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Electromagnetic Fields and Life

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Abstract

This review paper analyzes the role of natural and man-made magnetic and electromagnetic fields in origin and evolution of life as well as the effects of contemporary magnetic/electromagnetic fields on human life. Both, hazard and benefit of these fields is discussed with the review of variety of signals that affect human life. The emphasis is on the use of electromagnetic fields in medicine for diagnostics and therapy. The paper demonstrates basic science and clinical achievements in planning and executing studies and clinical trials, as well as the perspectives for future development of magnetotherapy.

Keywords: Electromagnetic field; Magnetotherapy; Medicine

The Role of Magnetic/Electromagnetic Fields in Origin and Evolution of Life

The entire development of natural sciences, such as biology, physics, geology provides substantial evidence that the first primitive cell originated in the presence of a number of physical factors with terrestrial and space origin including magnetic and electromagnetic fields. It is well accepted that Earth possesses own magnetic field formed during the geological evolution of the planet. As a part of the Universe, the Earth has been exposed to the influence of radiation from Sun and other space objects. This includes both ionizing and nonionizing radiation.

However, despite development of physics and geology, reliable information about the values of the magnetic/electromagnetic fields during the evolution of the planet and of the life in the biosphere is missing and eventually will never be known.

Contemporary science now has convincing evidence that the geomagnetic field serves as a protector against space ionizing radiation and magnetic fields reaching the atmosphere, thereby protecting biosphere and all forms of life. The Earth magnetosphere is determined by the Earth's magnetic field, as well as by the solar and interplanetary magnetic fields. In the magnetosphere, a mix of ozone molecules, free ions, and electrons from the Earth's ionosphere is confined by electromagnetic forces.

Once again, life on Earth developed and is sustained under the protection of this spatially and time-variable magnetosphere. The magnetobiology has evidence that when living creature is placed in an environment that is shielded from ambient magnetic field, some changes in the organisms are observed [1]. When microorganisms confined in μ-metal cylinder are missing usual geomagnetic field, the cells are searching for adaptation to newly created conditions and find this way through the mutation in their genetic apparatus.

Contemporary EMF Conditions and Hazard with Wi-Fi Communications

At the same time, contemporary conditions of life put the mankind and the biosphere in dependence on the complex of various physical influences and in the first place - on electromagnetic fields. It could be affirmed that the natural EMF are characterized with their continuous and comprehensive action through the entire living activity of any organism [2-4].

During the last 120 years the biosphere has been exposed to increasing number and variety of electromagnetic fields related to discovery of industrial methods for generating electricity and further innovations in technology, communication, transportation, home equipment, and education.

After initial excitement of advantages for mankind from the use of electricity, voices became raised that it might be some detrimental effects of electromagnetic fields on biosphere and human life. Very often the news media discuss how dangerous electromagnetic/magnetic field might be for human and environmental health, especially in relation to cancer initiation. The hazard should be considered in respect to the continuous exposure to electromagnetic fields in workplace and/or occupational conditions, while at the same time short, controlled exposure to specific electromagnetic fields makes possible therapeutic benefit.

In the USA the hazard issue has been discussed since middle 1980s, beginning with the power-line electromagnetic fields and continuing after 2000 with wireless communications.

Every evaluation of the "hazard" as well as every standard for the permissible level of exposure should be done following the precautionary principle: If we do not know that a given food, drink, medication, physical, or chemical factor is safe, we treat it as potentially hazardous. Having this in mind, the evaluation and prediction of the potential adverse effects from using wireless communications (any mobile device, including), especially for children, becomes a question of crucial importance. The twenty-first century is marked with exponentially increasing development of technologies that provide wireless communications. To the pollution of the atmosphere with radio and TV signals, not only satellite communications but also any varieties of the Wi-Fi networks are added.

By the 2010 in the USA, 285 million mobile phone subscribers have been registered (for a little bit more than 300 million inhabitants). The estimate for the world is more than 5 billion mobile phone users at approximately 7 billion people living on this planet.

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The fast development of satellite communications, followed by wireless communications and recently Wi-Fi technology dramatically, changes the electromagnetic environment. To continuous action of complex and unknown (by sources, amplitudes, frequencies) electromagnetic fields is exposed entire biosphere and every organism living on this planet. It is usually neglected the complex influence of radio and TV transmissions, satellite signals, mobile phones and base stations and wireless communications [5].

The hazard issue is frequently represented as "controversial", and it is absolutely incorrect. It is not controversial issue; it is conflict of interest of industry on one side and mankind and environment on the other.

What science actually knows about nonionizing radiation? Basically NOTHING. Even the simplest and longer studied behavior of natural magnetic, electric and electromagnetic fields (EMFs) are far of complete knowledge. On the other hand, the planet is exposed to various EMFs with space origin. The most sophisticated analysis of the evolution of biosphere from the viewpoint of space - earth relationships was done by Chizevskii long time ago [6]. More than 45 years ago, in 1976 brilliant Soviet magnetobiologist Kholodov wrote a book "Man in the magnetic web." Long before the occurrence of mobile communications, Kholodov pointed out that the entire biosphere is immersed in the ocean of the electromagnetic waves [7].

Speaking on the potential hazard of Wi-Fi technologies, one should not forget that it includes not only mobile phones but also more importantly all means of emitters and distributors of Wi-Fi signals, mainly antennas, base stations and satellites. In many public locations, own systems are introduced in order to facilitate the work performance. Well, this might be understood. However, why Wi-Fi communications are secured in the subway tunnels? At the time of writing this paper, the USA news media arte discussing the possibility to allow use of mobile devices during the flight. It obviously requires high and oriented power to which are exposed all passengers in the trains and planes. Just to make comfortable the users of mobile devices. It is forgotten that in the conditions of confined subway tunnels and planes, to use mobile signal significant increase of the delivered power of the signal is needed.

It is remarkable that IARC (International Agency of Research on Cancer) in the summer of 2011 classified radiofrequency electromagnetic fields as possible cancerogene [8].

So far, the potential hazard from electromagnetic fields is discussed in regard to the human population. However, especially with development of satellite and wireless communication, all living creatures in the biosphere are exposed to electromagnetic fields. This influence is continuous, in most cases 24/7 action.

Benefits of Clinical Application of EMF

The human history provides numbers of evidence for benefit obtained by using various magnetic and electromagnetic fields. Despite the fact that magnetic field use for treatment of various health problems has long and widespread history, the western medicine is still skeptical and reluctant to accept the magnetotherapy as an effective, even complimentary, method for helping patients in cases when pharmaceutical or other therapies failed.

The application of magnetic fields for treating specific medical problems such as arthritis, fracture unification, chronic pain, wound healing, insomnia, headache, and others has steadily increased during the last decades. In contrary to pharmacotherapy, magnetotherapy provides noninvasive, safe, and easily applied methods to directly treat the site of injury, the source of pain, and inflammation [9].

There is a large body of basic science and clinical evidence that time-varying magnetic fields can modulate molecular, cellular, and tissue function in a physiologically and clinically significant manner, most recently summarized in several books and review articles [9-13].

Mechanisms of Detection and Response to EMF

The fundamental question for engineers, scientists, and clinicians is to identify the biochemical and biophysical conditions under which applied magnetic fields could be recognized by cells in order to further modulate cell and tissue functioning. It is also important for the scientific and medical communities to comprehend that different magnetic fields applied to different tissues could cause different effects. Nevertheless, hundreds of studies had been performed in search of one unique mechanism of action of magnetic field on living systems. It would be fair to say that these efforts are determined to fail. Why? For the same reason that during the millions of years of evolution of life, enormous number of different living systems originated. It is difficult to believe that the same response will be seen at bone and soft tissue, at elephant and butterfly, and at microorganism and buffalo. Biology knows that the geographical and climate conditions created genetic and physiological differences in the organisms from the same species [14].

The problem of mechanisms of interactions might be discussed from different points of view, engineering and physics, biology, and medicine. More plausible is to follow the signal-transduction cascade that postulates that in any biological system the modifications that may occur as a result of the influence of the applied magnetic field on structures such as cellular membrane or specific proteins, conformational changes, and/or charge redistribution could be initiated and by signal-transduction mechanism can be spread over the cell or tissue [14].

Does Threshold Exist?

Electromagnetic fields are frequently discussed under the umbrella "radiation" in the category of non-ionizing radiation. For that reason, the research of effects of electromagnetic field is going in parallel with studying the effects of ionizing radiation. As basic physics teaches, radiation constitutes energy, and for that reason the energy interactions with any physical or biological body are connected with damage or heating of the body when the intensity of the radiation is above certain threshold level. Yes, this is correct for ionizing radiation. For decades the same approach has been applied in non-ionizing research. For example, the idea of thermal effects in bioelectromagnetics had been introduced and became the subject of intensive discussions, related to Specific Absorption Rate (SAR) as useful criteria. It is clear that SAR requires a threshold value determination.

However, hundreds of studies and publications reported biological and clinical effects at low-intensity and low-frequency electromagnetic fields, as well as at static magnetic fields. At these interactions it is very unlikely, or even impossible, to expect thermal effects, and the threshold level approach is not reasonable. An important point in these considerations is that even when exposed to static magnetic fields, a relative movement of charged particles (electrons and ions) in magnetic field occurs and magnetic field initiated effects that depend on the specific parameters of the applied field, but not at threshold. Having in mind that even the simplest biological systems are nonlinear systems, the possible means of interactions might involve an informational transfer.

Magnetotherapy

As it was already mentioned, the use of magnetic fields for treatment of medical problems has a long history. However, there are still a lot of problems related to implementation of this approach.

What should magnetotherapy be, and how should it be developed? Magnetotherapy is a part of bioelectromagnetic technology, and therefore requires rigorous interdisciplinary research efforts and coordinated, educational programs. Magnetotherapy cannot be developed without the joint efforts of physicists, engineers, biologists, and physicians. An important role will be played by medical practitioners, including physical and occupational therapists, who routinely use physical modalities, while the scientists need to create dosimetry and methodology for magnetotherapy. It should be noted that magnetic field stimulation requires as precise dosage as any other therapy. However, "dosage" in magnetotherapy is more complicated because it requires understanding a number of physical parameters which characterize the magnetic field generating system. It is important to establish the proper target for magnetotherapy. For example, it has been shown that to stimulate coagulation, one combination of parameters of applied field is required, whereas stimulation of anticoagulation requires another field configuration [15,16]. In other words "different magnetic fields produce different effects in different biotargets under differing conditions of exposure" [17].

An evaluation of the efficacy of these modalities should be based on recognition of the clinical problem, identification of the physiological responses, and a critical review of the reported basic science and clinical data (which includes patient characteristics). Any magnetic stimulation starts with identification of the magnetic field parameters needed for the desired target tissue. The ability of magnetic fields to modulate biological processes is determined first by the physiological state of the injured tissue, which establishes whether or not a physiologically relevant response can be achieved and, secondly, by achieving effective dosimetry of the applied magnetic fields at the target site.

Why in this paragraph the emphasis is on magnetic, not electromagnetic fields? The reason is that for static and low frequency electromagnetic fields the only important value is magnetic field strength. In case of the EMF, the electric field component does not penetrate any physical and biological body, but is transferred in electrical current over the body surface.

In general, EMF therapeutic modalities can be categorized in five groups:

- Static/permanent magnetic fields
- Low-frequency sine waves
- Pulsed Electromagnetic Fields (PEMF)
- Pulsed Radiofrequency Fields (PRF)
- Transcranial magnetic/electric stimulation.

Permanent magnetic fields can be created by various permanent magnets as well as by passing Direct Current (DC) through a coil.

Low-frequency sine wave electromagnetic fields mostly utilize a 60Hz (in USA and Canada) and a 50Hz (in Europe and Asia) frequency used in power lines.

Pulsed Electromagnetic Fields (PEMF) are usually low frequency fields with very specific wave shapes and amplitude. The variety of commercially available PEMF devices makes it difficult to compare the physical and engineering characteristics of devices, and it is the main obstacle in the analysis of the biological and clinical effects of those devices.

Pulsed Radiofrequency Fields (PRF) utilize the frequency of 27.12MHz in two modifications: in continuous mode it usually produce deep heat, while pulsed (non thermal) mode is used for soft tissue stimulation.

More recently, *millimeter waves* (having very high frequency of 30–100GHz) have been used in the treatment of a number of diseases, especially in the countries of the former Soviet Union.

Transcranial magnetic stimulation represents stimulation of selected portion of the brain by applying very short magnetic pulses of up to 8 Tesla.

Magnetic stimulation provides beneficial and reproducible healing effects even when other methods have failed. However, there is a lack of uniformity among medical practitioners with respect to stimulation, the parameters of the applied fields, and lack of defined biophysical mechanism capable of explaining the observed bioeffects. Therefore a systematic study of MF action on biological systems has to consider the following important parameters:

- Type of field
- Intensity of induction
- Gradient (dB/dt)
- Vector (dB/dx)
- Frequency
- Pulse shape
- Component (electric or magnetic)
- Localization
- Time of exposure
- Depth of penetration.

A common problem when comparing the effects of magnetic devices is that each manufacturer uses their own system of characterizing the product and in most cases the stated magnetic field strength is often different than direct measurement. My own experience with distributors of magnetotherapeutic systems suggests that the description of the field parameters in the promotional and technical materials is overstated when indicating the magnetic field strength. Sometimes it is done because of inaccurate evaluation of the parameters, but in many cases the reason is to show that the field is very strong. Unfortunately, in magnetotherapy, more does not necessarily mean better.

Magnetic and electromagnetic stimulation

Several decades of clinical application of various electromagnetic fields have clearly demonstrated the potential benefit of the use of selected magnetic fields for treatment of various medical problems. The success of magnetotherapy depends on the proper diagnosis and selection of physical parameters of applied fields. To be more precise, any therapy that involve magnetic/electromagnetic fields should mandatorily include knowledge of the exact parameters of the field at the target site. Not what is the magnetic field ate generator, but what is the field at the target [9,15,17].

Several double-blind studies published at the late 1990s have demonstrated the potential of a static magnetic field to provide significant pain relief. Valbona's study [18] showed that an SMF of 300-500G decreases the pain score in postpolio patients as 76% vs. 19% in placebo group, and Colbert's study used mattresses that utilize ceramic permanent magnets with surface strength of about 1,000G [19]. The estimated field strength on the body surface in Colbert's study was in the range 300–500 G, depending on the body mass of the patient. This magnetic field helps patients suffering from fibromyalgia, and improves the status of the patients in the real treatment group with more than 30%.

Soft tissue and bone/cartilage systems have been successfully treated with the most notable being treatments for problems related to muscular-skeleton system [15, 20-23]. Magnetotherapeutic systems have been successfully applied to treat vascular, immune, and endocrine systems [15,22,23].

A literature survey indicates that many electric and magnetic modalities have been developed to heal non union fractures and wounds [24-27]. The non invasive EMF most often employed in the U.S. for soft tissue applications is short-wave Pulsed Radio Frequency (PRF), based on the continuous 27.12 MHz sinusoidal diathermy signals and used for decades for deep tissue heating. The pulsed version of this signal was originally reported to elicit a non thermal biological effect by Ginsburg [28]. PRF magnetic fields have reduced posttraumatic and post-operative pain and edema in soft tissues, and applied to wound healing, burn treatment, ankle sprains, hand injuries, and nerve regeneration [20,26,27]. Pulsed radiofrequency magnetic field treated pressure sores in patients resulting in significant reduction (up to 47%) in the mean sore area after 2 weeks of treatment; while the mean duration of pressure sores (before treatment) was 13.5 weeks [29].

In addition to accelerated wound healing, MF modalities have been shown to significantly increase local blood flow in the stimulated area improving the status of the ischemic tissue [30-32]. Magnetic and electric stimulation has been associated with increased collagen deposition, enhanced ion transport, amino acid uptake, fibroblast migration, ATP, and protein synthesis, including a significant increase in the rate of protein and DNA synthesis after stimulation of human fibroblasts in tissue culture [11,23,33]. One area of interest, mainly in basic science, is the effect of EMF and MF on cell proliferation. Most cells normally differentiate to a specific morphology and function. In pathological conditions, cell proliferation is usually suppressed (in conditions of chronic wounds) or enhanced (in the case of neoplastic growth). Magnetic field stimulation of the skin fibroblast resulting in significant increase in collagen secretion and protein concentration has been reported, and these results suggest a favorable alteration in the proliferative and migratory capacity of epithelial and connective tissue cells involved in tissue regeneration and repair [34].

Over the past two decades, several methods for therapy of the peripheral vascular system using static magnetic fields have been developed [35,36]. The clinical outcome of this therapy includes analysis of hemodynamics, microcirculation, transcapillary phenomena, morphological, and cytochemical characteristics of blood components, including lymphocytes, erythrocytes, leukocytes, and thrombocytes. The therapeutic efficiency depends on the status of the patient (age, general health, gender) as well as on the disease stage. There is also a distinct relationship between specific diseases and the magnetic field parameters which initiate optimal response [36].

Improved blood perfusion in the magnetically stimulated tissue has been an assumed mechanism for the stimulatory effects on the regenerative processes. These clinical observations, along with the findings that blood flow and metabolic activity increase after long-term muscle stimulation, motivated a series of studies of the effects of magnetic fields on different health problems [32,37].

The Future

Analyzing the reported biological and clinical data obtained with devices and signals in use for magnetic field therapy, one might conclude that some types of signals are more promising for the future development of the magnetic field therapy. It appears that semi sinewaves are more effective compared to continuous sine waves. This approach is based on rectification of the continuous sinusoidal signal. Let me note that the actual shape of the rectified signal significantly differs from the ideal semisinewave drawing in the text books.

It is too early to generalize, but the future research should clarify the importance of the short DC component between the consecutive semi sinewaves. In an unpublished study, we have found that the duration of this DC component is associated with different biological response in several outcomes. There have been reported two different approaches for utilization of these signals. One relies on constructing an elliptical or spherical coil which could be moved around the patient body [38] and the other, applies the magnetic field on the upper or lower limbs, assuming that the results appear following systemic effects when the benefit is obtained at sites distant from the site of application [39].

It is reasonable to expect that the advantages of powerful computer technologies should be used in the designing new magnetotherapeutical devices. At first, it should be the computerized control of the signal and maintenance of the parameters of the signal during the whole treatment session. This has been implemented already in a large number of therapeutic systems. Next, is the inclusion of user-friendly software packages with prerecorded programs, as well as with the ability to modify programs depending upon the needs of the patients. With appropriate sensors, the feedback information could be recorded and used during the course of therapy. Third, the computer technology provides the opportunity to store the data for the treatment of individuals in a large database and further analyze the cohort of data for particular study or disease.

Finally, let us say that nearly all therapeutic devices are engineered without consideration of biological properties of the target tissue - only by the intuition of the design engineers. Therefore, these empirically designed devices require both physical and biophysical dosimetry. While the physical dosimetry is dealing with the physical characteristics of the generating system, the biophysical dosimetry requires exact knowledge for the magnetic field at the target site.

In a recently published paper, Parker and Markov [40] propose analytical approach in designing the therapeutic signal. This approach requires knowledge about the spontaneous magnetic field generated by normal and injured tissues. Such signals could be obtained by using SQUID magnetometers and appropriate elaboration of the recorded data and designing the signal that might be therapeutically effective [40].

Much work remains to be done in designing both technology and methodologyof application of magnetotherapeutic devices. The proper diagnosis of the medical problem and the understanding of the biophysical mechanisms of EMF interactions with injured/diseased tissues are the first two steps to be implemented in choosing the type of PEMF stimulation. Further, the design of the appropriate treatment protocol and the choice of clinical outcomes might facilitate the success of the therapy.

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