

HOW TO GO FOR MAGNETIC FIELD THERAPY?

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Abstract

The last two decades of the XX century and the beginning of the XXI century are marked with an increasing interest toward the application of magnetic fields for therapeutical purposes. Magnetotherapy provides non-invasive, safe and easy to apply methods to directly treat the site of injury, the source of pain and inflammation, as well as other types of injury. The 50 years of worldwide experience in studying basic mechanisms of action and clinical applications of various magnetic fields becomes more and more accepted by the mainstream of western medicine. The physiological basis of the use of magnetic fields for tissue repair as well as the physical principles of dosimetry and the application of various magnetic fields are discussed in this paper. A critical analysis of the magnetic and electromagnetic stimulation and a discussion of the advantage of magnetic field stimulation compared with electric current stimulation are connected to the physical and biophysical dosimetry at the target site and planing of the treatment.

Introduction

The last 15 years marked an increasing interest in the alternative and complementary medicine in the USA. This logically leads to investigation of the potential benefit of using magnetic fields (MF) for therapeutic purposes. Now magnetic and electromagnetic fields are widely accepted as real physical entities existing in the environment. For a period of time, interest was focused on the potential hazards of electromagnetic fields (EMF) in respect to the initiation of cancer (Wartenberg and Savitz, 1993; Deno and Carpenter, 1994; Werheimer et al., 1995). In the period 1991-1996 the Congress of the USA dedicated 60 million dollars for research in this direction. After 5 years of intensive research, the RAPID program finished with a statement that there are not sufficient evidence to affirm the link between electromagnetic fields (EMF) and cancer. Unfortunately, there was practically no governmental money available for studying the beneficial effects of magnetic and electromagnetic fields for the treatment of various injuries and diseases. The basic source of funding are the small, starting companies which must provide regulatory agencies with evidence that their technologies are save and effective. Despite insufficient funding, more and more scientists and medical practitioners have become convinced of the prospect that the first decade of this millennium will mark a revolutionary new approach toward treatment of various injuries and pathologies by using modalities such as magnetic and/or electromagnetic fields. It is well accepted now that the magnetotherapy provides non-invasive, safe and easy to apply methods to directly treat the site of injury, the source of pain and inflammation. Both static and time varying magnetic fields were successfully applied to treat therapeutically resistant problems in the musculoskeletal system.

It should be noted that a number of diagnostic devices also exploit EMF. The most popular among them are whole body NMR and MRI units. Magnetoencephalography, magnetocardiography, magnetopulmonography as well as functional MRI are relatively new diagnostics possibilities. Despite significant difference in the range of amplitudes applied for diagnostic and therapeutic purposes, some common features, especially in respect of requirement for safety of patients and more importantly – for the operator of the instrumentation still remain in the focus of investigators. Authors frequently claim “EMF appear to be unique in

their safety during clinical use” (Markov, 2002). This valid statement does not preclude necessity of exact dosimetry of the space within and around of the EMF generating devices.

A large body of publications suggests that MF and EMF can have profound effects on a large number of biological processes, most of which are of critical importance for tissue healing and recovery (Todorov, 1982; Markov and Todorov, 1984; Markov, 1987; Bassett, 1989 and 1994; Pilla, 1993; Pilla and Markov, 1994; Markov and Pilla, 1995, Jerabek and Pawluk, 1998; Markov and Colbert, 2001). It should be recognized that very little is known about the mechanisms of action of MF and EMF and this represents a serious barrier for the clinical application of electromagnetic fields. Immediately after World War II in Japan were performed first series of magnetotherapy. Later on magnetotherapy was developed in Romania and the former Soviet Union. During the period 1960-1985, most European countries had already manufactured magnetotherapeutic systems. The first clinical application of electromagnetic stimulation in the USA is dated 1974 (Bassett et al., 1974). The first book on magnetotherapy, written by N. Todorov, was published in Bulgaria in 1982 covering the use of magnets for the treatment of more than 2700 patients with 33 different pathologies (Todorov, 1982).

Today there is an abundance of experimental and clinical data which suggest that various exogenous MF at surprisingly low levels can have a profound effect on a large variety of biological systems. The most effective clinical applications of these physical factors are related to bone unification as well as reduction of pain and edema in soft tissues. For musculoskeletal injuries and post-surgical, post traumatic and chronic wounds, magnetic fields are recognized as a modality that contributes to reduction of edema (Todorov, 1982; Bental and Cobban, 1985; Detlavs, 1987; Bassett 1989 and 1994; Bental, 1990; Vodovnik and Karba, 1992; Pilla, 1993; Markov, 1994; Detlavs et al., 1994, Seaborne et al., 1996). Noninvasive EMF are now a common part of the orthopedist's armamentarium for the care of fresh and delayed fractures. Recalcitrant fracture repair (delayed and non-union of bone) has had the longest history in EMF clinical application in the USA (Bassett, 1978,1989,1992,1994). During the past 20 years more than a million patients have been treated worldwide, with application of EMF to practically all areas of fracture management, including nonunion, failed pseudo-arthrodes, osteonecrosis and chronic refractory tendinitis. This large number of patients exhibited a success rate of approximately 80%, with virtually no reported complications after nearly three decades of use (Bassett, 1989; Pilla, 1993; Markov and Pilla, 1995). While the success rate for EMF therapies are comparable to those produced surgically for delayed and non-union fractures, the cost of this non-invasive therapy is significantly less. This cost substantially decreases when appropriate permanent magnets are applied directly to the site of injury. To continue this analysis the following information may be useful: Each year approximately 2 million long-bone fractures occur in the United States. Of these, 5% fail to heal normally within 3-6 months, and some never heal, ending in amputation. Considering the above information that 80% of these fractures will be healed quicker by electromagnetic stimulation, this is an enormous benefit for the patient, his/her family, the health care system and society.

A number of clinical studies, in vivo animal experiments and in vitro cellular and membrane research, all suggest that magnetic and electromagnetic field stimulation can accelerate the healing processes. (Bental and Cobban, 1985; Bental, 1990; Vodovnik and Karba, 1992; Pilla, 1993; Markov and Pilla, 1994b; Detlavs et al., 1994). MF and EMF are also capable of enhancing such fundamental properties of the human organism as nerve repair and regeneration. It is now clear that endogenous electromagnetic and magnetic interactions are associated with many basic physiological processes ranging from ion binding and molecular conformation in the cell membrane to the macroscopic mechanical properties of tissues. The investigation of the mechanisms of the effects of MF on biological systems which are in a state different than their normal physiological state represents the next frontier in electromagnetic biology and medicine. Currently, the biological effects of low-level magnetic and electromagnetic fields on living systems are being intensively studied. A number of experiments have demonstrated that both weak electromagnetic and magnetic fields are capable of eliciting in vivo and in vitro effects from different biological systems, inducing changes on the organism, tissue, cellular, membrane and subcellular levels (Markov and Todorov, 1984; Bassett, 1989; Pilla, 1993; Pilla and Markov, 1994; Markov, 1994; Polk, 1994; Liburdy, 1994; Cleary, 1994; Sisken and Walker, 1995; Markov and Colbert, 2001).

Therapeutic Magnetic Fields

The combined efforts of scientists and clinicians from various countries created a background for magnetotherapy. What should magnetotherapy be? Magnetotherapy is a part of today bioelectromagnetic technology. As with any technology, magnetotherapy requires rigorous interdisciplinary research efforts and coordinated educational programs. This research should include not only interdisciplinary teams of research, but more importantly, an integration of knowledge from such distinct areas as physics, engineering, biology and medicine. A very important role is dedicated to a large group of medical practitioners, physical and occupational therapists, who routinely use a variety of physical modalities.

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Getting the physics side of the equation right and the biological/medical side wrong has obscured understanding of the myriad of factors that influence bioresponses to magnetic fields (Bassett, 1989). There should be enormous efforts from basic science to create dosimetry and methodology of this type of stimulation. Saying that a patient was "magnetically stimulated" is thus as nonspecific as saying a patient was given a drug. It should be made clear that magnetic field stimulation requires as precise dosage as any other therapy. This "dosage" is even more complicated since it needs to take into account a number of physical parameters which characterize any magnetic field generating system. Last, but not least, the proper diagnostics will also be very important for magnetotherapy. For example, to stimulate the blood-coagulation system, a physician needs one combination of parameters of the applied field, while for stimulation of the anticoagulation system he needs another field configuration (Todorov, 1982; Markov and Todorov, 1984). It should be taken into account that different MF produce different effects in different biotargets under differing conditions of exposure (Markov, 2000).

What one needs to know when decided to enter the area of magnetotherapy? The first important classification shows that the EMF therapeutic modalities can be categorized in following six groups:

- permanent magnetic fields
- low frequency sine waves
- pulsed electromagnetic fields (PEMF)
- pulsed radiofrequency fields (PRF)
- very high frequency fields in millimeter range of wavelengths (MMW)
- transcranial magnetic 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 60 Hz (in USA and Canada) and 50 Hz (in Europe and Asia) frequency used in distribution lines. Pulsed electromagnetic fields (PEMF) are usually low frequency fields with very specific shape and amplitude. The large variety of commercially available PEMF devices makes it difficult to compare the physical and engineering characteristics of devices and this variety of signals is the main obstacle in the analysis and comparison of the biological and clinical effects obtained by using different devices. Pulsed radiofrequency fields (PRF) utilizes the frequency of 27.12 MHz for soft tissue stimulation. This frequency, especially in the USA is specifically designated for clinical use. When applied in continuous mode, PRF creates deep heating, while the pulse mode (usually 65 μ s pulse bursts) affect the target tissue by the incident magnetic field only. Transcranial magnetic stimulation has been introduced in middle 1980's as a non-invasive method of stimulation of cerebral cortex. It consists of application of short, very intensive pulses of magnetic field. The last 10 years marked the increasing use of millimeter waves (having very high frequency of 30-100 GHz) for treatment of a number of diseases and pathologies, especially in the countries of the former Soviet Union (Devjatkov and Betski, 1994; Pakhomov et al., 1998; Rojavin and Ziskin, 1998).

An evaluation of the efficacy of this modality 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. Extremely important for the success of magnetotherapy is the proper diagnostics and the correct choice of the modality and the parameters of this modality. It should be articulated that any magnetic stimulation must start with identification of the MF parameters at the desired target tissue. Again, not the characteristics of the generating system, but the magnetic field at the target site. For some modalities the proper estimation of the magnetic field is not an easy task. Therefore, each new device must be accompanied with an explanation how to estimate the field configuration at the target site.

The ability of MF 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 MF at the target site. The therapeutic effect depends upon the spatial distribution of MF and induced current in the injured site, which is determined by tissue dielectric parameters (conductivity, permittivity, etc.).

Electric and magnetic stimulations have been proven to provide beneficial and reproducible healing effects even when other methods have failed. However, some confusion appeared among medical practitioners with respect to the application of these modalities due to the variety of methods of stimulation, parameters of the applied fields, and lack of defined biophysical mechanism capable of explaining the observed bioeffects. In order to achieve good reproducibility of the observed bioeffects, each study should take good care of the following: complete dosimetry of the study, well-established biological and clinical protocol, as well as a complete report of the experimental conditions of each study. Failure to reproduce the reported effects of a

biological or clinical study is, in many case, due to the failure to explain the exact conditions and/or negligence of some details which appear to be obvious. Model systems and magnetic field parameters vary largely and, in most cases, they are selected not based on rigorous analysis but by the engineering and physics abilities of a given exposure system and by the intuition of the investigator. Fortunately, the situation is improving and better conditions for reproduction of the effects are being created. Improvement reflects increasing awareness that magnetic field parameters should be matched with the bioprocesses being studied. Threshold or “window” requirements must be coupled with the proper exposure conditions and a receptive functional state of the biotargets for beneficial effect to occur.

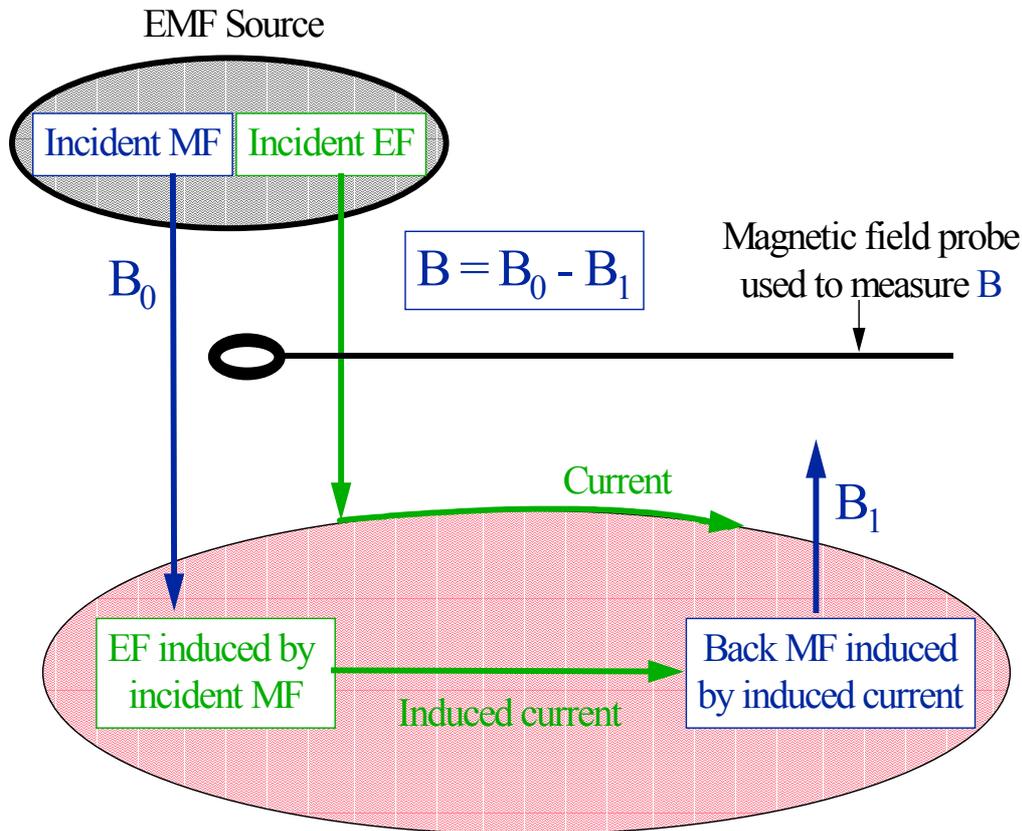


Figure 1. Illustration of ditribution of incident magnetic and electric fields over and in biological tissues. The electric field component basically do not penetrate the tissue, while for magnetic fields tissues are “transparent”. The importance of induced fields increases with the increase of frequency of the incident field and became important in case of megahertz and gifgahertz signals. When magnetic field is measured between the source and the target, the actual reading of the probe is the resulting value of incident field B and back MF induced in the tissue.

Therefore a systematic study of MF action on any particular biological system has to consider the following parameters:

- ◆ type of field
- ◆ intensity or induction
- ◆ gradient (dB/dt)
- ◆ vector (dB/dx)
- ◆ frequency
- ◆ pulse shape
- ◆ component (electric or magnetic)
- ◆ localization
- ◆ time of exposure

depth of penetration.

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One very important feature of magnetic/electromagnetic stimulation needs to be taken into account. For most electromagnetic fields (especially in the relatively low frequency range), electric and magnetic field components behave differently. Once an electric field reaches a material surface, it transfers into electric current along the surface. Conversely, most of the materials are transparent for the magnetic field component which penetrates deep into the body. An advantage of magnetic field stimulation is the fact that for a large interval of frequency, the dielectric properties of human tissue are very close to those in air. Therefore, if the values of incident magnetic fields are measured on the surface of the body with a good approximation this knowledge could be applied to underlying tissues. However, one needs to remember that this applies only for homogeneous fields, and not to the modalities that rely on permanent magnets. For permanent magnets the most important parameter to be considered is the depth of penetration which exponentially decrease with the distance from the surface of the magnet. The depth of penetration also depends on the technology of generating the magnetic field, i.e. the composition, volume, shape and surface area of the magnet.

Both animal and clinical data demonstrate that the physical parameters and patterns of the application can affect both the type of effect and the efficiency in producing a given response. Evidence of bioresponse specificity has been collected in a number of tissue culture, animal, and clinical settings. More details are available elsewhere (Bassett, 1978 and 1994; Markov and Todorov, 1984; Markov and Pilla, 1995) which indicate that amplitude, frequency, and exposure pattern windows apparently determine whether a bioeffect will occur and, if it does occur, what its nature will be.

Limited medical acceptance and use of magnetic fields

Despite years of experience elsewhere, documented successful use of magnetic field stimulation, hundreds of papers on the beneficial effects of magnetic and electromagnetic stimulation, magnetotherapy still has limited acceptance in the US main stream medicine. Essential elements of the rapidly growing and expanding database on reproducible biological and clinical effects of selected magnetic fields are largely unknown or wrongly interpreted by the physical, medical, regulatory and public sector of society. As a result:

- ❖ Medical practitioners are uneducated and unprepared to utilize this breakthrough biomedical technology to its full advantage for their patients
- ❖ Regulatory activity is unnecessarily restrictive to the detriment of patient care and of cost containment.
- ❖ Public concern about the safety of magnetic and electromagnetic fields is engendered by the news-media.

From early days in medical school, students live in a world based on and surrounded by biochemistry and they receive little knowledge of how to analyze biological responses and clinical outcomes from the viewpoint of physics and biophysics. Even being perfectly prepared in the principles of chemistry and pharmacology, without serious knowledge of the principles of thermodynamics and electrodynamics, biomechanics, electricity and magnetism, today's and tomorrow's medical practitioners will be ill prepared to apply magnetotherapy in their practice.

Another obstacle facing magnetotherapy is the question: "What is the mechanism of action?" Yes, this is a very legitimate question, but the fact that the exact answer to this question is not yet available (and probably years and/or decades will pass before the question will be answered) should not prevent the application of this modality. It will be appropriate to say that we always make a statement that the mechanism(s) of action of EMF is not yet understood, and this is correct. But at the same time, much more is known about the mechanisms of action of this modality than the mechanisms of action of many pharmaceuticals. Even the question about a unique mechanism of action is not correct. As it was previously discussed, MF used in clinical practice differ in their physical parameters, so it is very unlikely that such a complex system as the human body will have only one way to respond to various stimulations. For example, the physics of static magnetic field predominates different biological responses from those of the same system when a high frequency magnetic field is applied. At least, because the high frequency magnetic field will induce significant electrical current within the target tissue and two different factors need to be considered: incident magnetic field and induced electric current. A very important question needs to be answered: Whether and to what extent magnetic fields may represent a hazard. It must be clarified that the scientific reports and newsmedia publications are based on epidemiological studies that assumed continuous exposure to low frequency electromagnetic fields. It is very unlikely that the therapeutic application of magnetic fields may create a dangerous situation for the patient. Unfortunately, epidemiological studies most frequently deal with a very complex living and working environment without enough information for the changes of all physical and chemical pollutants during the time of analysis. It appears that long lasting follow up which may provide adequate information on the possible hazards of the

therapeutic application of magnetic fields will be extremely difficult, due to the complexity of the problem and the high cost of such follow up.

Physiological Basis for the use of Magnetic Stimulation in Tissue Repair

The available literature worldwide which underline the successful healing of injuries in different tissues can be very useful in any attempt to highlight those cellular and tissue components and processes that may be plausible targets for MF action. Having in mind that the most important clinical principle of injury management is to provide a natural physiological environment for optimum healing, the proper choice of the MF parameters may significantly enhance the healing process. Basic science studies suggest that nearly all participants in the healing process (such as fibrinogen, leukocytes, fibrin, platelets, cytokines, growth factors, fibroblasts, collagen, elastin, keratinocytes, osteoblasts, and free radicals) exhibit alterations in their performance when exposed to the action of MF (Markov, 1987; Bassett, 1989; Pilla and Markov, 1994; Jerabek, 1994, Markov 2000; Markov and Colbert, 2001). MF may also affect vasoconstriction and vasodilation, phagocytosis, cell proliferation, formation of cellular network, epithelization, and scar formation (Markov,1995; Markov, 2000).

It is accepted that healing occurs via a series of integrated stages, each of which has particular objectives essential to the repair processes. Therefore, it is important to evaluate the contribution of basic cellular activities which occur at any one of the distinct stages of tissue repair. This extremely complex phenomenon involves a number of well-orchestrated processes such as vascular responses, cellular and chemotactic activity and release of chemical mediators within the injured tissues. The list may also include regeneration of parenchymal cells, migration and proliferation of both parenchymal and connective tissue cells, synthesis of extracellular matrix proteins, remodeling of connective tissue, collagenization and acquisition of tissue strength. The interactions of MF with injured tissues could initiate biophysical and biochemical changes which in turn modify the physiological pathways that contribute to the healing process. Since the applied magnetic fields have energy below the threshold level, it is more likely that MF trigger some important biophysical/biochemical cascade, and affect signal/transduction pathways.

Magnetic and electromagnetic stimulation

Several decades of clinical application of various magnetic fields clearly demonstrate the potential benefit of the use of a selected magnetic field for the treatment of a specific pathology. It should be noted again that the success of magnetotherapy strongly depends upon correct diagnostics and selection of proper physical parameters

of the applied fields. A survey of the existing literature indicates that a large variety of electric and magnetic modalities have been developed to heal non-unions and wounds (Bassett, 1989; Vodovnik and Karba, 1992; Pilla,

1993; Markov and Pilla, 1994; Markov, 1995; Jerabek and Pawluk, 1998, Markov and Colbert, 2001; Markov, 2002). PRF magnetic fields have been applied for reduction of post-traumatic and post-operative pain and edema in soft tissues, wound healing, burn treatment, ankle sprains, hand injuries, and nerve regeneration (Wilson, 1974; Barclay et al., 1983; Markov, 1995, Kloth et al., 1999). For example, a pulsed radiofrequency magnetic field was used (Seaborne et al., 1996) for treatment of pressure sores in patients aged between 60 and 101 years resulting in significant reduction (up to 47%) in the mean sore area after 2 weeks of treatment.

Several methods for therapy of the peripheral blood-vessel system using static MF have been developed during the last two decades (Detlavs, 1987; Jerabek, 1994). The clinical outcome of this therapy includes analysis of hemodynamics, microcirculation, transcapillary phenomena, morphological and cytochemical characteristics of blood components, such as lymphocytes, erythrocytes, leukocytes, trombocytes. It has been shown that low intensity static MF stimulates the microcirculation, and initiates compensatory/adaptational reactions of elderly patients who have been diagnosed with arteriosclerosis (Zukov and Lazarevich, 1989).

Therapeutic efficacy depends on the status of the patient (age, general health, and gender) as well as on the stage of pathology/disease. It has also been found that there is a distinct relationship between specific diseases and MF parameters which initiate optimal response. Using non-contact methods for analysis of the histochemical permeability of capillaries and partial oxygen pressure, Zukov and Lazarevich (1989) developed a method for dosage of the therapy.

Several double blind clinical studies on the effects of magnetic field stimulation have been published recently (Vallbona et al., 1997; Weintraub, 1998). They demonstrate the potential of the static magnetic field to provide significant pain relief in different disorders. In a double blind study it was shown that static magnetic

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field of 300-500 G decreases the pain score in postpolio patients with 76% vs.19% in the placebo group (Vallbona et al., 1997). Another double blind study was performed by Colbert et al. (1999) on using mattresses that utilize ceramic permanent magnets with gauss strength of about 1000 G on the surface of the magnet. It has been shown that this magnetic field significantly benefits patients suffering from fibromyalgia and improves the status of the patients in the real treatment group by more than 30%. In a pilot study Weintraub (1998) reported significant improvement in the 75% of patients with diabetic neuropathy who used permanent magnetic field stimulation. These three very recent studies deal with pain management for patients having quite different symptoms. It should be emphasized that the proper choice of the application of the magnet, in particular on trigger points for postpolio patients, play great importance for the success of the therapy.

Advantages of MF stimulation compared with current stimulation

Electric current stimulation has the longest history of application as a therapeutic modality. However, there are significant differences between electric current and MF modalities. Electric current stimulation requires skin contact electrodes. Electrode size, spacing and polarity are the most critical factors to the delivery of an adequate stimulating current. The conduction of electrical current through biological tissues occurs as a result of movement of charges along specific pathways. This charge transfer might result in electrothermal, electrochemical, and electrophysical effects depending on the type of the electrical current and can occur at the membrane, cellular or tissue level immediately after applying the voltage. The direct responses usually result in a multitude of indirect cellular reactions, which subsequently may alter further steps in biochemical and physiological pathways.

MF represents a significantly more effective approach to the healing process - it is uninvasive, easy and comfortable therapy. MF modalities do not exhibit the complications of contact electrodes because contact is not necessary to achieve the desired dose at the tissue level. Thus, MF can be applied in the presence of a cast or wound dressing because the MF applicator does not need to contact either the skin, cast or the dressing. The risk of infection is thereby significantly reduced, and the dressings may remain as long as the therapy requires.

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The choice of a therapeutic device usually is based on the biological and clinical effectiveness it produces. The field amplitude, the spatial distribution and duration of exposure must be adequate to meet the requirement of therapy. All available modalities which utilize electric current, magnetic or electromagnetic fields suffer from the requirement that the patient should be available for certain periods of time daily at treatment facilities. It becomes more important to promptly evaluate MF initiated bioeffects as the number of electromagnetic technologies and devices used in clinical practice grows. The routine use of the equipment and the treatment protocol must assure simple and easy manipulation with stimulation devices by clinicians and, in some countries, even by the patients.

Therefore the stimulation units must be small, portable, safe and easy to operate. In addition, MF and especially permanent magnets better resolve the safety problems: There are no problems with electrical contacts or with the amplitude of the applied field: the World Health Organization recommendations allow fields up to 1 T to be used for therapy (WHO, 1987).

Taken together, basic science and clinical reports indicate the potential benefit of using permanent MF in the treatment of acute and chronic injuries, especially for cases where all conventional methods have failed. Theoretically, the beneficial effects can occur by direct interaction of MF with important biological molecules and structures, or by indirect mechanisms mainly involving signal-transduction pathways. One should not forget the importance of nerve regeneration in injured tissues, which also is a subject of magnetic stimulation. Furthermore, the benefit may be seen in a substantial reduction of pain and discomfort, as well as quicker return to normal standard of life and working habits.

Therapy that utilizes static magnetic fields

Recently, an enormous interest of the US newsmedia and general public is concentrated on using permanent magnets to alleviate pain of various origins and manifestations. Today, the largest area of the market is occupied by two types of permanent magnets: "hard" materials which include ceramic or exotic metal magnets such as neodymium-iron-boron or samarium-cobalt, and flexible magnetic sheets referred to as plastilloy. As was already stated, the use of static magnetic fields for therapeutic purposes represents only a part of the entire area of magnetotherapy. It must be emphasized and understood that the magnet itself does not heal. The permanent magnets represent only a tool, a system that creates magnetic fields. The reported beneficial effects are due to the magnetic fields delivered to the target tissues.

The controversial discussions about the possibilities of magnets to heal have a serious background. On one hand, the distributors of magnets do not pay attention to the necessity for proper characterization of their products. To characterize the potential of one or another source of magnetic fields to initiate alteration of the existing biochemical and biophysical processes and reactions or to modify the physiological pathway, one needs to consider the parameters of the magnetic fields already shown. The only appropriate chain is physics-biology-therapy. Any attempt to jump or neglect one or another component may have serious negative effects. For example, most of the companies promote permanent magnets with unrealistically high magnetic field strength such as 3,950 G or even 12,000 G. Only a few companies use the term "gauss rating" to characterize their products. But even this term is misleading, since "gauss rating" may be used to characterize the magnet itself, but not the magnetic field outside the magnet. In the best case scenario, the magnetic field strength at close proximity to the surface of the magnet is 4-10 times smaller than the "gauss rating" of the magnet.

The next problem is connected with the existence of two systems of delivering magnetic field, based upon "unipolar" and "bipolar" magnets. "Bipolar" are those magnets whose technology of manufacturing allows such a structure of materials that create repeatable north/south polarity on the same side of the material. These magnets are usually thin and flexible. The use of the term "unipolar" may be accepted only as an alternative to the "bipolar" arrangement. It is absolutely impossible to have magnets with only one pole. More appropriate may be the use of the term "unidirectional application", especially since most of the products available include a number of magnets in a pad. These types of magnets may be neodymium, ceramic or plastic alloy. Basic physics states that the magnetic field strength strongly depends on the number of elementary magnets in a unit volume, which during the magnetization process became unidirectionally oriented. For that reason metal-based magnets possess a great potential to deliver stronger magnetic fields. The fact that in "unipolar" magnets both poles are at different sides of the material predetermines larger depth of penetration for those magnets. Again, basic physics laws suggest that the continuum of magnetic field lines will have a significantly smaller arc when both poles are on the same side of the magnet. In general there is a 4-8 times difference in the depth of penetration of "unipolar" vs. "bipolar" magnets in favor of the "unipolar" magnets.

A biologically and clinically relevant characteristic of the magnetic field is the field strength at the target site. For practical purposes this term is used more frequently instead of the suggested by physicists term "magnetic flux density". This means that the complete three-dimensional dosimetry of the magnetic field is extremely important to analyze and further predict the biological effects at a given target. A number of studies of "in vitro" biological responses to applied magnetic fields suggest the existence of biological windows (Bawin and Adey, 1976; Markov et al., 1976; Garkavi et al, 1976). The "windows" represent such combinations of amplitude and exposure duration within which the optimal response is observed, and once outside this range the response is significantly smaller. In other words, this demonstrates the principle "more does not necessarily mean better". In the particular case of static magnetic field several "windows" have been detected at 5-20 G, 150 G and 450-500 G (Markov et al., 1976; Traikov et al., 1994; Markov, 1994).

It should be emphasized once again that the expected therapeutic results strongly depend on the magnetic field strength at the target tissue. Therefore, "gauss rating" and even the field strength at the surface of the magnet are still insufficient and irrelevant to predict expected therapeutic effects. Again, and again - the relevant physical parameter is the magnetic field at the target site. Having in mind all the above, it becomes evident that "bipolar" magnets are capable of creating biologically significant magnetic fields in a relatively small distance from the surface of the magnet (usually with the range of 1-1.5 cm). In a very well designed study McLean et al (1995) suggested that not only the field strength, but also the gradient of the field may be of importance for receiving desired biological and clinical effects.

MF effects appear at different structural levels: from the organism's to the molecular level. MF are, in principle, capable of inducing selective changes in the microenvironment around and within the cell, as well as in the cell membrane. Therefore, MF might be a suitable practical method for inducing modifications in the cellular activity which in turn may correct selected pathological states. Assuming that the exogenous signal can be detected at the cell or tissue level, the biophysical mechanism(s) of the interaction of weak magnetic fields with biological tissues as well as the biological transductive mechanism(s) remain to be elucidated.

Summary

The experimental and clinical data clearly demonstrate that MF and EMF of surprisingly low levels can have profound effect on a large variety of injuries and pathologies. Perhaps the greatest challenge for what we

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may term electromagnetic biology is to evaluate the proper dosimetry for modulation of the desired biochemical cascade. This will have a significant impact upon the cost of health care worldwide. The correct evaluation of the efficacy of magnetic stimulation for the acceleration of healing requires measurements and computations of a variety of parameters, such as amplitude, field gradients, duration of exposure, etc. Not only the precise characteristics of the applied MF, but also the exact diagnosis and all other clinical data should be considered. Further research in the area of magnetic stimulation needs to answer questions regarding which magnetic fields are detectable by cells or subcellular structures. The cooperation between experts from different areas of knowledge would also significantly help in improving EMF-based therapy (Markov, 1987 and 1995; Bental, 1990).

REFERENCES

- Barclay V, Coflier RJ, Jones A. Treatment of various hand injuries by pulsed electromagnetic energy (Diapulse). *Physiother*, 1983; 69: 186-188.
- Bassett CAL. Pulsing electromagnetic fields: A new approach to surgical problems.. In: Buchwald H. and Varco RL (eds.). *Metabolic Surgery*, N.Y. Grune and Stratton, 1978:255.
- Bassett CAL, Fundamental and practical aspects of therapeutical uses of pulsed electromagnetic fields (PEMs). *Critical Review of Biomedical Engineering*, 1989; 17: 451-529.
- Bassett CAL. Therapeutic uses of electric and magnetic fields in orthopedics. In: Karpenter D, Ayrapetyan S. (eds.). *Biological Effects of Electric and Magnetic Fields*, San Diego: Academic Press, 1994; 13-48.
- Bassett CAL, Pawluk RJ, Pilla AA. Acceleration of fracture repair by electromagnetic field (a surgically non-invasive method). *Ann NY Acad Sci*. 1974, 238, 242
- Bawin SM, Adey WR- Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. *Proc Natl Acad Sci USA* 1976; 73: 1999-2003.
- Bental RHC. Electromagnetic energy: A historical therapeutic perspective. In: O'Connor ME, Bental RHC, Monaham JC. (ads.). *Emerging Electromagnetic Medicine*, New York: Springer Verlag 1990; 1- 17.
- Bental R.K Cobban RM. Post operative use of radiofrequency emitting spectacles for control of edema and bruising following blepharoplasty. *Proc 7th BEMS Meeting*, Can Francisco CA, 1985; H-3.
- Cleary SF. Biophysical aspects of electromagnetic field effects on mammalian cells. In: Frey, A., (ed) *On the Nature of Electromagnetic Field Interactions with Biological Systems*, R.G.Landes Co., Austin TX, 1994; 28-42.
- Colbert AP, Markov MS, Baneti M, Pilla AA. Magnetic mattress pad use in patients with fibromialgia: A randomized double blind trial – *J. Back Musculoskeletal Rehab*, 1999; 13: 19-31.
- Deno DW, Carpenter DO. Sources and characteristics of electric and magnetic fields in the environment. In: Carpenter D.O., Ayrapetyan S. (eds.) *Biological effects of Electric and Magnetic Fields*, Academic Press, San Diego, 1994, v. 1:7-52.
- Detlavs I. (ed.) *Electromagnetic Therapy in Traumas and Diseases of The Support-motor Apparatus*. Riga RMI, 1987, 198 p.
- Detlavs I, Dombrovska I, Klavinsh I, Turauska A, Shkirmante B, Slutski L. Experimental study of the effect of electromagnetic fields in early stage of wound healing. *Bioelectrochemistry and Bioenergetics*, 1994; 35: 13-17.
- Devjatkov ND, Betskii OV *Biological Aspects of Low Intensity Millimeter Waves*. Moscow, Moscow University Press, 1994, 336p.
- Dunn MG, Doillon CH, Berg RA. Wound healing using a collagen matrix: effect of DC electrical stimulation. *J Biomed Mater Res* 1988; 22A: 191-206.
- Garkavi LH, Kvakina EB, Ukolova MA – Magnetic fields, adaptational reactions and resistivity of the organism – Reaction of biological system to the action of magnetic fields – *M. Nauka*, 1976, 131-148
- Jerabek J. An overview of present research into magnetotherapy. In: Coghil R *Proceedings of First World Congress on Magnetotherapy*, Lower Race, Pontypool 1994: 5-78.
- Jerabek J, Pawluk W. *Magnetic Therapy in Eastern Europe*. ISBN 0-9664227-0-8. Chicago, Advance Magnetic Research Institute, 1998: pp 207
- Karba R, Vodovnik L, Jercinovic A, Trontelj K, Benko FL Savrin R- Promotion of wound healing by electrical stimulation. *Biomedizinische Technik*, 1995; 40: 20-24.
- Kloth LC, Berman JE, Sutton CH, Jeutter DC, Pilla AA, Epner ME. Effect of pulsed radiofrequency stimulation on wound healing: a double blind pilot clinical study. In Bersani F.(ed) *Electricity and Magnetism in Biology and Medicine*. Kluwer Academic/Plenum Publishers, 1999: 875-878.
- Liburdy RP. Cellular interactions with electromagnetic fields: experimental evidence for field effects on signal transduction and cell proliferation. In: Fray A (ed.) *On the Nature of Electromagnetic Field Interactions with Biological Systems*. RC Landes, Austin TX 1994; 99-125.

- Markov MS. Biophysical aspects of the application of electromagnetic fields in orthopedics and traumatology. In: Detlav I. (ed). *Electromagnetic therapy in traumas and diseases of the support- motor apparatus*. Riga: Zinatie, 1987; 76-86.
- Markov M. Biological effects of extremely low frequency magnetic fields. In: Ueno S (ed.). *Biomagnetic Stimulation*. New York: Plenum Press, 1994; 91-103.
- Markov MS. Electric current and electromagnetic field effects on soft tissues. *Wounds* 1995; 7: 94-110.
- Markov MS. Magnetic and electromagnetic fields – a new frontier in clinical biology and medicine. *Proceedings of the Millennium International Workshop on Biological Effects in Biology and Medicine – Crete 17-20 October 2000*, 363-372 ISBN 960-86733-0-5.
- Markov MS Can Magnetic and electromagnetic fields be used for pain relief? – *Bulletin of American Pain Society* 12:#1; 2002:3-7
- Markov MS, Colbert AP. Magnetic and electromagnetic field therapy. *Journal Back Musculoskeletal Rehabilitation* 15; 2001: 17-29.
- Markov MS, Pilla AA. Static magnetic field modulation of myosin phosphorylation: calcium dependence in two enzyme preparations. *Bioelectrochemistry and Bioenergetics* 1994; 35: 57-61.
- Markov MS, Pilla AA. Electromagnetic field stimulation of soft tissues - *Wounds* 1995; 7: 143 -151.
- Markov MS, Todorov NG. Electromagnetic field stimulation of some physiological processes. *Studia Biophysica* 1984; 99- 151-156.
- Markov MS, Todorov SI, Ratcheva MR. Biomagnetic effects of the constant magnetic field action on water and physiological activity. In: Jensen K, and Vassileva Yu. (eds.). *Physical Bases of Biological Information Transfer*. Plenum Press, N.Y., 1976; 441-445.
- McLean MJ, Holcomb RR, Wamil AW, Pickett ID, Cavopol AV. Blockage of sensory neuron action potentials by a static magnetic field in the 10 mT range. *Bioelectromagnetics* 1995; 16: 20-32.
- Pakhomov AG, Akyel Y, Pakhomova ON, Suck BE, Murphy MR. Current state and implications of research on biological effects of millimeter waves: a review of literature. *Bioelectromagnetics* 1998- 18: (in press).
- Pilla AA. State of the art in electromagnetic therapeutics. In: Blank M (ed.) *Electricity and Magnetism in Biology and Medicine*, San Francisco Press Inc., 1993; 17- 22.
- Pilla AA, Markov MS. Weak electromagnetic field bioeffects. *Review of Environmental Health*, 1994; 1 0: 155-169.
- Polk C. Therapeutic application of low frequency electric and magnetic fields. In Lin JC (ed.) *Advances in Electromagnetic Fields in Living Systems*. Plenum Press NY 1994:129-154.
- Rodeman HP, Bayreuther K, Pfleiderer G. The differentiation of normal and transformed human fibroblasts in vitro is influenced by electromagnetic fields. *Exp Cell Res* 1989; 182: 610-621.
- Rojavin MA, Ziskin MC, Medical application of millimeter waves. *Q. J. Med* 1998; 91: 57-66.
- Saisido R, Fisher S et al. An animal-model and computer-controlled surface pressure delivery system for the production of pressure ulcers. *J Rehab Res and Developm* 1995; 32: 149-161.
- Seaborne D, Quirion-deGirardi C, Rousseau M., Rivest M, Lambert J. The treatment of pressure sores using pulsed electromagnetic energy (PEME). *Physiotherapy Canada*, 1996; 48:131-137.
- Shealy CN, Mortimer JT, Reswick JB. Electrical inhibition of pain by stimulation of the dorsal columns: Preliminary clinical report. *Anesth. Analg.* 1967; 46: 489.
- Sisken BF, Walker J. Therapeutic aspects of electromagnetic fields for soft tissue healing. In: Blank M (ed.) *Electromagnetic Fields: Biological Interactions and Mechanisms*, *Advances in Chemistry v.250*, Washington DC 1995: 277-286.
- Todorov N. *Magnetotherapy*, Sofia: *Medizina i Physcultura Publishing House*, 1982 pp. 106.
- Traikov LL, Kuzmanova MA, Ivanov SP, Markov MS. Static magnetic field effects basic glycoprotein complex of the erythrocyte membrane. In: Allen MJ, Cleary SF, Sowers AE (eds) *Charge and Field Effects in Biosystems-4*. World scientific 1994; 334-348.
- Vallbona C, Hazlewood C, Jurida G. Response of pain to static magnetic fields in postpolio patients: A double blind pilot study-*Arch Phys Med Rehab* 1997; 78: 1200-1203.
- Vodovnik L, Rebersek S, Stefanovska A, Bajd T. Indirect and direct effects of electrical currents on pathological neuromuscular systems. *Studia Biophysica* 1986; 112: 99-104.
- Vodovnik L, Karba R. Treatment of chronic wounds by means of electric and electromagnetic fields. *Med & Biol Engin & Comput.* 1992; 30: 257-266.
- Wartenberg D, Savitz DA. Evaluating exposure cutpoint bias in epidemiological studies of electric and magnetic fields. *Bioelectromagnetics* 1993; 14:237-245.
- Weintraub M. Chronic submaximal magnetic stimulation in peripheral neuropathy: Is there a beneficial therapeutic relationship. *Amer J Pain Management.* 1998; 8: 12-16.

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- Werheimer N, Savitz DA, Leeper E. Childhood cancer in relation to indicators of magnetic fields from ground current sources. *Bioelectromagnetics* 1995; 16: 86-96.
- Wilson DH. Comparison of short-wave diathermy and pulsed electromagnetic energy in treatment of soft tissue injuries. *Physiother* 1974; 80: 309-3 10.
- World Health Organization. *Magnetic Fields*. United Nations Environment Programme. The International Labour Organization. Geneva, VAIO, 1987.
- Zukov BN, Lasarovich VG. *Magnetotherapy in Angiology*. Kiev, Zdorovie, 1989; 1 1 1 p.