Magnetotherapy and its place in modern medicine

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SUMMARY

The issues of magnetotherapy are considered - the use of alternating magnetic fields for therapeutic and prophylactic purposes. The basic physical principles of magnetotherapy and biophysical mechanisms of action of alternating magnetic fields are analyzed from the standpoint of dosimetry. Attention is drawn to the features of the use of alternating magnetic fields of low intensity in a pulsed mode in therapy.

Key words: magnetotherapy, alternating magnetic fields, dosimetry,low intensity alternating magnetic fields, pulsed alternating magnetic fields.

RESUME

The use of alternating magnetic fields for therapeutic and prophylactic purposesmagnet therapy is discussed. Basic physical principles of magnetic therapy and biophysical mechanisms of action of alternating magnetic fields from the standpoint of dosimetry are analyzed. The detailed attention is given to therapeutic application of alternating magnetic fields of low intensity in pulsed mode.

Keywords: magnet therapy, alternating magnetic fields, dosimetry, alternating magnetic field of low intensity, alternating magnetic field in pulsed mode.

Introduction

Magnetotherapy is a method based on the effect of magnetic fields on the human body, pursuing therapeutic or prophylactic goals [1]. The entire history of the existence of magnetotherapy is characterized by many ups and downs. In recent years, interest in magnetotherapy has been steadily growing due to the development of medical technology, which has made it possible to create new devices for exposure to magnetic fields with various parameters [2]. An important role in the development of magnetic therapy was played by progress in the methods of clinical diagnostics, thanks to which reliable evidence of the presence of magnetic fields with a pronounced therapeutic and prophylactic effect was obtained. Currently, the main attention to the biological action of AMF is concentrated in the field of industrial frequencies (50/60 Hz), for which it is implied, $B = B_f \sin 2\pi ft$, where B_f -amplitude, and f - frequency [3]. Such studies are aimed at identifying the possibility of adverse effects on human health, in particular on the oncology, which gives rise to the need to have reliable factual data from the field of biology and epidemiology [4, 5].

However, in magnetotherapy, the patient is exposed to a constant, alternating, pulsed, as well as a running or rotating magnetic field, which significantly expands the therapeutic capabilities of this physical factor [6]. However, in comparison with the volume of studies on the biological effect of magnetic fields of industrial frequencies, AMF used in magnetotherapy have been studied incomparably less. Thus, even at the present time there is still a lot of unclear, both in the mechanisms of interaction of magnetic fields with cells and organs, and in the ways of transforming the energy of the magnetic field into the response of the organism.

Modern concepts of PMF dosimetryThe concept of dosimetry for PMP is to quantify their impact on biological objects and systems of various levels of organization and, accordingly, complexity [7, 8]. For a detailed assessment of the data obtained in the study of the biological effects of AMF, the exposure parameters must be carefully controlled and measured. In these cases, AMF dosimetry is very difficult, since it is necessary to take into account many, often ambiguous, factors. The accuracy and reliability of dosimetry must be weighed against existing conditions and actual or potential adverse effects or non-therapeutic effects of AMF. In the past, much of the research in dosimetry has relied on induced electrical currents in the body as the main measured parameter. and therefore dosimetry indicators were determined by this quantitative parameter. Relatively recently, the study of the relationship between the action of an external AMF and induced electric currents has been recognized. In order to better understand the biological effects, and, as a consequence, to get a deeper understanding of the therapeutic effect, it is necessary to have more data on the internal electric fields arising from external influences of AMF. Numerical dosimetry is one of the most promising methods for calculating internal electric fields caused by the combined action of external AMFs as applied to magnetotherapy [9]. Calculations of the vector addition of oscillations in different phases and the effect of magnetic fields in accordance with their spatial variation are necessary to assess the main issues of AMF dosimetry. Together with that, there is a need for additional improvement of microdosimetric models that take into account the cellular architecture of neural networks and other complex organ systems that are most sensitive to the effects of induced electric currents. The human body does not have a noticeable distorting effect on the distribution and structure of the magnetic field. AMF induces currents in the human body, the values of which are determined by the radius of the current path, the frequency of the field and its intensity at a given place or point of the body. The density of the PMF flow inside the body is practically the same as outside. The intensity of the PMF-induced electric field and the corresponding current densities are maximum at the periphery of the body, where the current paths are the longest. The current density is also influenced by the electrical conductivity of tissues, since the specific paths of current passage in a complex way depend on their conductive properties, which differ significantly in different tissues depending on the water content in them [10].

Modern knowledge about the mechanisms of interaction is not complete enough, and therefore, the conditions of therapeutic exposure are often quantitatively expressed in terms of the intensity of the external AMF and the duration of exposure, which is considered as a dose. In this case, it is necessary to take into account a number of factors, some of which, affecting the interaction of AMF with the body, can be summarized in the following form.

The characteristics of the PMP:

1. Frequency.
2. Modulation (pulse, amplitude, frequency), rise and fall times (dB / dt).
3. Polarization.
4. Field strength.
5. The nature of the field (homogeneity).
6. Properties of surrounding materials.

Parameters relevant to exposure:

1. Properties of fabric (electrical conductivity, magnetic permeability and their anisotropy).
2. Dimensions (geometry).
3. Orientation relative to polarization (vector).
4. The nature of the impact (local, general).

The current state of knowledge about the mechanisms of interaction of magnetic fields with living systems and the resulting biological effects allows us to consider some physical mechanisms of interaction of low frequency AMF with biological systems [4, 7, 8]. The leading mechanism of interaction is magnetic induction, according to which, according to Faraday's law, magnetic fields varying in time cause potentials and circulating currents in biological systems: $J = E\sigma = (\pi r^2 / 2 \pi r) \times (dB / dt) \times \sigma = (\sigma r / 2) \times (dB / dt)$, where J - current density (A / m^2), E - evoked potential (V / m), r -radius of the induction circuit (m), σ - tissue electrical conductivity (S / m), dB / dt - rate of change in magnetic flux density. For sinusoidal fields with frequency f the above equation takes the form $J = \pi r f \sigma B_0$, where B_0 - amplitude of the magnetic field.

Thus, the values of the induced electric field and current density are proportional to the radius of the contour, tissue conductivity and the rate of change in the magnetic flux density. The dependence of the induced field and current on the radius of the circuit through which flux linkage occurs is a very important factor for biological systems. AMFs of moderate intensity at the macroscopic level can excite significant circulating currents; however, at the cellular level, currents are characterized by significantly lower values [11, 12]. Since PMFs induce internal electric (eddy) currents in a biological object (organism), the estimate can be based on the density of the electric eddy current (intensity electric field) in vital organs. In this case, one should take into account the field strength, the shape of the pulses (rise and fall times) and their frequency, the orientation of the body and the duration of exposure.

The density of the induced current can be used as one of the most indicative parameters in assessing the biological effects of exposure both at the cellular level and at the level of the whole organism. However, the search for the optimal therapeutic dose for a person by comparing the current density in the tissues with the intensity of the external PMF is rather difficult as applied to magnetotherapy. Currently, the following relationships have been established between the values of the induced current density and the corresponding values of the magnetic flux density of a sinusoidal homogeneous PMF, and mainly for frequencies of 50/60 Hz, which cause biological effects when exposed to the body as a whole [4]:

- at an induced current density of 1-10 mA / m^2 (induced magnetic fluxes with a density of 0.5–5 mT at 50/60 Hz or 10–100 mT at 3 Hz) minimal biological effects are observed;
- at an induced current density of 10–100 mA / m^2 (5-50 mT at 50/60 Hz or 100–1000 mT at 3 Hz), pronounced biological effects are noted, including those from the visual and nervous systems;
- at an induced current density of 100-1000 mA / m^2 (50-500 mT at 50/60 Hz or 1-10 T at 3 Hz) excitable tissues are stimulated and there is a possibility of a health hazard;
- when the density of the induced current is higher than 1000 mA / m^2 (more than 500 mT at 50/60 Hz or 10 T at 3 Hz), acute health problems occur, including extrasystoles and ventricular fibrillation.

It should be especially emphasized that for AMFs with a different nature of the signal (non-sinusoidal or pulsed) with short-term pulses of the fields, the rate of variation of the magnetic flux density with time should be taken into account. In this case, in the analysis of some biological effects arising from the action of pulsed magnetic fields, it is necessary to take into account the amplitude (peak) values of the induced current density, the values of which will be different.

General mechanisms of the biological action of AMF

The question of the effect of AMF on biological objects has been debated for many years, but the final opinion on the primary physical mechanisms responsible for these interactions has not yet been finally formed [11–14]. There are the following mechanisms of the primary action of constant and variable magnetic fields on biological objects.

A wide range of physical interaction mechanisms can take place between magnetic fields and living tissue. At the level of macromolecules and larger structures, the interaction of AMFs with biological systems can be characterized as electrodynamic or magnetomechanical. Electrodynamic effects arise when magnetic fields interact with moving electrolytes, which contributes to the induction of electrical potentials and currents. Magnetomechanical phenomena include orientational effects on assemblies of macromolecules in homogeneous fields and translation of paramagnetic and ferromagnetic molecules in strong gradient fields. PMFs also interact with living tissues at the macro- and microscopic levels, promoting the formation of circulating currents through the mechanism of magnetic induction. The interaction of AMF with biological tissues by magnetic induction is carried out in the following ways [4].

Electrodynamic interactions with electrolytes

In mobile charge carriers (ions), AMFs excite Lorentz forces and, therefore, amplify the induced fields and currents. This interaction is the basis of magnetically induced potentials in the blood flow system, which were studied as under the influence of low-frequency AMF. The same mechanism is the physical basis for the appearance of weak evoked potentials that create sensory signals in some animals when they cross magnetic field lines.

Faraday currents

Low-frequency AMF induce currents in living tissues in accordance with Faraday's law of induction. It is assumed that this mechanism may underlie visual-sensory stimulation, which induces the formation of magnetophosphenes and other effects in electrically excitable tissues. In addition, indirect evidence suggests that rapidly changing magnetic fields can affect many cellular and tissue systems by inducing local currents, the levels of which are higher than those found in natural conditions. This effect can serve as the basis for a wide range of biological changes observed when exposed to pulsed magnetic fields.

An important factor that should be taken into account when assessing the response of biological systems to the action of AMF is the waveform, which can be sinusoidal, rectangular, exponential, or impulsive. For these fields, two parameters are of key importance: the rise and fall times of the signal, which determines the maximum rate of change of the field in time (dB / dt) and,accordingly, the maximum instantaneous (peak) values of the density of currents excited in the tissues. Of great importance is the conductivity of the tissue, which, in turn, depends on the frequency and is different for different tissues.

Experimental data on the reactions of organisms to the action of AMF indicate that phenomenologically they can be explained by three biological effects:

a) induction of electrical potentials in the circulatory system; b) induction of magnetophosphenes by low-frequency pulse and PMF with temporal indicators of changes of 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 observed;

c) induction of AMF of a wide range of changes at the cellular and tissue levels at an induced current density of more than 10 mA / $m^2$when many of these effects are likely due to interactions with components of the cell membrane.

Among the numerous proposed biophysical mechanisms of direct interaction of AMF with the human body, three are distinguished as the most probable: induced electric fields in neural networks, free radical pairs, and biogenic magnetite. Electric fields induced in the PMF tissues directly stimulate single myelinated nerve fibers when the internal field strength exceeds several V / m. Unlike individual cells, much weaker fields can affect synaptic transmission in neural networks. Such signal processing by nervous systems is commonly used by multicellular organisms to detect weak environmental signals [14]. It was suggested that the lower limit of the signal intensity distinguished by the neural network is 1 mV / m, however, given the latest data,

The mechanism of free radical pairs is one of the most probable mechanisms of AMF action on special types of chemical reactions. Such changes are manifested in magnetic fields with an induction of less than 1 mT and can be considered as one of the probable mechanisms of biological action [15]. However, the ability of such interactions to cause significant changes in cellular metabolism and functions is sometimes questioned. Especially controversial is the lower limit of the impact of AMF, on the basis of which it can be judged whether or not this mechanism may be the leading one in biological effects.

Magnetite crystals, small ferromagnetic crystals of iron oxides of various shapes (ferromagnetic material of biological origin - biogenic magnetite Fe_3O_4), are present in tissues of animals and humans and accumulate inside cells in the form of magnetosomes [16]. Calculations based on extreme assumptions allow us to conclude that the lower limit of the effects of AMF action on magnetite crystals is 5 μT [17]. Based on these results, it was suggested that the effect of external AMFs on the cells of the body can also be realized through this mechanism. Attempts to elucidate the localization of magnetoreceptors in animals and humans were aimed at searching for magnetite deposits in tissues, as well as identifying those structures of the nervous system that can participate in the perception or transmission of signals. In experiments on animals, a wide distribution of deposits of magnetite in the head and other parts of the body of rodents was found. The current absence of any information on the presence of magnetite particles in the pineal gland does not allow us to assert that the cells themselves perceive AMF; most likely, these reactions of the pineal gland are mediated through the neuroendocrine system [18]. According to modern data, the presence of magnetite crystals in the human brain does not allow us to unequivocally assert any selective sensitivity to external AMF, but in

Under certain conditions, such information can be of key importance.

Recently, other types of direct biophysical effects of AMF have been considered, such as: disruption of chemical bonds, exposure to charged particles, heat shock proteins (HSP-70) and various mechanisms of narrow-band "resonance" associated with the participation of intrinsic cellular magnetic fields [19, twenty].

It should be especially noted that too few systematic studies have been devoted to the effect of low-frequency AMF, with the exception of fields of industrial frequencies of 50/60 Hz, so that it would be possible to determine those threshold characteristics of the field, as well as frequencies that cause reliable and unambiguously directed changes in biological functions.

Magnetotherapeutic aspects of the biological action of PEMIn the quantitative assessment of the effect of PMF on a person and the determination of the therapeutic dose, the corresponding dimensioned values are used. The term “appropriate” means that these values should reflect, as accurately as possible, those physical processes that are most closely related to the biological effects of AMF. As the main parameter for assessing the impact on a person of AMF with a frequency of 10 Hz to 100 kHz, the density of the electric eddy current is taken. By comparing the current density, biological effects in the human body can be predicted by analogy with those found in animal and isolated cell studies. The human exposure assessment methodology that uses current density is primarily based on the concept of dose, the main values of which can be expressed in terms of the permissible current density, and their derivatives - in terms of the effect of external AMF, for which it is necessary to clarify the field strength, frequency, body orientation and exposure. The refinement parameters are the values of the field gradients, partial effects on the body, etc. Induced eddy currents in organs are currently not measurable in practical conditions. Thus, the only significant parameters that can be practically used in order to assess the impact of AMF are the theoretical assessment of the distribution of the magnetic flux density of the field in the human body and the values of the densities of the induced currents. The refinement parameters are the values of the field gradients, partial effects on the body, etc. Induced eddy currents in organs are currently not measurable in practical conditions. Thus, the only significant parameters that can be practically used in order to assess the impact of AMF are the theoretical assessment of the distribution of the magnetic flux density of the field in the human body and the values of the densities of the induced currents. The refinement parameters are the values of the field gradients, partial effects on the body, etc. Induced eddy currents in organs are currently not measurable in practical conditions. Thus, the only significant parameters that can be practically used in order to assess the impact of AMF are the theoretical assessment of the distribution of the magnetic flux density of the field in the human body and the values of the densities of the induced currents.

Magnetotherapy is one of the components of bioresonance therapy (BRT), more precisely, exogenous BRT, which uses the effect of PMF at fixed frequencies [21]. The therapeutic effect of exogenous BRT is due to the introduction of an external signal into the biological system, which, acting in a stochastic manner, captures the frequency and phase of endogenous rhythms, which forms a variety of connections between the signal itself and spontaneously oscillating physiological processes in the body. Based on this, the choice of biologically effective frequencies is very important for exogenous BRT, the resulting action of which leads to a therapeutic effect. This approach can be empirically implemented based on the clinical results obtained with the therapeutic application of the selected frequencies.

In exogenous BRT, impulse AMPs are used, since the impact in the rhythmic (impulse) mode is the closest to those in the body and is more easily absorbed by the functional systems of the body. In addition, adaptation to PEM in a pulsed mode develops to a much lesser extent; it becomes possible to significantly diversify the effect according to its physical characteristics, which greatly facilitates the individualization of treatment.

To implement the therapeutic effect of PMP, devices for magnetic therapy made in the form of a solenoid or a frame inductor are connected to devices for carrying out exogenous BRT ("IMEDIS-EXPERT", "MINIEKMPERT"). The therapeutic effect is pulsed PMF in the frequency range from 0.1 Hz to 15 kHz, the intensity of the magnetic field in the center of the device for magnetic therapy in the range from 0 to 5 mT.

The Imedis Center has carried out a large scientific and practical work on the selection of both individual frequencies and combinations of frequencies with specific therapeutic effects. [26, 27, 28]. A number of works [29, 30, 31] have shown their effectiveness in the clinic and in experimental models. An important feature of exogenous BRT is the individual selection of the therapeutic effect, its intensity, duration, and the area of application of devices for magnetic therapy by methods of electropuncture diagnostics.

At the same time, it should be noted that, despite the available publications, the therapeutic use of PEM in a pulsed mode requires further study, in particular the relationship between the therapeutic effect and the effective dose [22]. It is likely that such studies are complicated by the spectral composition of pulsed signals, especially at low values of the magnetic flux density, although it is precisely these AMFs that are used in exogenous BRT.

Recently, the interest in the use of AMF in a pulsed mode in biomedical research has significantly increased. There have been published data showing that an AMF with a frequency of 75 Hz at 3 mT in a pulsed mode has a protective effect against local cerebral ischemia and the development of acute myocardial infarction in animals in experiment [23, 24]. According to the results of other experimental studies, AMF in a pulsed mode with a frequency of 15.95–16 Hz at 80 mT prevents the development of experimental myocardial infarction [24]. However, in the cited publications, only the values of frequencies and induction of the PMF are given, and there is no information about the magnitude of the effective dose in the context of the current density induced by the magnetic flux used in the experiment.

Conclusion

Considering the issues of biological assessment of PMF of complex spectral composition, it can be assumed that a consistent way of solving this problem consists in the experimental establishment of the regularities of the action of fields of specific frequencies with special attention to the issues of dosimetry. It should be especially noted that at present, comprehensive studies on this the issue is almost completely absent. It can be assumed that such studies of the biological action of PEM in a pulsed mode, which have a complex spectral composition, will contribute to the optimal choice of the parameters of the active factor and the individual susceptibility of the patient's body to it. Evaluating the results of the available research, we can conclude that this approach is very promising from the point of view of resonant effects on organs and tissues, taking into account the rhythmic nature of the processes occurring in them, and can be successfully used in the practice of traditional medicine.

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