^2$, daily for 40 minutes three times a day with a 3 hour interval between the influencing action. The irradiation of the animals was carried out in special echoless chambers, which permitted to create a uniform distribution of the electromagnetic field. After the influencing action (irradiation) the animals remained under observation for two months with the aim of studying the recovery period.

The results of the observations showed that the influencing factor of the microwaves during the first days of irradiation (10 to 14 days) was accompanied by a certain change in the general condition of the organism. It was observed that within this period the animals of the first and second groups, where the EFD was respectively 1000 and 500 $\mu W/cm^2$, had an enhanced motor activity which later on disappeared. After 2 months of the factor influence the first group of animals developed conjunctivities and spots of local baldness appeared on the skin coats of several rats, six of them lost the usual shine.

The animals of other groups, where the microwave EFD was equal to 100-10 $\mu W/cm^2$, in the course of the experiment showed a usual activity, not reacting externally to the factor effect and their behaviour did not differ in any way from the behaviour of

the check group animals.

Analysing the dynamics of the weight of the animals it became possible to determine definite changes in this characteristic. The weight of the Ist group animals (EFD equal to 1000 $\mu W/cm^2$) within the entire period of the microwave effect, exceeded the weight of the check group animals by 50%. In the after effect period these relationships were 30% and 10% (correspondingly with the month). The weight of the 2nd group animals (EFD equal to 500 $\mu W/cm^2$) in the course of the first two months of the factor influence did not substantially differ from the weight of the check group animals. However, after 3 months of the experiment the animals of this group had considerably gained in weight - the incremental weight was 30% higher than that of the check group white rats. After a two months recovery period the weight values of the 2nd group of animals were similar to the check group values. As to the other animal groups changes in this characteristic were not revealed.

A study was conducted of the state of the muscular efficiency, by swimming, to determine the character of the microwave effect on the general state of the animal organisms.

The most expressed changes in this characteristic were observed for the animals of groups I-III (FED from 1000 to 100 $\mu W/cm^2$) were marked by a substantial reduction of the average swimming time from the first month of the experiment. Changes in the endurance for the animals of groups IV-V (EFD from 50 to 25 $\mu W/cm^2$) were noticed after two months of irradiation, the reduction in the degree of endurance is less acute. The level of the efficiency of the animals which were subjected to the effects of the microwaves at the EFD equal to 10 $\mu W/cm^2$ (group IV) remained stable, as a whole, during the entire period of the experiment and was equal to the

level of the efficiency of the check group animals. The results of these studies make it possible to determine the influence of the electromagnetic energy on the efficiency and the motor activity of the animals, the dependence of the expressiveness of the biological effect on the irradiation intensity.

The obtained data of the general condition of the organism and the dynamics of the weight and the state of efficiency give a reason to assume that the change in these characteristics of the organism is the result of the functional disturbances of the central nervous system and of some of the metabolic processes of the organism.

In order to determine this, the investigations were carried out of the bioelectrical activity of the cerebral cortex of 42 rabbits. The results of these investigations showed that the changes in the electrical activity in the studied brain areas appeared in different periods depending on the intensity of the field. Thus, the authentic changes in the electrocephalogram of the rabbits at the EFD from 1000 to 500 $\mu W/cm^2$ were observed after 1 to 1 1/2 month of the factor influence and were characterized by the increase in the alpha-rhythm indices, in the main, at the expense of the oppression of the slow potentials. The biocurrent activation in the occipital area occurred somewhat earlier and was of a more expressed and diverse character. During the application of the functional load (at the flash of a photostimulator of 5; 8 and 12 Hz) a well expressed reaction of the assimilation of the light flickering rhythm was observed in the motor and visual area of the cortex. The authentic changes in the encephalogram of rabbits at 100 to 50 $\mu W/cm^2$ were revealed only in the visual area after 2 months of irradiation. At this time the index of the fast

potentials increased by 30 to 40% (22.8 against 17.5 of the background) and of the slow ones it dropped by 19.7% (30.2 against 34.6 of the background). The duration of the restoration of electrical activity shifts of the cerebral cortex of animals depended on the value of microwave EFD and varied within 2 weeks and one month. The effect of the microwaves at 25 and 10 $\mu W/cm^2$ under our conditions did not cause any change in the bioelectrical activity of the sensomotor and the visual area of the cerebral cortex of animals.

The given data make it possible to mark an increase in the excitation of the cerebral cortex cells of rabbits under the effect of microwaves of 1000 to 500 $\mu W/cm^2$ and the improvement of the assimilation of the reaction of the light flickering rhythm of all the studied frequencies - the increase in the lability i.e. functional mobility of the nervous system centres. The unequal expression of the reactions on the influencing action of the microwaves of the sensomotor and the visual areas of the cortex characterizes the functional heterogeneity of various structures of the cerebral cortex.

In order to solve the problem of the state of hemodynamics of the experimental animals, investigations were carried out on the cardiac output by registering the electrocardiogram (ECG) in three standard leads.

A change in the characteristics being registered has been established (shortening of interval R-R, reduction in the PQ duration after carrying out an orthostatic test, increase in wave P amplitude, and tendency for the decrease in wave T) after one month effect of the EFD of 1000 to 500 $\mu W/cm^2$. After a two months irradiation at the EFD of 1000 to 500 $\mu W/cm^2$ the electrocardiographic in-

dices revealed a sufficiently stable picture of the change in the R-R interval in the direction of its shortening, decrease and widening of wave T of the ventricular complex, increase in wave P. In the ECG of animals undergoing irradiation for one month at the EFD of 100 to 50 $\mu W/cm^2$, a tendency was observed for the increase in the cardial rhythm frequency and shortening of the R-R interval. After two months of the factor effect a slowing down of the pulse and an increase of the R-R interval, reduction in wave P and increase in wave T, a change in segment ST and its shifting higher than the isoline with a convexity towards the bottom were noted in the ECG. No changes in the ECG indices were noted for the animals which remained under the effect of the EFD of 25 to 10 $\mu W/cm^2$. All the electrocardiographic parameters of the cardiac output in the course of the entire experiment varied within the initial data. Changes in the wave height and the duration of the intervals were noted at the preservation of the basic proportions of the ECG and were not authentic.

During the recovery period of the I and II group animals (EFD of 1000 to 500 $\mu W/cm^2$) the electrocardiographic indices characterized the state of the animals, as a symphathocomplex, and of the III and IV group animals (EFD of 100 to 50 $\mu W/cm^2$) - the return of the initial indices of the background record. In some cases a tendency was noted towards bradycardia.

Thus, the effect of the microwaves at 1000 to 50 $\mu W/cm^2$ has a very little influence on the cardiovascular system changing its reactivity. These reactions depend on the intensity and duration of the irradiation and reflect different stages of the adaptive reorganization of the organism.

Taking into account that in our experimental investigations

definite changes have been revealed with regard to the nervous system we have tried to determine the activity of the blood cholinesterase whose physiological role is tightly linked with the activity of the central nervous system.

The results of the investigations indicated that the microwave electromagnetic field at the RFD from 1000 to 500 $\mu W/cm^2$ under conditions of our experiment produces an inhibiting effect on the activity of the cholinesterase of the blood of test animals (Table 1). The normalization of the cholinesterase activity was observed 2 months following the after effect. The action of the microwaves at the EFD of 100 $\mu W/cm^2$ produced a cholinesterase activation after two months of irradiation. However, during a further irradiation deviations of the cholinesterase activity from the check values were not noted.

Proceeding from the obtained data, it is possible to suppose that the decrease in the cholinesterase activity causes a disturbance in the biochemical reactions ensuring a normal progress of the nervous process in the organisms of animals.

The most complete and fine adaptation of the organism to the changes in the external medium provides complex and multiform ways of the regulation of carbohydrate, protein and other types of metabolism. The disturbance of the protein metabolism under the influence of microwaves may substantially affect also the carbohydrate metabolism since the proteins take part in the energy metabolism both of direct oxidation of the nitroget-free remains of the amino acids and as a source of carbohydrates.

The microwave effect on the carbohydrate metabolism was evaluated by the quantitative content of glucose in the blood, glycogen and lactic acid in the organs as well as the activity of the

phosphorylase ferment in the ionoplasms of the liver and brain tissues; on the condition of the protein metabolism - by the quantitative content of the metabolism end product - the urea and the sum of all the nitrogenic fractions of the blood (except the protein fraction nitrogen), called the residual nitrogen.

Table 1

Activity of Cholinesterase in the Blood (μg/min) of Animals under the Microwave Effect

EFD, $\mu W/cm^2$	Statistical criteria	Prior to irradiation	In irradiation period, months				In the recovery period, months	
			1	2	3	4	1	2
1000	M±m	164.2 ±3.0	167.4 ±2.03	177.9 ±3.78	121.4 ±5.59	125.5 ±5.43	130.0 ±2.0	152.0 ±4.7
	P		>0.05	<0.05	<0.01	<0.01	<0.01	>0.05
100	M±m	164.4 ±1.43	167.4 ±1.68	176.4 ±1.98	165.4 ±6.2	168.1 ±1.8	168.0 ±1.9	168.1 ±1.8
	P		>0.05	<0.05	>0.05	>0.05	>0.05	>0.05
10	M±m	162.1 ±1.59	162.1 ±1.59	163.3 ±3.57	164.6 ±3.57	165.0 ±3.9	168.4 ±4.6	165.4 ±5.3
	P		>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
0	M±m	162.1 ±1.32	165.1 ±1.85	165.1 ±3.84	167.1 ±3.44	165.0 ±2.9	163.2 ±3.1	164.5 ±2.8

The results of our investigations showed that the change in the content of glucose in the blood was revealed only in animals of groups I and II (EFD of 1000 to 500 $\mu W/cm^2$) but to the statistically significant values only after three months of irradiation. One

month after the factor effect stopped the content of glucose approached the check level.

It should be noted that simultaneously with this during the microwave effect at the EFD of 1000 to 100 $\mu W/cm^2$ an authentic reduction in the content of glycogen in the liver and brain was observed together with the increase in the content of the lactic acid in the liver tissue and at the EFD of 1000 to 500 $\mu W/cm^2$ an increase was noted in the activity of the phosphorylase (Table 2).

The mentioned violations of the carbohydrate metabolism in the liver tissue limit ihs energy resources and may by one of the functional disorders during the microwave effect.

The investigations conducted by us on the protein metabolism showed that at the EFD effect of 1000 to 100 $\mu W/cm^2$ an increase in the content of the urea was observed after 3 months of exposure. Only 2 months after the effect stopped the level of urea approached the check values. The influencing action of the microwaves at the EFD of 50 $\mu W/cm^2$ and lower did not show any effect on the content of the urea in the blood of the test animals.

Similar changes were obtained when determining the residual nitrogen in the blood.

Consequently, on the basis of the obtained results it is possible to ascertain definite changes with regard to the protein metabolism during the effect of the microwave electromagnetic field at the EFD from 1000 to 100 $\mu W/cm^2$.

Table 2

Indices of the Glycogenolysis in the Liver and Brain Tissues of Rats under the Effect of Microwaves

Field intensity, $\mu W/cm^2$	Statistical criteria	Glycogen, mg %		Activity of phosphorylase, mg %		Lactic acid, mg %	
		liver	brain	liver	brain	liver	brain
1000	M±m	705.0 ±42.3	68.5 ±12.3	118.7 ±7.9	80.5 ±6.9	40.5 ±3.8	47.8 ±4.1
	P	<0.05	<0.05	<0.05	<0.05	<0.05	>0.05
100	M±m	712.0 ±84.5	70.0 ±9.56	120.4 ±8.2	82.4 ±6.7	37.4 ±3.1	44.2 ±3.8
	P	<0.05	<0.05	<0.05	<0.05	<0.05	>0.05
50	M±m	965.0 ±78.2	72.2 ±21.5	114.7 ±7.4	70.6 ±5.2	30.8 ±3.7	45.6 ±2.7
	P	>0.05	>0.05	<0.05	>0.05	>0.05	>0.05
Check	M±m	1050.0 ±86.4	102.0 ±10.2	87.5 ±7.12	60.78 ±6.8	26.8 ±3.0	42.2 ±3.8

The biological effect of the microwave electromagnetic field, as well as of any other external medium factor, rendering a definite influence on the vital activity of the organism, cannot be sufficiently fully characterized without taking into account its influence on the sympatheticoadrenal system of the organism. The effect of the electromagnetic field causes hormonal shifts in the organism and the stimulation of the sympatheticoadrenal system.

Taking into account the extremely important value of the oxidizing ferment of the ceruloplasmin catalysing the oxidation of the adrenalin, norepinephrine, histamin and serotonin and the pre-

ferable value of the adrenergic structures of the central nervous system in the regulation of the content of the metaloferments, an investigation was carried out of the activity of the ceruloplasmin and the saturation of the transferrin with iron. The obtained results (Table 3) testify to the decrease in the activity of the ceruloplasmin at the EFD effect of 1000 to 100 $\mu W/cm^2$ in the course of the entire period of irradiation (4 months). In group IV where the EFD is 50 $\mu W/cm^2$, the decrease in the activity of the ferment has been marked after 4 months of the effect and in the other groups (EFD 25 to 10 $\mu W/cm^2$) no change in the indices has been revealed. The saturation of the transferrin with iron of the blood serum has statistically authentically increased at the irradiation with the EFD field from 1000 to 50 $\mu W/cm^2$.

Thus, the revealed during the microwave effect reduction of the ceruloplasmin in the blood serum of the animals and the saturation of the transferrin testifies that this factor, apparently affects the redistribution of the microelements between the organs and the tissue. This should be considered as the protective reaction of the organism directed at the normalization of the disturbed metabolical processes.

The biological experiment has been completed by the pathomorphological and histochemical investigations. With the aid of the general pathomorphological methods of the study of the brain, liver and heart tissues the disturbances of the hemo- and lymphodynamics were revealed and rarely perivascular edems and microfocus infiltration of the hyperchromic lymphocytes. These changes were determined in animals at the EFD of 1000 to 25 $\mu W/cm^2$. The degree of their expressiveness was in direct dependence on the intensity of the electromagnetic field.

Table 3

Activity of Ceruloplasmin and Saturation with Iron of Blood Serum Transferrin of Rats During the Microwave Effect

Characteristics	EFD, $\mu W/cm^2$	Statistical criteria	In irradiation period, months		Two months after irradiation
			1	4	
Ceruloplasmin, nominal unit		M ± m	38.2 ±2.1	31.7 ±1.92	54.1 ±1.4
	1000	P	<0.01	<0.01	>0.05
	100	M ± m	43.4 ±1.7	41.6 ±1.8	50.3 ±1.5
		P	<0.02	<0.01	>0.05
	10	M ± m	50.7 ±1.75	52.4 ±1.7	51.3 ±1.65
		P	>0.05	>0.05	>0.05
	check	M ± m	53.2 ±1.7	54.8 ±1.4	50.6 ±2.85
Transferrin, nominal unit	1000	M ± m	0.31 ±0.03	0.30 ±0.02	0.23 ±0.02
		P	<0.01	<0.01	>0.05
	100	M ± m	0.3 ±0.02	0.3 ±0.03	0.21 ±0.01
		P	<0.01	<0.01	>0.05
	10	M ± m	0.21 ±0.01	0.21 ±0.015	0.22 ±0.01
		P	>0.05	>0.05	>0.05
	check	M ± m	0.22 ±0.01	0.20 ±0.015	0.21 ±0.01

After conducting the investigation it became possible to ascertain that the microwave electromagnetic field even of a low-intensity, counted in microwatts per square centimeter (1000 to 100 $\mu W/cm^2$) at a comparatively low exposure, causes notable changes with regard to the general state, nervous and cardiovascular system and some metabolic processes of the organism of test animals.