JPRS L/10514

12 May 1982

USSR Report

LIFE SCIENCES

EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

(FOUO 1/82)

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APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000500060027-1

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CONTENTS

UDC 538.6:611.81

ACUTE EXPERIMENTAL EMOTIONAL STRESS IN RABBITS UNDER CONDITIONS OF MODULATED ELECTROMAGNETIC FIELD

Moscow IZVESTIYA AKADEMII NAUK SSSR: SERIYA BIOLOGICHESKAYA in Russian No 5, Sep-Oct 81 (manuscript received 10 Jul 80) pp 774-780

/Article by A. V. Gorbunova, N. V. Petrova, V. V. Portugalov and S. K. Sudakov, Institute of Normal Physiology imeni P. K. Anokhin, Moscow/

/Text/ The effect of a modulated electromagnetic field on the course of acute emotional stress induced by intermittent and combined stimulation with an electric current of ventromedian nuclei of the hypothalamus and of the skin of limbs and ears of Chinchilla-line male rabbits was studied. The content of water soluble proteins was determined according to Lowry in the extramural ganglia of the autonomous nervous system and in sympathetic trunk ganglia at the level of the fourth to sixth thoracic segments. The spectrum of lactate dehydrogenase isoenzymes was determined in those locations, as well as in the cardiac conductive system. It was shown that the number of rabbits pertaining to the group of rabbits predisposed to the development of stress in the modulated electromagnetic field decreased. There was no significant decrease in the content of water-soluble proteins, which occurs under emotional stress, when rabbits in a state of stress were placed in the modulated electromagnetic field. On the contrary, their content increased significantly. The existing tendency toward increased aerobic metabolism in the cardiac conductive system under emotional stress was not manifested in the modulated electromagnetic field. The activity of fast-moving lactate dehydrogenase fractions slightly increased in the superior cervical, stellate and nodose ganglia in rabbits in a state of emotional stress placed in the modulated electromagnetic field. In the immobilized intact rabbits in the modulated electromagnetic field the content of water-soluble proteins increased significantly and the activity of fast-moving lactate dehydrogenase fractions in all the studied formations of the nervous system increased slightly.

The effect of a modulated electromagnetic field leads to complex changes in cortical-subcortical relations in animals, selectively stimulating limbic structures and suppressing the ascending activating effects of the reticular formation of the stem on the cerebral cortex /1/. It is well known that a modulated electromagnetic field of certain parameters can change vegetative reactions and self-stimulation reactions arising during an electric stimulation of emotion-producing zones of the hypothalamus /2/. There are indications of a positive effect of electromagnetic fields on the course of cardiovascular disturbances of various origins /3, 6/. A dissimilar effect of electromagnetic fields with different modulation frequencies was established. It turned out that modulated electromagnetic fields with a modulation frequency of 7 Hz had the greatest biological activity (4, 13 and 14).

Direct electric stimulation of ventromedian nuclei of the hypothalamus alternating with electrocutaneous stimulation induces acute emotional stress characterized by individual changes in cardiovascular functions in rabbits /9/.

Taking into consideration the effect of a modulated electromagnetic field on reactions connected with the stimulation of hypothalamic structures, an attempt was made to clarify the effect of a modulated electromagnetic field on the course of acute emotional stress induced by intermittent and combined stimulation of ventromedian nuclei of the hypothalamus and electrocutaneous stimulation. Solving the question of the possibility of increasing the resistance of animals to acute experimental emotional stress by means of a physical factor, which a modulated electromagnetic field is, and clarifying the nature of the response of the structures of the autonomous nervous system to it were the basic tasks of this investigation.

Material and Methods

The experiments were conducted on 86 Chinchilla-line male rabbits weighing 2.5 kg. Nichrome bipolar electrodes were inserted in ventromedian nuclei of the hypothalamus of 66 experimental animals fixed in a special machine tool.

The development of emotional stress was induced by combined or intermittent stimulation with an electric current of the nuclei of the hypothalamus and of the skin of limbs and ears of rabbits. The experimental conditions were described in the article by A. V. Gorbunova and coauthors /8/. Thirty-three rabbits in a state of emotional stress were placed in a modulated electromagnetic field for 3 hours, while the electric stimulation was continued. To clarify the nature of the effect of immobilization on cardiovascular functions, 10 animals were immobilized and the arterial pressure and cardiac rate were recorded for 3 hours. The 10 immobilized animals were placed in a modulated electromagnetic field for 3 hours and then subjected to a biochemical investigation. Fourteen rabbits kept in a vivarium served as control.

The modulated electromagnetic field had a voltage of 30 V/m, carrier frequency of 39 mHz, modulation frequency of 7 Hz and modulation depth of 80 percent. The field was created between two capacitor plates connected with an ultra-high frequency generator. The immobilized animals were placed between the plates so that the sagittal body line was horizontal and perpendicular to the power lines of the modulated electromagnetic field.

The content of water-soluble proteins was determined according to Lowry and coauthors in the nodose ganglion of the vagus nerve, superior cervical and stellate ganglia, sympathetic ganglia and sympathetic trunk ganglia at the level of the fourth to sixth thoracic segments. The spectrum of lactate dehydrogenase isoenzymes was investigated in the ganglia of the autonomous nervous system and the cardiac conductive system isolated according to M. N. Umovist and A. F. Sinev /10/. The results obtained were processed statistically according to Van-der-Verden's nonparametric criterion /5/ and Student's significance criterion.

Results and Discussion

Three groups with characteristic changes in the arterial pressure are detected in acute experimental emotional stress induced by stimulation with an electric current of ventromedian ganglia of the hypothalamus. Animals whose arterial pressure remains at the initial level during the 3-hour experiment form the first group. Either a decrease or increase in the arterial pressure is observed in (adaptable) rabbits of the second group. However, these changes are not accompanied by the death of animals. The third group includes rabbits predisposed to the development of stress, which died during different times of the 3-hour effect [9].

Under the conditions of a modulated electromagnetic field under emotional stress there are no qualitative shifts in the reactions of the arterial pressure, but there is a significant change in the correlation of the number of animals of specific groups (table 1). The number of animals resistant to changes in the arterial pressure under the effect of a stress producing factor increases 2.7-fold. The number of adaptable animals under the conditions of a modulated electromagnetic field also increases 1.6-fold as a result of an increase in the number of rabbits with a falling arterial pressure during the experiment. The number of rabbits with hypertensive reactions kept in the modulated electromagnetic field during stress is reduced by a factor of 2.5. The total number of animals, which died in the modulated electromagnetic field during emotional stress, proved to be 1.9 times lower than under "pure" stress. In other words, the stay of animals in a state of emotional stress in a modulated electromagnetic field greatly increases the resistance of their cardiovascular functions.

Table 1. Number of Rabbits of Various Groups Under Emotional Stress and Stress+ a Modulated Electromagnetic Field

Type of cardiovascular Reaction	Emotional Stress	Emotional Stress+Modulated Electromagnetic Field
Resistant	3	8
Adaptable:		
with lowered arterial pressure	4	12
with elevated arterial pressure	5	2
Predisposed	21	11

The placement of rabbits in a state of emotional stress in the modulated electromagnetic field led to a significant increase in the content of water-soluble proteins in the homogenates of the nodose ganglion. In the homogenates of the superior cervical ganglion the content of water-soluble proteins did not differ from control and in the homogenates of the sympathetic trunk and the stellate ganglion it was higher. At the same time, the content of water-soluble proteins in the superior cervical and stellate ganglia and the sympathetic trunk did not differ significantly (table 2).

The fact that these changes slightly differ from each other in various groups of rabbits is of great interest. For example, a decrease in water-soluble proteins (figure 1) was observed in rabbits from the group of animals predisposed to the development of stress, in the homogenates of the nodose--sensitive--parasympathetic ganglion, whereas in resistant (figure 2) and more adaptable animals there was an increase in the content of water-soluble proteins as compared with control (figure 3).

Significant changes in the arterial pressure and the cardiac rate were not detected in the immobilized rabbits during 3 hours of observation.

Table 2. Content of Water-Soluble Proteins in Ganglia of the Autonomous Nervous System, μg/mg of Raw Tissue

	Объект исследования (1)	КВ (2)	ЭС (3)	X_1	ЭС+МЭМП (4)	X_1	ИМ+МЭМП (5)	X_1
(6)	Верхний шейный ганглий	48	48		46		58*	3,33
(7)	Звездчатый ганглий	43	50*	3,29	49*	4,25	51	1,55
(8)	Симпатическая цепочка	33	41	2,12	44*	4,65	38*	3,07
	Узловатый ганглий (9)	45	36*	3,63	55*	4,47	68*	2,87
	Число животных (10)	12	7	3,24	11		5	
	X_0					4,18		2,72

Key:

1. Object of investigation
2. Vivarian control
3. Emotional stress
4. Emotional stress+modulated electromagnetic field
5. Immobilization+modulated electromagnetic field
6. Superior cervical ganglion
7. Stellate ganglion
8. Sympathetic trunk
9. Nodose ganglion
10. Number of animals

X_1 and X_0--conventional units, computed and table values at a significance level of 5 percent.

* Significant difference as compared with control.

In the immobilized rabbits during exposure to the modulated electromagnetic field the content of water-soluble proteins increased significantly in all the investigated structures--stellate, superior cervical and nodose ganglia and the sympathetic trunk (table 2).

Intermittent 3-hour stimulation of negative emotion producing zones of the hypothalamus under the conditions of a modulated electromagnetic field did not lead to a disturbance in cardiac activity. Whereas under stress in the cardiac conductive system there was a tendency toward an increase in the activity of fast-moving isoenzyme fractions, in the modulated electromagnetic field the spectrum of its isoenzymes did not differ from the norm (table 3).

In the modulated electromagnetic field in rabbits in a state of emotional stress there was a significant change in four lactate dehydrogenase fractions. At the same time, the activity of fractions of lactate dehydrogenase$_5$ and lactate dehydrogenase$_4$ decreased, while lactate dehydrogenase$_3$ and lactate dehydrogenase$_2$ increased. The activity of lactate dehydrogenase$_3$ increased in the nodose and stellate ganglia. In control rabbits in the modulated electromagnetic field the activity of lactate dehydrogenase$_5$ also decreased significantly in all extramural ganglia, while lactate dehydrogenase$_3$ increased in the superior cervical and stellate ganglia. The activity of lactate dehydrogenase$_2$ increased significantly in the superior cervical ganglion (table 4). Thus, a significant tendency toward increased aerobic metabolism in all the investigated ganglia of the autonomous nervous system in a modulated electromagnetic field in animals in a state of emotional stress is established.

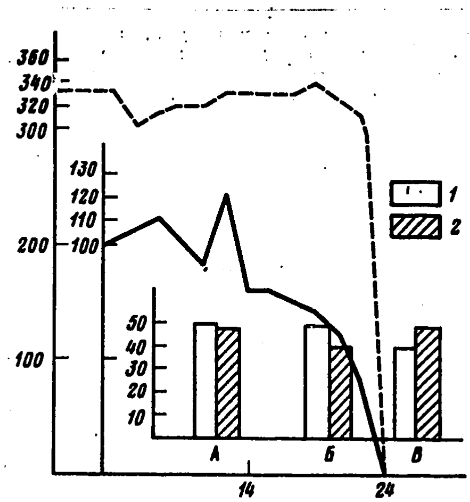

Figure 1. A rabbit from the group of rabbits predisposed to emotional stress. The value of arterial pressure in mm Hg and the cardiac rate are plotted on Y-axis. The time of the experiment in hours, on X-axis. The columns designate the content of water-soluble proteins (γ/mg): A--superior cervical ganglion, Б--nodose ganglion, B--sympathetic trunk. 1--control, 2--emotional stress.

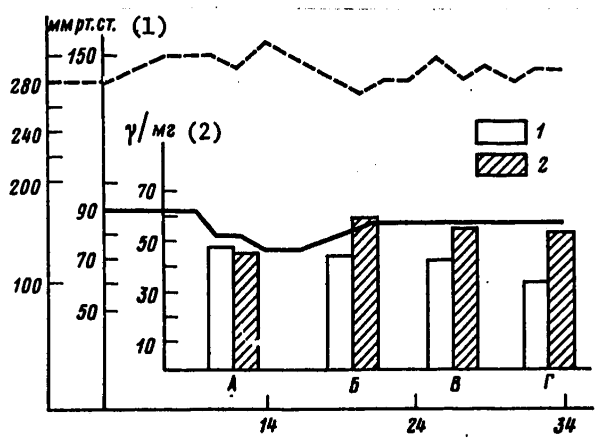

Figure 2. A rabbit with stable arterial pressure. The value of arterial pressure in mm Hg and the cardiac rate are plotted on Y-axis. The time of the experiment in hours, on X-axis. The columns designate the content of water-soluble proteins (γ/mg): A--superior cervical ganglion, Б--nodose ganglion, B--stellate ganglion, Г--sympathetic trunk. 1--control, 2--emotional stress.

Key: 1. mm Hg 2. γ/mg

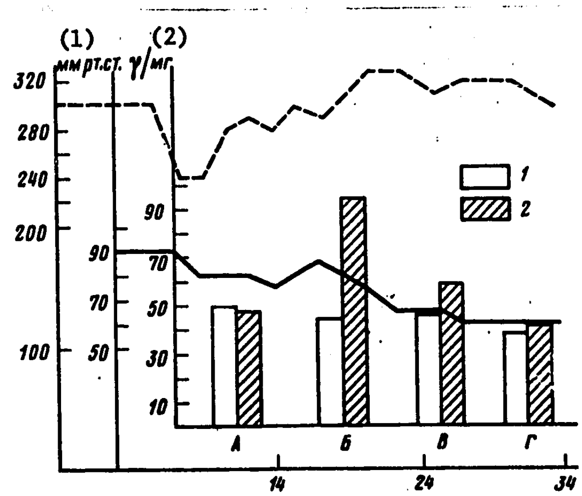

Figure 3. A rabbit "adapting itself" to the effect of a stress producing factor. The value of arterial pressure in mm Hg and the cardiac rate are plotted on Y-axis. The time of the experiment in hours, on X-axis. The columns designate the content of water-soluble proteins (γ/mg); A--superior cervical ganglion, Б--nodose ganglion, B--stellate ganglion, Г--sympathetic trunk. 1--control, 2--emotional stress.

Key:
1. mm Hg
2. γ/mg

Table 3. Correlation of the Activity of Lactate Dehydrogenase Isoenzymes of the Cardiac Conductive System of the Rabbit

(1) Число животных	(2) КВ, M±м	(3) Эс, M±м	f	(4) ЭС+МЭМП, M±м	f
	8	10		5	
(5) ЛДГ₁	64,16±3,2	70,97±9,1	1,82	67,2±4,5	0,55
(5) ЛДГ₂	18,02±1,55	17,37±1,13	0,33	17,2±0,7	0,51
(5) ЛДГ₃	11,95±1,18	9,6+1,1	1,46	12,2±2,1	0,1
(5) ЛДГ₄	4,07±1,22	1,5±1,0	1,66	2,64±1,7	0,68
(5) ЛДГ₅	1,78±0,56	0,57±0,38	1,77	0,74±0,7	1,1

Key:
1. Number of animals
2. Vivarian control
3. Emotional stress
4. Emotional stress+modulated electromagnetic field
5. Lactate dehydrogenase

f--Student's significance criterion.

Table 4. Correlation of the Activity of Fractions of Lactate Dehydrogenase Isoenzymes in Ganglia of the Autonomous Nervous System

Число животных (5)	(1) Верхний шейный ганглий				(2) Звездчатый ганглий				(3) Симпатическая цепочка				(4) Узловатый ганглий			
	КВ (6)	ЭС (7)	ЭС+МЭМП (8)	ИМ+МЭМП (9)	КВ (6)	ЭС (7)	ЭС+МЭМП (8)	ИМ+МЭМП (9)	КВ (6)	ЭС (7)	ЭС+МЭМП (8)	ЭС+МЭМП (9)	КВ (6)	ЭС (7)	ЭС+МЭМП (8)	ИМ+МЭМП (9)
	7	7	6	7	6	5	6	6	7	7	6	5	6	6	6	6
(10) $ЛДГ_1$	21,3	20,8	27,9	24,8	20,2	24,6	28,0	24,8	23,2	26,2*	27,1	26,6	25,1	23,4	28,2	27,9
(10) $ЛДГ_2$	21,7	19,5	26,6*	27,0*	22,2	21,6	26,6	25,9	24,9	22,6	26,3	26,8	26,0	22,3	28,0	28,0
(10) $ЛДГ_3$	21,7	23,0	27,6*	26,1*	21,6	25,0	26,2*	27,5*	27,4	30,7	25,2	26,5	20,5	23,4	26,4*	24,9
(10) $ЛДГ_4$	21,8	23,0	14,4*	18,1	23,5	18,5	15,0	17,8	18,2	15,7	16,2	14,1	18,7	21,4	13,0	15,5
(10) $ЛДГ_5$	13,5	13,7	3,5*	4,0*	12,5	10,3	4,2*	4,0*	6,3	4,8	5,2	6,0	9,7	9,5	4,4*	3,7*

Key:

1. Superior cervical ganglion
2. Stellate ganglion
3. Sympathetic trunk
4. Nodose ganglion
5. Number of animals
6. Vivarian control
7. Emotional stress
8. Emotional stress+modulated electromagnetic field
9. Immobilization+modulated electromagnetic field
10. Lactate dehydrogenase

* Lactate dehydrogenase fractions, whose activity differs significantly from control.

With what can the protective effect of the modulated electromagnetic field on the organism be connected? In the literature there are data on an increased resistance of the organism to some forms of stress producing effects under the action of an alternating magnetic field /11, 12/. In our experiments the resistance of rabbits to a stress-producing effect in the modulated electromagnetic field increased. In physiological parameters the basic number of rabbits could be included in the group of rabbits adaptable to a stress-producing effect. The content of water-soluble proteins in homogenates of the nodose ganglion of the immobilized rabbits in the modulated electromagnetic field increased significantly as compared with control and with the group of animals in a state of emotional stress. The activity of fast-moving lactase dehydrogenase fractions of extramural ganglia in them was slightly elevated, as in rabbits in a state of stress in the modulated electromagnetic field. It is well known that constant and alternating low-frequency magnetic fields are used for a contactless change in the functional activity of both the entire brain and the hypothalamus. The organism responds to the effect of physical environmental factors with the development of general adaptive reactions based on the effect of hypothalamo-hypophysial structures /12/. The effect of the modulated electromagnetic field on the immobilized intact animals in our experiments was manifested in an increased content of water-soluble proteins in all the investigated cellular formations of the peripheral autonomous nervous system. In other words, they were not overstimulated under these conditions. In all probability, low-frequency modulated electromagnetic fields are weaker as compared with the direct electric stimulation of the hypothalamus with stimuli. As a result of the effect of the modulated electromagnetic field on animals in a state of emotional stress in the studied structures of the autonomous nervous system changes assumed the same nature as during its effect on the immobilized intact rabbits. Possibly, the organism becomes resistant to the quite large amount of stimulation as a result of the increase in protective forces "aroused" by the modulated electromagnetic field. In other words, under a simultaneous effect of two stimuli the organism responds to the weaker stimulus. There is reason to believe that this is possible, because there are great energy expenditures under stress /7/ and, if the organism is affected by a stimulus to which it can respond with lesser expenditures, this will be an easier and, therefore, more acceptable way for the organism. It can be assumed that the effect of the modulated electromagnetic field transfers the organism to another level of reaction. Comparing the reaction of rabbits from various groups to the modulated electromagnetic field, it can be easily noted that, basically, it differs in the response of the sensitive (nodose) ganglion of the vagus nerve. Thus, there is reason to believe that the change in the reactivity of the nodose ganglion is one of the factors determining the resistance of the cardiovascular system of rabbits under experimental emotional stress. In those predisposed to its development during stress catabolic processes predominate over anabolic processes and in adaptable rabbits, conversely, anabolic processes predominate over catabolic processes.

The modulated electromagnetic field of the used parameters, selectively activating limbic structures and suppressing the ascending activating effects of the reticular formation on the cerebral cortex, increases the resistance of animals to emotional stress and their adaptability in a conflict situation. Under the conditions of an effect of a modulated electromagnetic field the activity of fast-moving lactate dehydrogenase isoenzymes increases and the content of water soluble proteins in extramural ganglia of the autonomous nervous system rises.

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CSO: 1840/5

UDC: 612.821.6

RAT BEHAVIOR IN 'OPEN FIELD' AFTER EXPOSURE TO MAGNETIC FIELD

Moscow ZHURNAL VYSSHEY NERVNOY DEYATEL'NOSTI IMENI I. P. PAVLOVA in Russian Vol 32, No 1, Jan-Feb 82 (manuscript received 21 Nov 80) pp 72-78

[Article by N. P. Smirnova, Moscow]

[Text] The study of integral functions of the brain, in particular behavioral reactions differing in complexity and significance, is of substantial importance to evaluation of the consequences of exposure to strong magnetic fields (MF). There is information in the literature concerning the effects of MF on unconditioned reflexes, on such mandatory components of an integral behavioral act as motor activity and work capacity, as well as on higher nervous activity [5, 7]. As we know, the "open field" test permits evaluation of an animal's integral physiological reaction to a new and unusual situation, including elements of motor, orienting-exploratory, emotional and stereotype behavior [9, 10, 11, 15].

Methods

In our experiments, the "open field" consisted of a plywood ring 100 cm in diameter and wall 30 cm high. This ring, which was divided into 32 squares 15x15 cm in size, was arbitrarily divided into three zones: peripheral (16 squares along the wall), intermediate (12 squares) and central (4 squares). The "field" was illuminated uniformly by either natural light or a daylight lamp on the ceiling of the experimental room. Tests were conducted in the "open field" for three successive days, simultaneously on control rats and rats exposed to MF. On the day of the experiment, the animals received feed and water ad lib. We observed the rats' behavior for 5 min, noting the following parameters every minute: horizontal travel (number of squares crossed); degree of adjustment to the "field" (going into the intermediate and central zones); vertical standing (rising on hind legs with and without use of wall for support); sniffing, directing the head up or toward the center; total time and number of grooming [washing-brushing (scratching)] cycles; number of fecal pellets and urinations. In processing the data, we analyzed the following: structure of rat behavior during the 5-min test; behavior on the first and subsequent days of the experiment; presence of trace reactions--behavior when retested after 1-3 weeks. In these experiments, we used 160 white mongrel and Wistar rats, mainly males, with average weight of 200 to 230 g in the different series.

The animals were exposed to vertical MF with 0.3 T induction with an SP-15A electromagnet or 1.6 T using an SP-57A electromagnet. Both electromagnets had flat parallel tips: rectangular 400×300 mm in size (SP-15A) and in the form of a circle with a radius of 450 mm (SP-57A), with interpolar distance of 100 mm, and they formed an interpolar space in the central part, in which the animals were placed (within the 300×200 mm or 380 mm radius range), a virtually homogeneous field, with no more than 15% decline of induction at the edge of the tips, in relation to the center. Unlike the strictly static MF formed with the SP-57A electromagnet, the SP-15A electromagnet generates an MF with a pulsating component of 100 Hz frequency, the induction of which constitutes up to 1.8% of the static component of the field.

The animals were exposed for 3-4 h daily for 3 consecutive days.

Results

Analysis of the experimental material revealed wide individual variations in reactions to the "open field," in both control rats and those exposed to MF. The Table lists averaged results of the experiments and, for the sake of simplicity, control data referable to exploratory motor behavior are combined for the two series. The digital data referable to grooming time and emotionality differed substantially in the different series, and for this reason they are listed with their own control.

The mean data enabled us to detect distinctions in the behavior of the rats both during the 5-min test and on subsequent experimental days. On the first day of testing, the rats manifested the most motor and orienting-exploratory activity: number of horizontal passages, entrances into the center of the "field," vertical stances and sniffing was reliably greater than on the next two days. There were less marked differences between the second and third days. The level of defecation, which characterizes the autonomic component of emotionality ("fear") remained constant on all 3 experimental days. Parameters of general motor and exploratory behavior were at a maximum in the 1st min of the test and decreased gradually or abruptly in the next 4 min (Figure 1). Grooming time and number of grooming cycles, which are indicators of stereotype behavior of rats directed toward "oneself," undergo irregular changes both in the course of a single test and on different experimental days.

The results of repeated experiments following the same set-up on the same animals, which were conducted 1-3 weeks after the first one are of some interest. As compared to the first experiment, on the first day of the second one the rats presented considerable decrease in number of horizontal passages ($P<0.001$), vertical stances ($P<0.001$), sniffing ($P<0.002$), with decrease in coefficient of adjustment to the "field" and no change in number of fecal pellets. The rats gained an average of 26% in weight between experiments, which could have been the cause of diminished motor activity. However, the aggregate of changes indicated that there was drastic decline of the orienting-exploratory component of the behavioral reaction in repeated tests. Moreover, unlike the first experiment, in the second one there was leveling off of the difference in magnitude of parameters of motor and exploratory behavior between the first and subsequent testing days. Apparently, the rats remembered the first experiment and the "open field" situation lost its novelty in the repeated tests. Such findings were also made by other authors [3, 8, 13, 14].

Influence of repeated exposure to MF on rat behavior in "open field" (mean data per rat per 5 min)

Day of experiment	Factor	Number of rats	Horizontal passages	Standing erect	Coefficient* of field assimilation
	Motor and orienting-exploratory activity				
First	Control	80	64,9±3,4	9,1±0,7	5,1±0,8
	0,3 T	35	70,0±4,9	11,2±1,0	6,9±2,0
	1,6 T	45	57,1±3,5 P>0,1	8,7±0,9	8,9±0,2 P<0,001
Second	Control	80	44,6±2,7	4,6±1,4	2,9±0,8
	0,3 T	35	30,3±3,6 P<0,002	3,6±0,6	1,6±0,6
	1,6 T	45	46,4±4,3	5,7±0,6	4,8±1,3 P>0,1
Third	Control	80	35,6±3,1	3,2±0,3	2,6±0,8
	0,3 T	35	21,9±2,5 P<0,001	4,0±0,7	1,1±0,5 P>0,1
	1,6 T	45	43,1±4,5 P>0,1	5,4±0,8 P<0,001	6,6±2,2 P<0,1

Day of experiment	Factor	Number of rats	Grooming time, s	Number of fecal pellets
	Stereotype behavior and emotionality			
First	Control	35	13,6±3,1	5,3±0,6
	0,3 T	35	14,7±2,6	5,8±0,5
Second	Control	35	9,7±1,6	5,2±0,5
	0,3 T	35	12,1±1,8	5,3±0,5
Third	Control	35	17,4±2,9	5,5±0,5
	0,3 T	35	24,7±4,5	4,9±0,6
First	Control	45	27,9±4,9	3,2±0,4
	1,6 T	45	26,5±3,7	2,6±0,4
Second	Control	45	30,3±4,0	2,8±0,3
	1,6 T	45	22,3±3,5	2,6±0,4
Third	Control	45	22,4±3,7	4,2±0,5
	1,6 T	45	27,1±4,2	2,8±0,4 P>0,1

*Entrances into center of the field are given a grade of 10 and into the intermediate zone 1. P is comparison to the control.

There was no appreciable difference from the control in structure of behavior of rats exposed to MF just prior to each test in the course of the 5-min test and on the 3 successive experimental days. Testing in the "open field," which was performed immediately after the first exposure to 0.3 T MF (1st day) failed to demonstrate any differences from control animals. After the second and third exposure (2d-3d experimental days) there was reliable decrease in number of horizontal passages and the coefficient of adjustment to the "field" diminished somewhat, as compared to the control. There was a more drastic decline of motor activity from the first to subsequent testing days than in control rats (Figure 2). A decrease in number of horizontal passages (16.6±2.3 on the 3d day versus 25.7±2.8 in the control; P<0.02) was also observed in rats exposed to an MF of 0.3 T a second time 1-3 weeks after the first experiment.

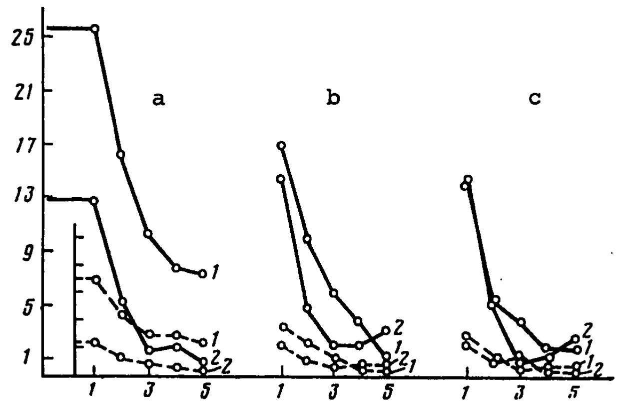

Figure 1. Dynamics of rat behavior in "open field" during 5-min test and on 3 successive experimental days. Control. Mean data. Y-axis, number of squares crossed (solid line) and erect stances (dotted line); x-axis, time, min

a, b, c) 1st, 2d and 3d days of testing, respectively
1) first experiment
2) second

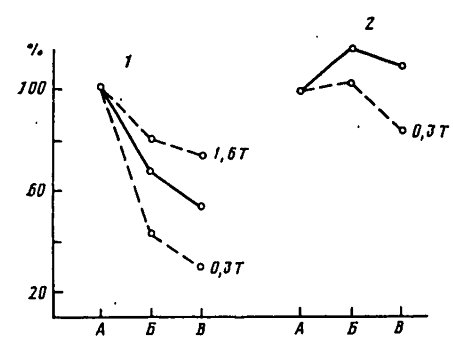

Figure 2.
Changes in horizontal activity on 2d and 3d days of testing in "open field" as compared to 1st day. Solid line--control; dotted line--exposure to MF. Other designations are the same as in Figure 1.

Different tendencies were demonstrated after exposure to 1.6 T MF. While there were no changes in number of horizontal passages, the rate of decline of motor activity from the first experimental day to the next was slower than in the control, and there were signs of intensification of exploratory behavior: on all three experimental days the coefficient of assimilation of the "field" was somewhat higher and the rats assumed an erect position more often (reliably on the 3d day).

The parameters of stereotype behavior and emotionality showed virtually no difference from the control with exposure to 0.3 and 1.6 T MF in both series.

Thus, according to the averaged results of all experiments, the most appreciable changes in rat behavior in the "open field," in the form of depression of motor and orienting-exploratory activity, were caused by repeated exposure to MF of 0.3 T. Significant increase in field induction to 1.6 T not only failed to enhance this effect, but showed a tendency toward activating exploratory behavior.

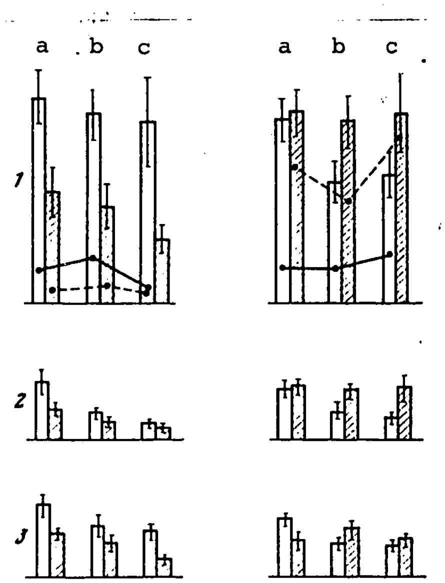

Figure 3.
Differences in behavioral reactions to MF of 1.6 T in 2 experiments on Wistar rats. White columns and solid lines--control; crosshatched columns and dotted lines--exposure to MF

a, b, c) 1st, 2d and 3d days of testing
1) horizontal activity (columns) and coefficient of adjustment to field (lines)
2) vertical activity
3) sniffing

Apparently, individual reactions to the magnetic field can be more marked, and they are more often in different directions. Thus, in 1 out of the 4 experiments involving exposure to MF of 0.3 T, activity was greater than in the control. With the use of MF of 1.6 T, there was prevalence of signs of intensification of motor and exploratory activity in 3 out of 4 experiments; conversely, drastic depression of activity was observed in 1 of them. We were unable to relate the differences in reactions to the MF to experimental conditions (season, air temperature, atmospheric pressure, sex, weight, strain of animals). As an illustration, let us examine the results of 2 experiments conducted on 28 Feb--2 Mar (on the left in Figure 3) and 3-5 Apr 1979 (on the right) on male Wistar rats exposed 3 times to MF with 1.6 T induction. On these days atmospheric pressure was 750-760 and 750 mm Hg, respectively, air temperature ranged from -2 to -8°C and from -2 to -5°C; ambient temperature in the room was 23 and 22°C; the rats weighted 239.0±6.2 206.5±3.6 g; horizontal activity (number of squares crossed in 5 min) constituted 75.4±9.8 and 66.9±7.0 in control rats on the 1st testing day; emotionality (fecal pellets in 5 min) constituted 2.4±0.7 and 2.4±0.7. Figure 3 illustrates the parameters of motor and exploratory behavior. We see that the two experiments conducted under similar seasonal and weather conditions on animals similar in sex, weight, level of activity and emotionality demonstrated the possibility of different manifestations of the behavioral reaction to exposure to recurrent, intensive MF: decrease in horizontal activity, in number of entrances into the center, sniffing and standing erect in one experiment and increase of these parameters in the other.

Discussion

The differences in nature and degree of behavioral reactions to MF can be attributed not only to individual sensitivity of animals, but difficulty of interpreting the results of "open field" tests. Although this test has been in use for 40 years, there are still discrepancies in assessing the significance of different parameters to characterization of behavior and physiological state of animals. One can evaluate a behavioral reaction properly only by considering all of its elements.

A high degree of horizontal activity can reflect exploratory behavior and the level of nonspecific excitability, correlating with vertical activity and hippocampal theta rhythm. On the other hand, since it is correlated with defecation, it is an indicator of the animal's high emotionality ("fear"). The long cycles of grooming, which are correlated with low horizontal and vertical activity, reflect a low level of nonspecific excitability [9, 15].

We analyzed the base psychophysiological state of 35 rats in the control group in the series of experiments with exposure to MF of 0.3 T. In 13 rats of this group, the 1st day of testing was characterized by high motor activity and in 13 others by low motor activity, as determined from the significant deviation of number of horizontal passages from the mean (67.8±5.2) for the entire group. In 11 rats, high horizontal activity was combined with frequent vertical stances, sniffing, high coefficient of adjustment to the "field" or short grooming cycles and low level of defecation. Rats having this combination of signs can be characterized as animals with high motor and exploratory activity and low emotionality. In two rats, a large number of horizontal passages was combined with infrequent erect stances and sniffing, movement only along the periphery of the "field," high level of defecation and longer grooming time. Conversely, 11 of the 13 rats with low horizontal activity presented either infrequent standing, sniffing, entrances into the center, or a high level of defecation. These rats manifested a passive defense reaction to being placed in an unusual situation and a high degree of "fear."

A difference in animals' base physiological state could also cause differences in reactions to MF, which leads to considerable scatter of data and inadequate reliability of differences from the control.

The reaction to MF could also depend on intensity of this factor. Differences were demonstrable in nature of changes in motor activity recorded on mice by the photoelectric method--activation, depression, biphasic reaction--as a function of degree of MF induction in the range of 0.05-0.4 T [1].

The absence of enhancement of the inhibitory effect during tests in the "open field" with considerable increase in intensity of MF could possibly be attributed to the difference in physical characteristics of MF generated by the two electromagnets that were used. The experiments with 1.6 T induction were conducted with the SP-57A electromagnet, which generates a steady homogeneous magnetic field without pulsation. The experiments with 0.3 T induction were conducted with the SP-15A electromagnet, which generates a magnetic field with pulsating component. The opinion is held that variable and gradient MF have greater biological effectiveness than strictly static ones.

The differences in characteristics and conditions of exposure to MF, as well as type of behavioral reaction studied, make it difficult to compare our findings to material in the literature. Such comparison can be made to data on the effects of constant MF on the most complex forms of behavior related to adjustment to the environment, processes of learning and memory formation. With exposure to MF of 0.2-0.8 T (induction that is comparable to the level used in our experiments), the main phenomenon demonstrated by most authors was inhibition of development and retention of conditioned reflex reactions of different modality [2, 4, 6, 12].

Conclusions

1. Exposure to a magnetic field (0.3 and 1.6 T) does not have a significant effect on the structure of rat behavior in the course of a 5-min test and on 3 consecutive days of tests in the "open field."

2. Individual behavioral reactions to MF are notable for wide variability and may occur in different directions.

3. According to the mean data, exposure to MF of 0.3 T (3-4 h/day for 3 days) leads to depression of motor and orienting-exploratory behavior in the "open field."

4. Increasing magnetic induction to 1.6 T does not intensify depression of the behavioral reaction to the "open field," which is indicative of the greater effectiveness of a mildly pulsating field, as compared to a static homogeneous magnetic field.

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CSO: 1840/122

UDC: 655.39(048)

USE OF THERMAL SHF RADIO-FREQUENCY RADIATION BY HUMAN BODY FOR MEASUREMENT OF VISCERAL TEMPERATURE: RESULTS AND PROSPECTS

Moscow USPEKHI FIZICHESKIKH NAUK in Russian Vol 134, No 1, May 81 pp 155-158

[Article by V. S. Troitskiy, A. V. Gustov, I. F. Belov, V. M. Plechkov, V. P. Gorbachev and L. K. Siz'mina]

[Text] The possibility of measuring temperatures within the human and animal body is very important to biomedical research, as well as medical practice. It is known that many diseases are associated with local changes in temperature of involved parts of the body due to inflammatory processes or neoplasms. Measurement of internal temperature opens up new possibilities in diagnosing diseases and pinpointing sites thereof in the body.

Until recently, there were no bloodless methods of measuring the temperature of internal organs. Thermoscopy based on measurement of the body's thermal infrared radiation provides the real temperature of only the topmost layer of the skin measurable in fractions of a millimeter. However, it does not reflect well the subsuperficial deep temperature of a living organism.

In recent times, methods of determining internal temperature began to be developed in our country and abroad, which are based on measurement of intensity of thermal radio-frequency radiation penetrating from deep in the body [1, 2]. For such readings, radiometers are used, which have been used for many years in radioastronomy, and a special probe-antenna that has to be placed on the human body. Thermal radio-frequency radiation from the human body comes from a layer, the thickness of which is of the order of depth of penetration of the corresponding wave. Penetration depth l for any human tissue equals approximately the wavelength in the tested tissue, i.e., $l = \lambda = \lambda_0/\sqrt{\varepsilon}$, where λ_0 is wavelength in vacuum and ε is the dielectric constant of tissue. For fatty and bone tissue, $\varepsilon \approx 6$ and $l \approx 0.5\ \lambda_0$; for muscle tissue $\varepsilon \approx 50$ and $l \approx 0.15\ \lambda_0$.

The resolution on the surface is determined by the dimensions of the probe-antenna, whose optimum diameter is of the order of the wavelength in the medium [environment], i.e., $D \approx \lambda_0/\sqrt{\varepsilon}$. The Fresnel zone of this antenna in tissues constitutes $2D^2\sqrt{\varepsilon}/\lambda_0 \approx 2\lambda_0\sqrt{\varepsilon}$, i.e., it equals double the depth of wave penetration. Consequently, accumulation [collection] of radiation proceeds from a cylinder of tissue which has a base with diameter D and height of the order of depth of penetration. Hence, we see that the use of lens antennas that are much larger than ambient wavelength does not focus and increase resolution due to considerable absorption of marginal beams, as compared to central beams. Only the central part will function, and its dimension equals the focal distance, which should be of the order of $l = \lambda_0/\sqrt{\varepsilon}$.

Radiometry was first used for measurement of internal temperature by Barrett et al. [1] (wavelength $\lambda_0 = 10$ cm). However, only relative body temperatures could be measured with any degree of reliability, and then mainly between symmetrical points. For this reason, diagnostic studies were made only of paired organs (mammary glands).

In order to use the method of measuring deep temperature in biomedical research and medical practice, it is necessary to measure absolute temperatures in any part of the body surface with accuracy of at least ±0.1°C. This requirement is related to the fact that differences between local temperatures and the mean of 37°C are usually in the range of ±(2-3)°C.

The main difficulty involved in measuring temperature accurately is related to the existence of a coefficient of radiation reflection on the antenna-body boundary, which changes markedly, depending on where the antenna is placed on the body. For example, with $\lambda_0 = 30$ cm, the coefficient of reflection for energy G^2 changes from 0.0 to 0.25. For this reason, even with an antenna that involves no loss, it is not the true body temperature T_x (in degrees Kelvin) that is measured, but $T_c = T_x(1-G^2)$. In the study mentioned [1], the authors tried to take reflection into consideration by measuring G^2. However, this does not solve the problem, since errors of the order of one degree remain, and this limits use of the method to relative measurements, when the position of the antenna on the body does not change. Moreover, there is a substantial interferential error [3].

An error also occurs because the antenna-probe does not pick up all radiation in principle, that is emitted by the body by virtue of inevitable presence of posterior lobes of the antenna's pattern.

Our theoretical and experimental study of noise in the input system and operation of the antenna enabled us to formulate the principles and methods for eliminating the above errors completely.

In brief, the principle consists of using the properties of a system in thermal equilibrium when the input part of the radiometer and body examined are placed in a black chamber and have the same temperature. In this case, the signal from the antenna equals exactly the temperature of the corresponding part of the body.

Let us consider a simplified input system, where the antenna is connected to the radiometer by means of an ideal valve. It can be demonstrated that the signal coming from the antenna, with consideration of its intrinsic noise, equals $T_c = T_\Sigma\eta(1-G^2) + T_a(1-\eta)(1-G^2)$, where η is efficiency of the antenna, T_a is the temperature of its material, T_Σ is temperature of the antenna related to the radiation received. This temperature equals $T_\Sigma = T_x(1-\beta) + T_\phi\beta$, where β is the coefficient of antenna scattering beyond the half-space occupied by the body and T_ϕ is temperature of the black chamber or generally the radiation temperature in the space around the body.

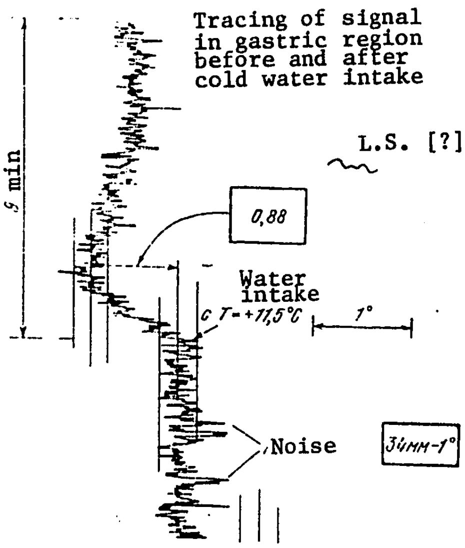

Figure 1.

Thermal radiation of an ideal valve directed into the antenna has a temperature of T_Z. This radiation, being reflected from the antenna, yields an additional signal $T_\Sigma G^2$. The complete signal going to the radiometer equals $T_c = [T_x(1-\beta) + T_\phi\beta] \times \eta\,(1-G^2) + T_a(1-\eta)(1-G^2) + T_Z G^2$. It is not difficult to see that by establishing thermal equilibrium, when $T_a = T_Z = T_\phi = T_x$, we shall have $T_c = T_x$, i.e., an undistorted reading of body temperature.

However, in actuality T_x is unknown and must be measured. Thermodynamic equilibrium can be only approximately achieved. For this reason, equilibrium is established for mean temperature $\overline{T}_x$ of the human body, which is 37°C. Considering $T_x = \overline{T}_x + \tau$ where, as we have indicated, $0 \leqslant |\tau| \leqslant 2$, we shall obtain $T_c = T_x - \tau(1-\eta+\beta+G^2)$. The influence of antenna losses, scatter and reflection are not ruled out, but diminish to such an extent that, for example, variations of G^2 in the range of 0.0–0.20 do not cause errors exceeding 0.1–0.2°C.

A radiothermometer for a wave of 32 cm with threshold sensitivity of 0.02°C (averaged for 4 s) was developed at the Scientific Research Institute of Radiophysics on the basis of these principles, and it is accurate to ±0.1°C in absolute temperature readings. Superficial resolution constitutes about 4 cm at a depth of probing temperature up to 20 cm. Various test measurements made with the radiothermometer of human body temperature and equivalents of its tissues demonstrate a good coincidence with readings taken with traditional thermometers.

In order to determine that it is indeed deep temperature that is measured, we took the temperature of the gastric region during intake of cold or hot water. Figure 1 illustrates a sample of such a tracing, where an immediate ~0.9°C temperature drop was observed at the time of intake of cold water followed by gradual equalization. The change in temperature and rate of its equalization differ in different patients. Figure 2 illustrates typical tracings of deep temperature of various organs.

In 1979, preliminary studies were conducted of 20 healthy subjects and 80 patients in clinics of Gor'kiy Medical Institute at the Oblast Hospital imeni Semashko. They revealed that both the healthy and the sick had substantially different internal temperatures in different parts of the body. It was demonstrated that deep temperature is a function of state of circulation. A study was also made of elevation of human brain temperature under the influence of intake of different doses of nicotinic acid. Studies were made of the effects of various physiotherapeutic procedures on the temperature of some organs.

This study revealed that malignant neoplasms of the stomach caused an 0.5-0.8°C elevation of temperature, as compared to normal, the maximum scatter of which is ±0.4°C. Temperature elevation of 0.8-2°C was observed in the presence of liver pathology (hepatitis, cholecystitis).

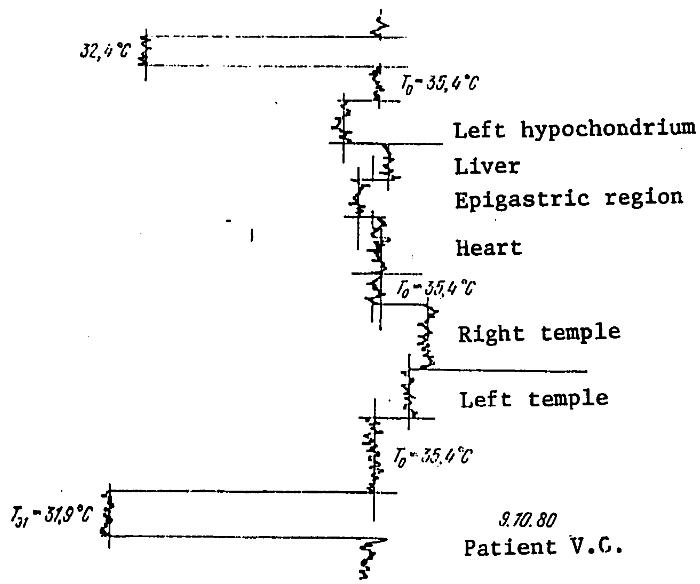

Figure 2.

Elevation of brain temperature was observed in the presence of tumors and, on the contrary, a drop in the presence of hemorrhages.

Thus, the first experience with the developed radiothermometer in medicine is quite encouraging, and it is indicative of the wide potential of this new method in biomedical research.

The studies revealed that it is becoming possible to develop a system of radiothermometers at different wavelengths, which permit measurement of the distribution of temperature in depth from the surface inward. This makes it possible to obtain human temperature fields in three readings.

We believe that, in time, radiothermometry will unquestionably become a very popular method in biomedical research and clinical diagnostication.

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APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000500060027-1

UDC: 655.39(048)

EQUIPMENT AND METHODS OF THERMAL SHF AND HF IN ONCOLOGY

Moscow USPEKHI FIZICHESKIKH NAUK in Russian Vol 134, No 1, May 81 pp 158-163

[Article by N. D. Devyatkov, E. A. Gel'vich, I. B. Davydova, V. V. Kirillov, D. N. Kolmakov, V. N. Mazokhin, V. I. Sinyagovskiy and P. I. Chilikin]

[Text] 1. Use of hyperthermia in oncology. Hyperthermia is artificial elevation of human body temperature to above normal levels, and it has gained considerable use in recent years to enhance the efficacy of treatment of malignant neoplasms [1, 2, 13].

Use of hyperthermia is based on the fact that overheated cancer cells become more sensitive to radiation and chemotherapy used to destroy them [1, 3-5, 9]. According to some reports, hyperthermia can also serve as an independent method of treatment of some diseases [16].

One of the first methods of controlled overheating of tumors was the method of regional perfusion [3, 12] (heating by means of infusion of heated blood from an extracorporeal circulation machine into the involved part of the body) and the method of total body heating in a water or whirlpool tub [1, 10, 11]. The perfusion method turned out to be ineffective in destruction of tumors and, at the same time, it injured healthy surrounding tissues, so that it is not used at the present time [3].

Hyperthermia obtained by means of electromagnetic energy has several advantages over most other methods. Electromagnetic heating is not a warming procedure as, for example, shower, solarium, water, air baths and other methods that transmit heat via blood flow and heat conductivity of tissues from the skin's surface to internal regions; rather, it directly heats the entire part of the body that is the target of hyperthermia. This reduces substantially the time spent on reaching the required temperature, reduces the heat load on the patient's skin and, consequently, on the cardiovascular system. Electromagnetic hyperthermia permits general heating of the body or localization thereof in a circumscribed part of the human body; it is relatively easy to maintain the required temperature level in the heated region and to control dynamically the force and time of treatment [1, 2, 13].

2. Difference between hyperthermia and microwave and UHF therapy. In spite of the fact that microwave and UHF therapy is used widely in medical practice,

the change to electromagnetic hyperthermia imposes rather rigid and sometimes difficult requirements. The reason for this is that the intensity of irradiation with electromagnetic therapy is set according to the patient's subjective sensations; the treatments do not elicit any unpleasant emotions or irritation, and the modes are far from critical. Yet, the optimum method of electromagnetic hyperthermia must provide delivery to various tissues (including superficial and deep tissues, normal and pathologically altered) of very specific temperature levels that are close to but do not exceed the safety threshold (45°C [2]). Excessive heat could lead to dangerous and sometimes irreversible consequences: burns, tissular necrosis, impaired function of the cardiovascular system, etc.

Hence there are rigid requirements of the heating procedure and equipment that provides it. There must be great flexibility in controlling the heating process and proper monitoring of the patient's condition. Automation of the heating procedure, automation of maintenance of required irradiation modes, maintenance of specified distribution of temperature in the part of the body to be submitted to hyperthermia are mandatory conditions for the design of such hyperthermia equipment. Of course, the existence of critical heat modes increases requirements as to accuracy of taking temperatures. The desirable accuracy of measurement of absolute temperature should constitute at least ±0.2°C.

3. Equipment for SHF and HF hyperthermia. We have developed a number of pieces of equipment to heat tissues situated at different depths in the human body for local SHF hyperthermia, and they are being used with success at the Scientific Research Institute of Oncology and Medical Radiology of the Belorussian Ministry of Health, as well as several other institutes in our country.

The Parus-1 machine, which operates at a frequency of 2450 MHz is used to heat subcutaneous tissues, the Plot unit (operating frequency of 915 MHz) serves to heat deeper tissues. The systems of these machines are identical. In these units, magnetrons that operate in a two-frequency mode, 2450±49 MHz and 915±19 MHz, respectively, with output power that is adjustable in the range of 5-200 W [1, 6], serve as generators of SHF waves.

The distinctive design of the magnetrons permits delivery of power directly from alternating current at the industrial frequency of 50 Hz from the secondary winding of a high-voltage transformer. The power supply circuit of the magnetrons is analogous to the circuit of a full-wave rectifier circuit--each magnetron half generates circuit voltage for part of the half-period.

The output power can be adjusted by two methods: changing the amplitude of supply voltage or changing the time of generation of SHF energy in each half-period.

With the second method, there is a change in cut-off angle of anode current of the magnetrons by means of a thyristor regulator. This is the method used in the Parus-1 and Plot machines for automatic adjustment of output power in order to obtain the required temperature modes in the target region. There is automatic feedback from temperature sensors placed in the heated zone. Copper-constantan thermocouples or special semiconductors serve as the sensitive elements of the sensors. The accuracy of maintaining temperature level at the monitored point is no worse than ±0.5°. The Parus-1 and Plot units have built-in devices for monitoring magnetron operation, indicators of power in the tract and concordance of emitter with the biological object, as well as a digital display of duration of hyperthermia session. An apparatus was developed that operates at frequencies of both 915 and 2450 MHz, used for treatment depending on the depth and size of a tumor, in order to broaden the potential of using SHF generators for hyperthermia.

Uniformity and speed of heating in the electromagnetic field depend largely on the structure of tissues, their shape and dimensions, blood supply, heat conductivity and other factors [8, 11].

The experimental Barkas unit was developed for total-body hyperthermia to deliver high-frequency heat with energy in the meter range of wavelengths. It has a generator that operates on a frequency of 13.56 MHz with adjustable output power in the range of 100 to $1.3 \cdot 10^3$ W. This unit also has different types of emitters and microclimate device. One can deliver heat for total [overall] hyperthermia at the rate of over 1°C/10 min, depending on the emitters used.

The required heating rate is obtained by setting the appropriate output power for the generator.

The set of inductive and capacitive emitters makes it possible to create both total-body and local hyperthermia in the meter range of wavelengths.

The microclimate device is intended to create and automatically maintain the set temperature and relative humidity of air in a closed space, as well as to prevent and compensate for the dehydration effect in the course of a treatment.

In addition, use of microclimate permits reduction of duration of overall heating to the required temperature, whereas after the HF generator is turned off it automatically maintains the temperature level reached for a long time.

This unit automatically maintains the temperature in the confined space in the range of 35-40°C with accuracy to ±1°C and creates up to 95% relative air humidity in the confined area.

4. Emitters. The Parus and Plot apparatus contains sets of horn radiators of the resonance type differing in diameter, from 30 to 90 mm [6, 7]. The optimum distance between the radiator and biological object for these emitters is in the range of 1.5-2 cm.

The radiators consist of a segment of a circular waveguide with smooth, tapered transition to a coaxial line that ends with a high-frequency coaxial connector.

The end part of the radiator has plates that form a capacitive clearance, which is the element that emits the electromagnetic field. One of the plates is connected to a central conductor of the coaxial line by means of a tape transformer (matching lobe). To widen the bandpass, a dielectric transformer is built into the coaxial part of the radiator. A drawing of the radiator is rendered in Figure 1. The minimal dependence of radiator matching characteristics on physical parameters of irradiated tissues (shape, ε, tan δ) and their composition (skin, muscle, fat, bone), which is required for reliable radiator function, is obtained by selection of transformer length, configuration of capacitive gap plates and distance between them. The overall YeSVn [natural medium-frequency waves?] of the tract and submerged radiator is in the range of 1.8-2.0 over the entire band of frequencies generated by the magnetron, with changes in ε, tan δ, shape and composition of irradiated objects in the range encountered in clinical practice.

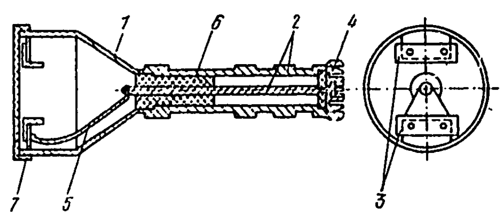

Figure 1.
Diagram of horn radiator
1) horn
2) coaxial
3) capacitive gap plates
4) SHF connector
5) matching lobe
6) dielectric transformer
7) protective cap

The averaged characteristics of distribution of electromagnetic and thermal fields of these radiators are illustrated in Figures 2 and 3.

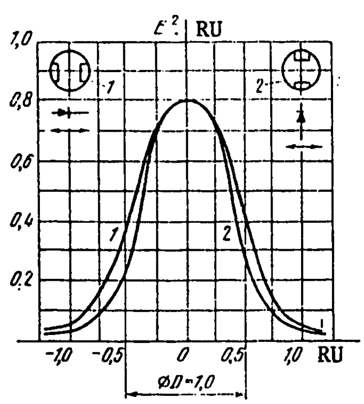

Figure 2.
Averaged characteristics of distribution of electric component of electromagnetic field of horn-type emitter with diameter D at frequency of 915 MHz

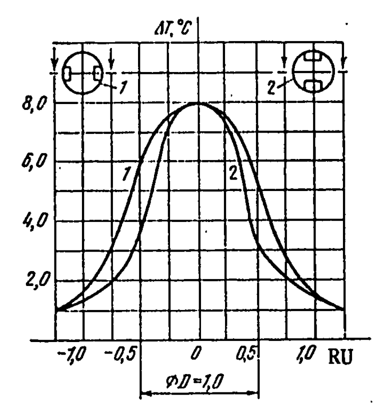

Figure 3.
Averaged characteristics of distribution of thermal field within simulator of biological object using horn emitter with diameter D at frequency of 915 MHz

Key for both figures:

1) perpendicularly to capacitive clearance
2) along the capacitive clearance
RU) relative units

Sometimes it is necessary to use cavity emitters. The specifications for their dimensions and design are determined by the anatomical structure of the human body (its cavities), as well as size and shape of tumors encountered in clinical practice, their location in the cavity.

The cavity emitters we developed in the SHF range are of the shaft type, with monopolar or dipolar excitation, assembled on a segment of the coaxial cable. The emitter is placed in a colpostat of the appropriate diameter, which protects the emitter from mechanical injury and its electric insulation from tissues.

There is a built-in system of forced water cooling to divert excessive heat from the walls of cavities and equalize heat in depth of tissues within the colpostat housing. Figure 4 is a schematic rendition of an emitter with colpostat.

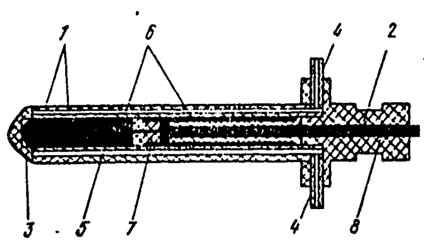

Figure 4.
Drawing of cavity emitter with colpostat
1) internal and external colpostat tubes
2) bracket
3) cap
4) input and output cooling tube
5) channels for coolant
6) dipole antenna elements
7) insulator
8) coaxial cable

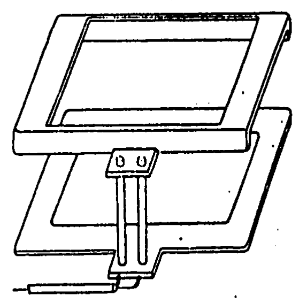

Figure 5.
Diagram of inductive radiator for general heating

The radiators contained in the Barkas unit, which operate at a frequency of 13.56 MHz, are designed for both general and local hyperthermia. The rather low operating frequency of radiation, as compared to SHF, permits heating of deep-lying regions of the body. Inductive emitters for general heating are executed in the form of two 500×500 mm or 500×900 mm frames, between which the biological object to be heated is placed (Figure 5). The distance between frames is adjusted from 250 to 400 mm (depending on the size of the biological object) [6]. Each frame has several coils of silver-plated copper tape connected in parallel. The efficiency of emitters connected to an HF generator by coaxial cable through a matching device can reach 40-70%, depending on the size, shape and composition of the biological object. In order to have a given nonuniformity of temperature distribution in the biological object, one must take into consideration the effects of blood flow, heating time intervals and other factors.

Both inductive and capacitive radiator systems are used to obtain local high-frequency hyperthermia.

The inductive radiator system consists of three connected resonance circuits. One of them operates as a matching device, while the other two are situated on either side of the heated biological object and localize the electromagnetic field in the space between them. The required localization of inductive current in body tissues in the plane that is perpendicular to the common axis of the three circuits is obtained by using special S-shaped emitting inductances (Figure 6).

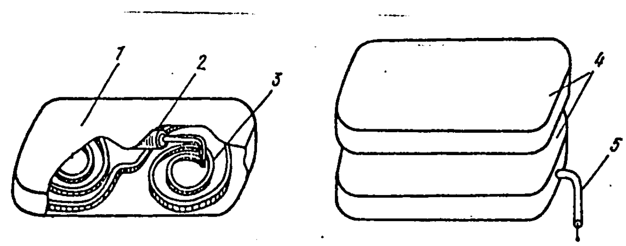

Figure 6. Drawing of inductive emitter system for local high-frequency heating

1) dielectric covering
2) capacitance of 3d circuit
3) inductance of circuit
4) 1st and 2d circuit of system
5) high-frequency cable

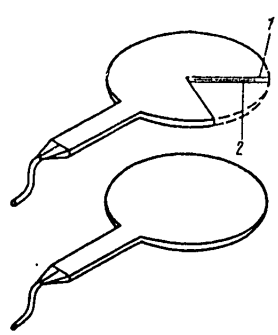

Figure 7.
Drawing of capacitance emitter for high-frequency heating
1) dielectric covering
2) condenser plate

The proper heating mode can be selected by monitoring the amplitude and phase of high-frequency current in the resonance circuits on either side of the biological object.

The capacitance emitter system (Figure 7) consists of a high-frequency condenser made up of two or more flat electrodes connected to the generator by a special matching device. In this case, specific parts of the body are heated chiefly by the electric component of the electromagnetic high-frequency field.

Thus, the existence of various systems of generators and emitters provides a more dynamic approach to local hyperthermia depending on the dimensions, shape, electrophysiological parameters of tissues, as well as physiological distinctions of the part of the body to be heated.

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000500060027-1

It should be noted that use of methods for scanning emitters over the surface of biological objects is one of the promising directions of expanding the functional capabilities of the devices.

5. Temperature measurement. Strict monitoring of temperature in the irradiated zone and possibility of automatic maintenance of a specified temperature with a specific degree of accuracy during the entire treatment are necessary for hyperthermic treatment of a tumor and to prevent the deleterious effects of heat on adjacent healthy tissues. The conditions for taking temperature are complicated by the fact that the temperature sensor must operate in high-frequency or superhigh-frequency fields with energy flux in excess of 1 W per square centimeter. At such levels, the metal sheaths heat up, and this leads to temperature measurement errors, which could lead to internal burns that are difficult to treat. Moreover, these sheaths and wires have a marked effect on distribution of the field in the irradiated zone. Repeated insertion of temperature sensors into tissue (before and during each treatment) is quite unpleasant for the patient.

The metal wires connecting heat-sensitive elements to measuring instruments are HF and SHF receiver antennas, which leads, on the one hand, to heating of thermistor or semiconductor sensors and, on the other hand, generates stray current, that is difficult to suppress, to the measuring equipment. Unfortunately, the currently available means of measuring temperature, with thermocouple, thermistor, thermoresistor and semiconductor sensors, have the above-mentioned flaws.

It is extremely important to provide for reliable temperature measurement during heating, regardless of orientation of the sensor in the field and frequency of electromagnetic waves, in order to broaden appreciably the range of application of the developed equipment. For this reason, it is a rather pressing task to develop a heat sensor that is insensitive to electromagnetic fields.

6. Results of using equipment for SHF hyperthermia. A method for administering local SHF hyperthermia was developed and has been used at the Minsk Scientific Research Institute of Oncology and Medical Radiology since 1971. After a comprehensive investigation and testing of this method on animals, it was used in clinical practice as one of the elements of treatment for patients with very advanced and recurrent tumors of the extremities. In a number of cases, radical surgery can be avoided or a sparing operation can be performed on the limb as a result of using local SHF hyperthermia in the treatment of such cases, combined with chemotherapy or radiation therapy. The dosage of chemotherapeutic agents was reduced to half the usual dose, while radiation was delivered in divided doses. Subsequently, local hyperthermia was used with success for treatment of breast cancer [4].

Because of the accumulated knowhow and results obtained with such treatment, in 1975 the USSR GUMS [Main Administration of Medical Service?] approved hyperthermia as a clinical method for treatment of patients at early stages of illness in the clinic of the Minsk Scientific Research Institute of Oncology and Medical Radiology.

By decision of GUMS, the method of local SHF hyperthermia was permitted in 1979 for use at the clinics of five other oncological institutes.

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