Biological action of alternating electric and magnetic fields

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SUMMARY

The article, which is of a review nature, examines the biological effects observed under the action of extremely low-frequency alternating and pulsed magnetic fields from sources of natural and artificial origin. Molecular and membrane mechanisms of interaction of magnetic fields with biological objects are analyzed. The results of experimental studies of the effect of variable and pulsed magnetic fields on the functional systems of the body are presented: nervous (behavior and neurophysiology), cardiovascular, immune, endocrine systems, etc.

Key words: alternating magnetic fields, pulsed magnetic fields, naturaland artificial sources of fields, mechanisms of biological action, molecular and membrane mechanisms of interaction, biological effects of action, influence on the functional systems of the body.

RESUME

A survey article considers biological effects observed during the action extremly low frequency alternating and pulse magnetic fields from the sources of natural and artificial origin. The molecular and membrane mechanisms of interaction between magnetic fields and biological objects are analyzed. The results of experimental studies of the effects of alternating and pulse magnetic fields on the functional systems of the body: nervous (behavior and neurophysiology), cardiovascular, immune, endocrine system, etc. are presented.

Keywords: alternating magnetic fields, pulse magnetic fields, natural and artificial sources of fields, the mechanisms of biological effects, mechanisms of molecular and membrane interaction, biological effects on functional systems of the body.

Introduction

Variable electric (PeEP) and magnetic fields (AEF) are part of the extremely low frequency (ELF) range of electromagnetic fields, which are most common in industrial conditions and in everyday life, and are also used for medicinal purposes. The analysis of publications devoted to the biological effect of ELF EMF indicates that most studies have been and are being carried out in relation to fields of industrial frequency (50 or 60 Hz). The main focus of the overwhelming number of these studies is hygienic, focused on assessing the risk to human health, substantiating and developing recommendations and standards regulating safe exposure levels.

The number of publications devoted to the biological action of PeEP and PeMP is currently enormous, and within the framework of one article it is not possible to touch upon all the subtleties of this most interesting problematic [1–7]. In this regard, the main focus was on those theoretical concepts and research that are currently considered the most experimentally substantiated. It should be noted that the problem of the biological action of PeEP and PeMP concerns not only the ecological and medico-biological significance of natural electromagnetic fields, but also, to a greater extent, electromagnetic radiation of technogenic origin in this frequency range. In this regard, the article will only consider fundamentally important questions of the biological action of PeEP and PeMP, necessary for understanding the mechanisms of the influence of fields on the processes occurring in a living organism.

PeEP and PeMP of natural and artificial originThe frequencies under consideration are in the range from 0 Hz to 100 kHz, including industrial frequencies (50/60 Hz), in which, as already mentioned, the largest amount of experimental research is concentrated. The electric and magnetic components of electromagnetic fields in this frequency range are considered separately.

Natural PeEP and PeMP are mainly of terrestrial origin. Considering each of the elements of terrestrial magnetism, it should be noted that they are not stable in time and experience periodic fluctuations or variations, which by their nature are divided into slow and fast. The component with slow or secular variations is called the main (constant) magnetic field and is mainly due to sources located inside the Earth. The variable component, in addition to the magnetic component, also contains an electrical component, thereby being part of the electromagnetic field (EMF) of the Earth, which owes its appearance to the activity of the Sun [8].

In addition to electromagnetic radiation from the Sun, a stream of charged particles (mainly protons and neutrons) is constantly moving, forming a solar wind propagating in all directions, which, flowing around the Earth, forms a magnetosphere around it. The geomagnetic field (GMF) prevents the penetration of the solar wind to the Earth's surface, but its energy is partially transformed in the magnetosphere, which itself becomes a source of EMF in the ELF frequency range. They are not screened by the ionosphere and are observed in the atmosphere as micropulsations. In a higher frequency range, there are PEECs of thunderstorm origin - atmospherics, the main part of which falls on a frequency section of the order of 10 kHz. The space between the Earth's surface and the lower layers of the ionosphere is considered as a cavity in which the propagating wavelength is commensurate with the linear dimensions, i.e. That is, it forms a kind of waveguide. Oscillations of the PeES in the "Earth-ionosphere" waveguide are excited by a lightning discharge formed during more than 2000 thunderstorms constantly occurring in the atmosphere, during which lightning strikes the earth's surface about 16 times per second, and are characterized by maxima at certain (resonant) frequencies of about 8 Hz, 14 Hz, 26 Hz and 32 Hz. These frequencies were named Schumann resonances by the name of the German physicist who discovered them (W.O. Schumann).

Artificial, or anthropogenic, PeEP and PeMP have, as a rule, a higher intensity than natural ones, which is especially true for the fields created by sources operating at industrial frequencies of 50 Hz (Europe, Russia, China) or 60 Hz (USA and Australia) ... In the surrounding space, these sources form fields with an intensity many orders of magnitude higher than natural fields of the same frequencies. Other anthropogenic sources are used in research, industry and medicine, as well as in some technological processes associated with the production and transmission of energy at a distance. The presence of PEEP and PMP in residential and industrial premises is due to the operation of many technical means and devices surrounding a person, among which are: household appliances, overhead power lines, transport, security systems,

In medicine, PeEP and PEM are used for diagnosis and treatment [9, 10]. Diagnostic methods using nuclear magnetic resonance (NMR) involve exposure to high-intensity fields. The modern generation of devices for obtaining NMR images used in clinical practice uses fields with an intensity of 0.3 to 2 T. Pulsed magnetic field (UTI) treatment is used to accelerate the healing of bone fractures, as well as improve wound healing and tissue regeneration. For this purpose, IMFs with an induction value of 0.3 to 2.5 mT are used, which induce peak electric field strengths in the bone in the range of 0.075–0.175 V / m. UTIs are also used in bioresonance therapy with frequencies closest to those of the body.

human signals. The therapeutic effect is realized in the frequency range 0.01 Hz to 15 kHz with intensities of IMF from 0.05 to 5 mT. The use in medicine of therapeutic devices that generate PEMs and UTIs is expanding especially rapidly.

Interaction of PeEP and PeMP with biological objects and mechanisms of action

PeEP and PeMP at the macroscopic level in organs and tissues can induce currents with an intensity that causes biologically significant effects, but at the cellular level their effect is much less [11–13]. An important factor that should be taken into account when assessing the response of biological systems to PeEP and PeMP is the waveform: sinusoidal or pulsed (rectangular, sawtooth, exponential, etc.). For these fields, two parameters are of key importance: the rise and fall times of the signal, which determines the maximum rate of change in the field intensity. In these cases, the electrical properties of tissues (conductivity and capacitance) are of great importance, which differ significantly for different tissues and, in turn, depend on frequency.

The concept of dosimetry for PEEP and PMP is to quantify the impact of the field on biological objects and systems of various levels of organization and, accordingly, complexity [11–14]. For a detailed assessment of the data obtained in the study of the biological effects of PeEP and PeMP, exposure conditions must be carefully controlled and measured. In these cases, the "dosimetry" of PeEP and PEM is very difficult, since it is necessary to take into account many, often ambiguous factors.

The modern understanding of the mechanisms of interaction of AMFs with biological media makes it possible to consider exclusively preliminary dosimetric concepts for low-frequency fields, since they are all very complex [15]. In the body, PeEP and PeMP induce currents, the values of which are determined by the radius of the current path, the frequency of the field and its intensity in a given place of the body. In contrast to the PeEP, for which the field strength inside is many orders of magnitude less than the external field, the magnitude of the PeMP flux density inside the body is approximately the same as outside it. The intensities of the induced PeEP and, for the PEM, the current densities are greatest at the periphery of the body, where the current paths are the longest. The value of the current density is also influenced by the electrical conductivity of the tissues, since the specific paths of current passage in a complex way depend on their conductive properties, significantly different in different fabrics. It should be noted that the value of the current induced in the tissues is of particular importance not only in the hygienic aspect, from the point of view of safety for humans, but during magnetotherapy [16].

The intensity of the induced or magnetically induced electric field and, accordingly, the current density in the tissues can be a quantitative quantity that determines the biological effects of the action of PeEP and PeMP at the cellular level [12, 13]. The main values of the induced currents are given in table. 16]. According to the calculations of the AMF in the frequency range of 1-100 Hz, which can cause a current in tissues with a density of about 1 mA / m^2 or less, do not directly affect the electrical activity of the brain. The study of human perception of PEM with an induction of 2.1 mT and a frequency of 60 Hz did not reveal reliably sensitive individuals among more than 200 examined. Several behavioral tests in mice exposed to 60 Hz PMF causing a current density of approximately 1 mA / m^2 in the peripheral part of the skull also gave negative results. The results of these studies made it possible to assume that the ELF AMFs should have significantly larger amplitudes than the theoretically calculated threshold values in order to induce changes in the behavior of the animal.

Table 1

Biological effects caused by the induced current density in the body. According to [6] with cheating.

Биологический эффект	Величина индуцированного тока
Отсутствие подтвержденного биологического эффекта	< 10 мА/м^2
Болевая чувствительность, магнитофосфены, стимуляция роста костей	10–100 мА/м^2
Возможное неблагоприятное действия, возбуждение в нервной системе	> 100 мА/м^2
Экстрасистолия, фибрилляция желудочков	> 1000 мА/м^2

It is not unreasonable to assume that one of the mechanisms is the interaction of induced electric fields and currents with the sheath of the nerve and muscle cells. Such interactions are capable of causing changes in the electrical excitability of these cells, which can lead to the development of further biological reactions [11, 14]. The permeability for ions of the membrane of a nerve or muscle cell depends on the membrane potential, due to which the cell is electrically excitable. Under the influence of an electric field, various charged side groups of some proteins of the cell membrane change their conformation, thereby causing more significant changes in membrane permeability, and the effect of the induced electric field may consist in a change in the ratio of ion channels. Thereby,$^+$, which contributes to its further depolarization. This is accompanied by a slower change in the permeability for K^+ and inactivation of Na^+-channels, which leads to membrane repolarization. Induced fields exceeding a threshold level of depolarization can generate an action potential that can stimulate other excitable cells. PEMs that cause such significant depolarization can lead to nerve irritation or muscle contraction, and sometimes even fibrillation. Low-intensity electric fields induced by AMF can also interact with the nervous system or modulate its activity, but the mechanisms of this phenomenon are not well understood. These interactions can cause changes in electrical excitability and contribute, for example, to the occurrence of magneto- or electrophosphenes in humans, which will be discussed below.

The above-described interactions of PeEP and PMP indicate the presence of a frequency-dependent threshold characteristic in the nervous tissue, which is well studied [5–7]. The main factors regulating this dependence are accommodation and ionic mobility. As a result, a characteristic U-shaped dependence of the threshold current density on frequency is observed with the smallest values for most nerve tissues in the range of 10 Hz – 10 kHz and above. At low frequencies, accommodation effects predominate, which are assumed to be associated with the slow inactivation of Na^+-channels. At higher frequencies, the time required in each cycle for ions to pass through the membrane becomes the limiting parameter; direct electrical excitation promotes heating when exposed to frequencies in the 100 Hz – 300 kHz range.

The mechanism of conversion of PeEP and PeMP for the ELF range has been confirmed in experiments performed on electrically excitable tissues. For other biological effects of ELF fields that induce current density at lower levels (below a level that can significantly affect the membrane potential of the cell), other transformation mechanisms are also assumed. For example, changes in receptor molecules on the cell surface and the binding of ions to the membrane surface, which can occur as a result of the action of PeEP and PEM. All this can cause electrochemical changes in the components of the cell membrane surface, which contribute to changes in intracellular biochemical and physiological functions. As part of the development of these concepts W. Adey proposed numerous theoretical models,

- long-range combined processes arising in the matrix of glycoproteins and lipoproteins that form the cell membrane;
- localized processes occurring at specific ligand-binding sites

(receptors) on the outer surface of the membrane, or phenomena that occur in ion-selective channels that connect the membrane and electrically bind the intra- and extracellular environment.

PeEPs induced in tissues by external PEMs are several orders of magnitude lower than the voltage gradient on the cell membrane, and therefore it is assumed that the cellular response to external ELF fields may include an amplification process, in which low-intensity PeEPs, induced in the extracellular fluid, act as a trigger mechanism for the initiation of cooperative phenomena with a large radius of action in the cell membrane. The main position underlying this theoretical concept is that the cell membrane is in a metastable, non-equilibrium state that can be changed by weak electrical stimuli. Within the framework of various physical models of such interactions, it is usually assumed that the cell membrane is a lattice in which PeEPs cause nonlinear oscillations, which are enhanced as a result of the collective excitation of molecules in certain areas of the membrane. The energy accumulated as a result of such collective excitation of molecules is then realized as metabolic chemical energy by activating ion pumps or enzymatic reactions in the cell membrane [19].

Interactions of PeEP and PeMP fields with the structures of the cell membraneModern experimental data and theoretical models confirm the concept that the interactions of PeEP and PeMP with cells occur at specific loci of the cell membrane [6, 7, 19]. Modern theoretical approaches substantiate the possibility that these low-intensity effects can significantly alter either the interactions between ligands and receptors on the membrane surface, or the transmembrane transport of basic cell electrolytes. There are the following theoretical and experimental developments in this area.

a) interactions between ligands and receptors

In the model proposed by A. Chiabrera, the microelectrophoretic movement induced in the cell membrane by PeEP affects the average distance between charged ligands and receptors located on the cell surface [20]. According to this theoretical model, the effect of PeEP is to decrease the average lifespan of the ligand-receptor complex on the membrane surface. It is assumed that this effect can affect various biological processes, such as the activation of leukocytes by antigens and various pectins, or the mechanisms that regulate membrane transport of various cations, for example, Ca ions.$^{2+}$...

b) combined interactions of constant and PMF

Some experimental data suggest that the effects of ion cyclotron resonance can occur between constants and AMFs, and at such intensity levels, the values of which are comparable to the intensity levels of the Earth's GMF [21]. There are results concerning the effect on the growth of yeast cells, the reaction of lysozyme with the substrate of the cell membrane, the behavior of rats and the rate of release of Ca ions^{2+} from brain cells exposed in vitro.

Some aspects of the biological action of PeEP and PeMPThe study of the biological action of PeEP and PeMP is of significant practical interest due to the greater prevalence of fields of industrial frequency 50/60 Hz both in domestic conditions and in the industrial sphere [2, 3]. EMFs in the ELF range are used in communication systems with submerged submarines, and the study of their biological action is primarily aimed at assessing possible environmental consequences [22]. All these studies are of independent interest, although the considerable amount of factual material accumulated over many years does not allow to assert that the problem of the biological action of ELF fields has been finally solved. In studies of the biological effects of UTIs, a significant proportion is occupied by the therapeutic use of UTIs, due to which it is possible to accelerate the healing of fractures or prevent osteoporosis, which occurs, for example, after the effect of weightlessness during long-term space flights [9, 10]. The subsequent analytical review of the biological effects arising from the action of PeEP and PeMP is based on modern literature data presented in collective monographs, published materials and recommendations of the World Health Organization and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [5–7, 9, 23].

Behavior. Studies of the behavioral reactions of animals to the action of PeEP and PeMP have shown that they are capable of perceiving them: mice avoid PeEP with a frequency of 10 Hz with a voltage of 3.5 kV / m, hamsters and rats - PeEP with a frequency of 50 Hz at 0.9 kV / m and 10 kV / m, respectively. The ability of migrating birds to orientate under the influence of PeEP with a strength of 0.07 V / m and PEM with an induction of 0.1–0.5 μT with frequencies of 72–60 Hz is impaired. It should be noted how high their sensitivity to AMF is - in this case, the induction is less than 1% of the Earth's GMF. The process of memorization in rats under the influence of PeEP with a frequency of 50 Hz throughout the experiment with a voltage of 50–70 kV / m, as shown by studies with conditioned reflexes, was impaired, and there was a tendency to prolong this effect.

Neurophysiological changes under the action of PeEP and PMP distinctly were registered in the first and in further studies of the biological effects of the action of fields.

A reduction in the reaction time was observed in monkeys exposed to PeEP at a strength of 56 V / m in the frequency range from 7 to 75 Hz, and for fields with a frequency of 7 Hz, a dependence on the intensity was established. In studies on volunteer subjects, a complex nature of changes in the time of a person's sensorimotor reaction to a light stimulus was found, depending on the magnitude of the PMF with a frequency of 50 Hz. From 0.4 to 6 kA / m, the reaction time increased, which indicated the development of inhibitory processes, with a further increase to an intensity of 7.8 kA / m it decreased, at 7.8 kA / m it did not change, and at 8.2–8 , 8 kA / m acceleration of the reaction time, characteristic of increased excitability, was noted. The results obtained correspond to the concept of three phases in the body's response to an increasing stimulus: PMF with a tension of up to 8 kA / m refers to weak stimuli that cause "preventive" protective inhibition, and over 8 kA / m - to stimuli of medium strength, causing an increase in excitability or the "activation" phase. According to some reports, the PeEP intensity of 1 mV / m is for most people a threshold value for changing the time of their reactions. There is also a frequency dependence of this parameter: PeEP with a frequency of 3 Hz slows down the response time, and with a frequency above 10 Hz, on the contrary, accelerates it.

In the experiments carried out under the direction of W. Adey, results were obtained that have not yet received a satisfactory explanation: an increase in the yield of labeled calcium ions [$^{45}Ca^{2+}$] from the brain tissue of chicken and cat in vitro. The paradox of the results obtained was that a statistically significant increase in the 45Ca yield^{2+} from the brain tissue occurred only at certain frequencies and only at certain intensities of the PeEP. Thus, the effect of 45Ca yield^{2+} was observed after a 20-minute exposure of a brain tissue sample at tensions of 10 and 56 V / m and a frequency of 6 and 16 Hz and, at the same time, was absent at intensities of 5 and 100 V / m and frequencies of 6, 16 and 32 Hz [24] ... After confirming the data obtained by carefully controlled experiments, these phenomena are called "frequency" and "energy windows". These results formed the basis for further numerous studies carried out both by the discoverers of this phenomenon and in many other scientific teams. For example, reliable results were obtained, indicating the presence of two amplitude maxima for the 45Ca ion yield $^{2+}$ from chicken brain tissue in vitro after a 20-minute exposure in

PeEP with a frequency of 16 Hz at 5–7 and 35–50 V / m and no influence at voltages 1–2; 10-30 and 60-70 V / m at the same frequency. Somewhat later, new results were obtained for the PeEP frequency range from 1 to 120 Hz and field strengths from 25 to 65 V / m with exposure for 20 minutes. The effect of increasing the yield of 45Ca ions2+ from chicken brain tissue was reliably observed at voltages: 35, 40, 45 and 50 V / m (frequency 45 Hz), 45 and 50 V / m (frequency 50 Hz) and 35 and 40 V / m (frequency 60 Hz) and not manifested itself at an intensity of 40 V / m at frequencies of 1; thirty; 42 and 120 Hz.

Sensory systems were one of the first objects of investigation of the AMF action. A well-studied biological effect associated with direct human perception of AMF is the so-called magnetophosphene. This long-known (it was discovered by D'Arsonval in 1896) phenomenon consists in the appearance in people with closed eyes of sensations of flashes of light when the head is irradiated with a PMF with an induction of more than 10 mT and frequencies of more than 10 Hz. At one time, there was an idea that the occurrence of magnetophosphenes was associated with the influence of PeMP on the excitable structures of the brain, but then the phenomenon of electrophosphenes was discovered, which also arises under the action of PeEP. As a result of the research, it was concluded that the mechanisms underlying phosphenes caused by the action of PEM or PeEP are the same. Investigations have established the optimum sensitivity in the range of 20–30 Hz, both for electro- and magnetophosphenes at induction in the range of 10–12 mT. Later, in experiments on the isolated retina of the frog eye, it was shown that the effect is not on the structures of the brain, but on the photoreceptor apparatus, and the effect is most likely realized in photoreceptors, and not in postsynaptic neurons. Recently, new theories of magnetophosphenes have appeared, which have yet to obtain experimental evidence of their validity [25, 26]. and not in postsynaptic neurons. Recently, new theories of magnetophosphenes have appeared, which have yet to obtain experimental evidence of their validity [25, 26]. and not in postsynaptic neurons. Recently, new theories of magnetophosphenes have appeared, which have yet to obtain experimental evidence of their validity [25, 26].

The cardiovascular system. As shown by the results of many studies, as a rule, there are no pronounced effects of the influence on the cardiovascular system of both PeEP and PeMP. There is only some information about the reliably observed effects. So, for example, 15 minutes after the exposure of the mice to the PeEP with a voltage of 5.3 kV / m, bradycardia was noted, after which the heart rate slowly increased and remained at the same level throughout the experiment, which lasted 21 days. In contrast to these results, in rats exposed to PeEP with a voltage of 80 kV / m, which alternated with periods of rest, at the beginning of exposure, the heart rate and respiration significantly increased, which subsequently returned to normal values.

The blood system under the influence of PeEP and PEM, as studies have shown, in the overwhelming majority of cases reacts with a change on the part of leukocytes, while the effect on the content of other cells is much less. A study of the blood of rats that had been in the PEEP with a voltage of 100 kV / m for 1 year showed a decrease in the total number of leukocytes, while the content of other blood cells remained unchanged. In experiments with rabbits with a daily exposure of animals for 8 hours a day for 3 months with a PEEP with a voltage of 40 kV / m, an increase in the number of leukocytes and a tendency to lymphopenia were revealed, which persisted throughout the entire exposure. In the blood of rats that were kept for 3 hours in an AMF with a frequency of 0.5 and 8 Hz with a tension of 4-ten3 A / m, an increase in the number of leukocytes was noted, and the time of blood coagulation also changed, while at the same frequencies and exposure time, but with a doubled intensity, the opposite effect was noted. Phase changes in the content of leukocytes in the blood of rats were observed during their entire stay (6 months) in the AMF with a frequency of 50 Hz with intensities of 75, 750 and 7500 A / m, and only in the case of 7500 A / m, leukopenia was noted at the very beginning of the experiment. The dynamics of morphological changes in the group lymphatic follicles of rabbits during a daily 6-hour exposure to AMF with a frequency of 50 Hz at 16000 A / m was sinusoidal.

Stay of mice in an IMF with a voltage of 3.5 kV / m and a pulse repetition rate of 10

Hz for 56 hours reduced the hematocrit value after 14 days, however, this effect disappeared during further exposure. In the case of using an MFI with a pulse repetition rate of 6 Hz with a strength of 4-ten3 A / m, when rats were exposed for 3 hours, the number of peripheral blood leukocytes increased, and with an increase to 4-ten6 A / m - decreased.

The immune system was studied from both nonspecific and specific immunity. In the process of changing the phagocytic activity of rat leukocytes under the influence of AMF with a frequency of 50 Hz for 14 days at an intensity of 1600 A / m, three phases were observed: stimulation, which develops 48 hours after the onset of exposure, inhibition, which forms on the 3rd day and, starting from the 5th day, adaptation phase. The dynamics of the complement content in the blood of rats upon exposure to the AMF under similar experimental conditions, but with an increased field intensity up to 16000 A / m, was characterized by maximum values 6 hours and 3 days after the start of the experiment and a decrease on days 2 and 7. Under completely identical exposure conditions, the proliferative processes in the rat spleen, assessed by the number of pyroninophilic cells, were activated in the course of exposure to PMP after 24 hours, on the 3rd and 14th days and were reduced on the 7th day of the experiment. The dynamics of proliferative processes in the thymus of rats (the number of lymphoblasts) with the same as in the previous case, parameters and time of exposure to AMF also had an undulating character: activation after 12 hours and 5 days, inhibition after 48 hours and on 7 days. The same changes are observed in the complement content in the blood of rabbits when exposed to an AMF at a frequency of 50 Hz with an induction of 45 mT for 15 minutes, which consists in a decrease on days 1 and 3, an increase on days 7 and again a decrease on days 14. parameters and time of exposure to PMF also had a wave-like character: activation after 12 hours and 5 days, inhibition after 48 hours and on 7 days. The same changes are observed in the complement content in the blood of rabbits when exposed to an AMF at a frequency of 50 Hz with an induction of 45 mT for 15 minutes, which consists in a decrease on days 1 and 3, an increase on days 7 and again a decrease on days 14. parameters and time of exposure to PMF also had a wave-like character: activation after 12 hours and 5 days, inhibition after 48 hours and on 7 days. The same changes are observed in the complement content in the blood of rabbits when exposed to an AMF at a frequency of 50 Hz with an induction of 45 mT for 15 minutes, which consists in a decrease on days 1 and 3, an increase on days 7 and again a decrease on days 14.

The endocrine system was studied when the rats were in the PEEP with a frequency of 50 Hz and a voltage of 100 kV / m for 12 days. Exposure led to an increase in the content of catecholamines in the blood and an increase in the level of their excretion in the urine. After 6 hours, an increase in the content of adrenaline in the blood of the animals prevailed, and after 12 days of exposure - norepinephrine. In other studies in rats that were kept in a PEEP with a frequency of 60 Hz at a voltage of 15 kV / m for 30 days, a drop in the level of corticosteroid in the serum was accompanied by a decrease in the body weight of the animals, hypertrophy of the pituitary gland and adrenal glands. However, the ability of rats to react to cold stress did not change.

The content of corticosterone in the blood of rats that were in the PEEP of frequent 60 Hz for 5.5 hours, in response to ACTH administration, increased 3 times at an intensity of 10 kV / m, at 5 kV / m the changes were statistically insignificant, and at 100 and There were no 1000 kV / m in comparison with the control animals. However, under in vitro conditions, the opposite effect was observed: after 2 hours of exposure to a PEEP with a frequency of 60 Hz at voltages of 5, 10, 100, and 1000 kV / m, the reaction of adrenal tissues after ACTH administration was observed only at 1000 kV / m.

The phasic nature of reactions from the endocrine glands was observed in mice during their stay for 5 to 320 days in a PEEP with a frequency of 50 Hz and an intensity of 40 kV / m. Exposure during the first 5–10 days in experimental animals increased the activity of the adrenal cortex and the epithelium of the thyroid gland, and by the 20th day, inhibition of the functional activity of both glands was recorded. Further stay of mice in PeEP caused a new wave of increased activity of the adrenal glands and, to a lesser extent, the thyroid gland on the 40th and 80th days. An increase in exposure to 160 and 320 days led to the disruption of adaptation processes.

Reproduction, development and growth began to be especially intensively studied after the results, which at one time caused a certain resonance in scientific circles, obtained in a team led by J. Delgado [27]. In these studies, the development of chicken embryos was traced after their exposure for 40 hours in the AMF at frequencies of 10, 100, and 1000 Hz with intensities of 0.12, 1.2, and 12 μT. A violation of embryogenesis was found only at a frequency of 100 Hz at 1.2 μT, while other frequencies and intensities did not have a significant effect or caused opposite effects.

Cultivation of three generations of mice in conditions of constant presence of PeEP frequency

60 Hz with a voltage of 10 kV / m showed no differences in the frequency of pregnancy in females or in the number of offspring compared with the control group of animals. However, offspring mortality increased at a young age after the first generation, which persisted with repeated exposure, but was observed at an earlier age. During a long, 10-month experiment on the effect of PeEP with a frequency of 60 Hz at a voltage of 160 V / m in mice, no significant differences in the frequency of reproduction of the offspring were found in comparison with control animals. In the range of PeES intensities with a frequency of 50 Hz from 1 V / m to 150 kV / m, the number of induced E. coli bacteria after a 2-hour exposure significantly increases only at 0.5 and 1 kV / m 3.4 and 2.18 times, accordingly, while an increase in intensity up to 150 kV / m leads to their decrease.

Metabolism was studied in mice during exposure to a PEB with a frequency of 50 Hz and a voltage of 4.8 kV / m. The results showed changes in comparison with animals under screening conditions (Faraday cage): after 1 hour, the oxygen consumption of the liver increased, and the body temperature increased.

Exposure of rats to a PEM at a frequency of 50 Hz with a voltage of 16 kA / m for 24 hours reduced the activity of hexokinase by an average of 25%, and an increase in the tension to 72 kA / m caused an even more pronounced decrease in its activity in the liver (by 30%). kidneys (by 28%) and in the heart (by 44%), while no such changes were observed in the brain tissue. The rate of the glycolysis reaction (anaerobic stage) S. cerevisiae in the PEM with a frequency of 1; 2 and 3 Hz accelerated after a 20–30-minute exposure in a field from 4.8 to 40 A / m, while at an intensity above 40 A / m, a reverse reaction was observed. In the case of using frequencies 0.01; 0.1; ten; 50 and 100 Hz at the same intensities of the AMF, the general direction of the responses was reversed.

The current state of knowledge about the mechanisms of interaction of magnetic fields with living systems and the emerging biological effects makes it possible to try to explain some biophysical mechanisms by which PEEP and AMF of low frequency interact with biological objects.

The existing experimental data on the biological reactions of organisms to the action of PeEP and PeMP indicate that phenomenologically they can be explained by three biological effects:

- induction of electrical potentials in the circulatory system;
- induction of magnetophosphenes by low-frequency pulse and PMF with time indicators of changes, amounting to more than 1.3 T / s, or sinusoidal fields of 15–60 Hz and strength from 2 to 10 mT, and in the latter case, a frequency dependence is noted;
- induction of PMF of a wide range of changes at the cellular and tissue levels when the density of the induced current is over 10 mA / $m^2$when many of these effects are likely due to interactions with components of the cell membrane.

It should be especially noted that too few systematic studies have been devoted to the effect of low-frequency PEEP and PMF to determine those threshold characteristics of the field that cause a dose-effect relationship in changes in biological functions. And despite the fact that although many studies in vitro describe various phenomena when inducing currents in the range of values from 1 to 10 mA / m^2, their biological significance has not been determined, which so far does not allow them to be used for dose assessment of the effect of low-frequency PEEP and PMF in relation to magnetotherapy.

In conclusion, it should be noted that the analyzed results of the experimental data allow us to make some generalizations concerning the biological action of PeEP and PeMP of the ELF range. The biological effects of exposure to low-frequency PEEP and AMP are found practically at all levels of organization of organisms - from molecular to organismal. The results of experimental studies indicate that the most sensitive physiological systems are the nervous, immune and endocrine systems. In the overwhelming majority of cases, all noted changes in physiological and biochemical parameters occur as part of the body's response to weak or moderate irritants. All these changes in a complex way depend on the energy and amplitude-frequency characteristics of the PeEP and PEM and the time of their action. The entire complex of experimentally observed functional changes caused by the action of PeEP and PeMP can be considered as evidence of the activation of the systems of nonspecific adaptation of the organism, which contributes to an increase in its resistance to the action of other unfavorable factors. At the same time, it should be emphasized that there is still a lot of unclear in the biological action of PeEP and PeMP, although the available research results will allow us to rethink the participation of ELF electromagnetic fields in the organization and regulation of biological processes that occur at the system level.

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