Bioelectromagnetics Applications in Medicine

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Overview

Bioelectromagnetics (BEM) is the emerging science that studies how living organisms interact with electromagnetic (EM) fields. Electrical phenomena are found in all living organisms. Moreover, electrical currents exist in the body that are capable of producing magnetic fields that extend outside the body. Consequently, they can be influenced by external magnetic and EM fields as well. Changes in the body's natural fields may produce physical and behavioral changes. To understand how these field effects may occur, it is first useful to discuss some basic phenomena associated with EM fields.

In its simplest form, a magnetic field is a field of magnetic force extending out from a permanent magnet. Magnetic fields are produced by moving electrical currents. For example, when an electrical current flows in a wire, the movement of the electrons through the wire produces a magnetic field in the space around the wire (fig. 1). If the current is a direct current (DC), it flows in one direction and the magnetic field is steady. If the electrical current in the wire is pulsing, or fluctuating--such as in alternating current (AC), which means the current flow is switching directions--the magnetic field also fluctuates. The strength of the magnetic field depends on the amount of current flowing in the wire; the more current, the stronger the magnetic field. An EM field contains both an electrical field and a magnetic field. In the case of a fluctuating magnetic or EM field, the field is characterized by its rate, or frequency, of fluctuation (e.g., one fluctuation per second is equal to 1 hertz [Hz], the unit of frequency).

A field fluctuating in this fashion theoretically extends out in space to infinity, decreasing in strength with distance and ultimately becoming lost in the jumble of other EM and magnetic fields that fill space. Since it is fluctuating at a certain frequency, it also has a wave motion (fig. 2). The wave moves outward at the speed of light (roughly 186,000 miles per second). As a result, it has a wavelength (i.e., the distance between crests of the wave) that is inversely related to its frequency. For example, a 1-Hz frequency has a wavelength of millions of miles, whereas a 1-million-Hz, or 1-megahertz (MHz), frequency has a wavelength of several hundred feet, and a 100-MHz frequency has a wavelength of about 6 feet.

All of the known frequencies of EM waves or fields are represented in the EM spectrum, ranging from DC (zero frequency) to the highest frequencies, such as gamma and cosmic rays. The EM spectrum includes x rays, visible light, microwaves, and television and radio frequencies, among many others. Moreover, all EM fields are force fields that carry energy through space and are capable of producing an effect at a distance. These fields have characteristics of both waves and particles. Depending on what types of experiments one does to investigate light, radio waves, or any other part of the EM spectrum, one will find either waves or particles called photons.

A photon is a tiny packet of energy that has no measurable mass. The greater the energy of the photon, the greater the frequency associated with its waveform. The human eye detects only a narrow band of frequencies within the EM spectrum, that of light. One photon gives up its energy to the retina in the back of the eye, which converts it into an electrical signal in the nervous system that produces the sensation of light.

Table 1 shows the usual classification of EM fields in terms of their frequency of oscillation, ranging from DC through extremely low frequency (ELF), low frequency, radio frequency (RF), microwave and radar, infrared, visible light, ultraviolet, x rays, and gamma rays. For oscillating fields, the higher the frequency, the greater the energy.

Endogenous fields (those produced within the body) are to be distinguished from exogenous fields (those produced by sources outside the body). Exogenous EM fields can be classified as either natural, such as the earth's geomagnetic field, or artificial (e.g., power lines, transformers, appliances, radio transmitters, and medical devices). The term electropollution refers to artificial EM fields that may be associated with health risks.

In radiation biophysics, an EM field is classified as ionizing if its energy is high enough to dislodge electrons from an atom or molecule. High-energy, high-frequency forms of EM radiation, such as gamma rays and x rays, are strongly ionizing in biological matter. For this reason, prolonged exposure to such rays is harmful. Radiation in the middle portion of the frequency and energy spectrum--such as visible, especially ultraviolet, light--is weakly ionizing (i.e., it can be ionizing or not, depending on the target molecules).

Although it has long been known that exposure to strongly ionizing EM radiation can cause extreme damage in biological tissues, only recently have epidemiological studies and other evidence implicated long-term exposure to nonionizing, exogenous EM fields, such as those emitted by power lines, in increased health hazards. These hazards may include an increased risk in children of developing leukemia (Bierbaum and Peters, 1991; Nair et al., 1989; Wilson et al., 1990a).

However, it also has been discovered that oscillating nonionizing EM fields in the ELF range can have vigorous biological effects that may be beneficial and thus nonharmful (Becker and Marino, 1982; Brighton and Pollack, 1991). This discovery is a cornerstone in the foundation of BEM research and application.

Specific changes in the field configuration and exposure pattern of low-level EM fields can produce highly specific biological responses. More intriguing, some specific frequencies have highly specific effects on tissues in the body, just as drugs have their specific effects on target tissues. The actual mechanism by which EM fields produce biological effects is under intense study. Evidence suggests that the cell membrane may be one of the primary locations where applied EM fields act on the cell. EM forces at the membrane's outer surface could modify ligand-receptor interactions (e.g., the binding of messenger chemicals such as hormones and growth factors to specialized cell membrane molecules called receptors), which in turn would alter the state of large membrane molecules that play a role in controlling the cell's internal processes (Tenforde and Kaune, 1987). Experiments to establish the full details of a mechanistic chain of events such as this, however, are just beginning.

Another line of study focuses on the endogenous EM fields. At the level of body tissues and organs, electrical activity is known to exhibit macroscopic patterns that contain medically useful information. For example, the diagnostic procedures of electroencephalography (EEG) and electrocardiography are based on detection of endogenous EM fields produced in the central nervous system and heart muscle, respectively. Taking the observations in these two systems a step further, current BEM research is exploring the possibility that weak EM fields associated with nerve activity in other tissues and organs might also carry information of diagnostic value. New technologies for constructing extremely sensitive EM transducers (e.g., magnetometers and electrometers) and for signal processing recently have made this line of research feasible.

Recent BEM research has uncovered a form of endogenous EM radiation in the visible region of the spectrum that is emitted by most living organisms, ranging from plant seeds to humans (Chwirot et al., 1987, Mathew and Rumar, in press, Popp et al., 1984, 1988, 1992). Some evidence indicates that this extremely low-level light, known as biophoton emission, may be important in bioregulation, membrane transport, and gene expression. It is possible that the effects (both beneficial and harmful) of exogenous fields may be mediated by alterations in endogenous fields. Thus, externally applied EM fields from medical devices may act to correct abnormalities in endogenous EM fields characteristic of disease states. Furthermore, the energy of the biophotons and processes involving their emission as well as other endogenous fields of the body may prove to be involved in energetic therapies, such as healer interactions.

At the cutting edge of BEM research lies the question of how endogenous body EM fields may change as a result of changes in consciousness. The recent formation and rapid growth of a new society, the International Society for the Study of Subtle Energies and Energy Medicine, is indicative of the growing interest in this field._

Figure 3 illustrates several types of EM fields of interest in BEM research.

Medical Applications of Bioelectromagnetics

Medical research applications of BEM began almost simultaneously with Michael Faraday's discovery of electromagnetic induction in the late 1700s. Immediately thereafter came the famous experiments of the 18th-century physician and physicist Luigi Galvani, who showed with frog legs that there was a connection between electricity and muscle contraction. This was followed by the work of Alessandro Volta, the Italian physicist whose investigation into electricity led him to correctly interpret Galvani's experiments with muscle, showing that the metal electrodes and not the tissue generated the current. From this early work came a plethora of devices for the diagnosis and treatment of disease, using first static electricity, then electrical currents, and, later, frequencies from different regions of the EM spectrum. Like other treatment methods, certain devices were seen as unconventional at first, only to become widely accepted later. For example, many of the medical devices that make up the core of modern, scientifically based medicine, such as x-ray devices, at one time were considered highly experimental.

Most of today's medical EM devices use relatively large levels of electrical, magnetic, or EM energy. The main topic of this chapter, however, is the use of the nonionizing portion of the EM spectrum, particularly at low levels, which is the focus of BEM research.

Nonionizing BEM medical applications may be classified according to whether they are thermal (heat producing in biologic tissue) or nonthermal. Thermal applications of nonionizing radiation (i.e., application of heat) include RF hyperthermia, laser and RF surgery, and RF diathermy.

The most important BEM modalities in alternative medicine are the nonthermal applications of nonionizing radiation. The term nonthermal is used with two different meanings in the medical and scientific literature. Biologically (or medically) nonthermal means that it "causes no significant gross tissue heating"; this is the most common usage. Physically (or scientifically) nonthermal means "below the thermal noise limit at physiological temperatures." The energy level of thermal noise is much lower than that required to cause heating of tissue; thus, any physically nonthermal application is automatically biologically nonthermal.

All of the nonthermal applications of nonionizing radiation are nonthermal in the biological sense. That is, they cause no significant heating of tissue. Some of the newer, unconventional BEM applications are also physically nonthermal. A variety of alternative medical practices developed outside the United States employ nonionizing EM fields at nonthermal intensities. For instance, microwave resonance therapy, which is used primarily in Russia, employs low-intensity (either continuous or pulse-modulated), sinusoidal microwave radiation to treat a variety of conditions, including arthritis, ulcers, esophagitis, hypertension, chronic pain, cerebral palsy, neurological disorders, and side effects of cancer chemotherapy (Devyatkov et al., 1991). Thousands of people in Russia also have been treated by specific frequencies of extremely low-level microwaves applied at certain acupuncture points.

The mechanism of action of microwave resonance therapy is thought to involve modifications in cell membrane transport or production of chemical mediators or both. Although a sizable body of Russian-language literature on this technique already exists, no independent validation studies have been conducted in the West. However, if such treatments prove to be effective, current views on the role of information and thermal noise (i.e., order and disorder) in living systems, which hold that biological information is stored in molecular structures, may need revision. It may be that such information is stored at the level of the whole organism in the endogenous EM field, which may be used informationally in biological regulation and cellular communication (i.e., not due to energy content or power intensity). If exogenous, extremely low-level nonionizing fields with energy contents well below the thermal noise limit produce biological effects, they may be acting on the body in such a way that they alter the body's own field. That is to say, biological information would be altered by the exogenous EM fields.

The eight major new (or "unconventional") applications of nonthermal, nonionizing EM fields are as follows:

1. Bone repair.

2. Nerve stimulation.

3. Wound healing.

4. Treatment of osteoarthritis.

5. Electroacupuncture.

6. Tissue regeneration.

7. Immune system stimulation.

8. Neuroendocrine modulations.

These applications of BEM and the evidence for their efficacy are discussed in the following section.

Research Base

Applications 1 through 5 above have been clinically tested and are in limited clinical use. On the basis of existing animal and cellular studies, applications 6 through 8 offer the potential for developing new clinical treatments, but clinical trials have not yet been conducted.

Bone Repair

Three types of applied EM fields are known to promote healing of nonunion bone fractures (i.e., those that fail to heal spontaneously):

* Pulsed EM fields (PEMFs) and sinusoidal EM fields (AC fields).

* DC fields.

* Combined AC-DC magnetic fields tuned to ion-resonant frequencies (these are extremely low-intensity, physically nonthermal fields) (Weinstein et al., 1990).

Approval of the U.S. Food and Drug Administration (FDA) has been obtained on PEMF and DC applications and is pending for the AC-DC application. In PEMF and AC applications, the repetition frequencies used are in the ELF range (Bassett, 1989). In DC applications, magnetic field intensities range from 100 microgauss to 100 gauss (G), and electric currents range from less than 0.1 microampere to milliamperes (Baranowski and Black, 1987)._ FDA approval of these therapies covers only their use to promote healing of nonunion bone fractures, not to accelerate routine healing of uncomplicated fractures.

Efficacy of EM bone repair treatment has been confirmed in double-blind clinical trials (Barker et al., 1984; Sharrard, 1990). A conservative estimate is that as of 1985 more than 100,000 people had been treated with such devices (Bassett et al., 1974, 1982; Brighton et al., 1979, 1981; Goldenberg and Hansen, 1972; Hinsenkamp et al., 1985).

Stimulation and Measurement of Nerve Activity

These applications fall into the following seven categories:

1. Transcutaneous electrical nerve stimulation (TENS). In this medical application, two electrodes are applied to the skin via wires attached to a portable electrical generating device, which may be clipped to the patient's belt (Hagfors and Hyme, 1975). Perhaps more than 100 types of FDA-approved devices in this category are currently available and used in physical therapy for pain relief. All of them operate on the same basis.

2. Transcranial electrostimulation (TCES). These devices are similar to the TENS units. They apply extremely low currents (below the nerve excitation threshold) to the brain via two electrodes applied to the head and are used for behavioral/psychological modification (e.g., to reduce symptoms of depression, anxiety, and insomnia) (Shealy et al., 1992). A recent meta-analysis covering at least 12 clinical trials selected from more than 100 published reports found that TCES can alleviate anxiety disorders (Klawansky et al., 1992). With support from the National Institutes of Health (NIH), TCES is under evaluation for alleviation of drug dependence.

3. Neuromagnetic stimulation. In this application, which has both diagnostic and therapeutic uses, a magnetic pulse is applied noninvasively to a part of the patient's body to stimulate nerve activity. In diagnostic use, a pulse is applied to the cerebral cortex, and the patient's physiological responses are monitored to obtain a dynamic picture of the brain-body interface (Hallett and Cohen, 1989). As a treatment modality, it is being used in lieu of electroshock therapy to treat certain types of affective disorder (e.g., major depression) and seizures (Anninos and Tsagas, 1991). Neuromagnetic stimulation also is used in nerve conduction studies for conditions such as carpal tunnel syndrome.

4. Electromyography. This diagnostic application detects electrical potentials associated with muscle contraction. Specific electrical patterns have been associated with certain abnormal states (e.g., denervated muscle). This method, along with electromyographic biofeedback, is being used to treat carpal tunnel syndrome and other movement disorders.

5. Electroencephalography. This neurodiagnostic application detects brainwaves. Coupled with EEG biofeedback it is used to treat a variety of conditions, such as learning disabilities, attention deficit and hyperactivity disorders, chronic alcoholism, and stroke.

6. Electroretinography. This diagnostic application monitors electrical potentials across the retina to assess eye movements. This is one of the few methods available for noninvasive monitoring of rapid eye movement sleep.

7. Low-energy emission therapy. This application uses an antenna positioned in the patient's mouth to administer amplitude-modulated EM fields. It has been shown to affect the central nervous system, and pilot clinical studies show efficacy in treating insomnia (Hajdukovic et al., 1992) and hypertension (Pasche et al., 1989).

Soft-tissue Wound Healing

The following studies have demonstrated accelerated healing of soft-tissue wounds using DC, PEMF, and electrochemical modalities:

* When wound healing is abnormal (retarded or arrested), electric or magnetic field applications may trigger

healing to occur. A review of several reports indicates that fields may be useful in this regard (Lee et al., 1993; Vodovnik and Karba, 1992).

* PEMFs have been used clinically to treat venous skin ulcers. Results of several double-blind studies showed that PEMF stimulation promotes cell activation and cell proliferation through an effect on the cell membrane, particularly on endothelial cells (Ieran et al., 1990; Stiller et al., 1992).

* ELF and RF fields are applied to accelerate wound healing. Since skin wounds have unique electrical potentials and currents, stimulation of these electrical factors by a variety of exogenous EM fields can aid in the healing process by causing dedifferentiation (i.e., conversion to a more primitive form) of the nearby cells followed by accelerated cell proliferation (O'Connor et al., 1990).

* An electrochemical treatment that provides scarless regenerative wound healing uses electricity solely to introduce active metallic ions, such as silver, into the tissue. The electric field plays no role itself (Becker, 1987, 1990, 1992).

* PEMF increases the rate of formation of epithelial (skin) cells in partially healed wounds (Mertz et al., 1988).

* AC EM fields promote the repair of injured vascular networks (Herbst et al., 1988).

* EM devices have been patented for treating atherosclerotic lesions (i.e., small blood clots that build up on the walls of arteries and cause cardiovascular disease) and to control tissue growth (Gordon, 1986; Liboff et al., 1992b).

Osteoarthritis

In a recent clinical trial using a double-blind, randomized protocol with placebo control, osteoarthritis (primarily of the knee) treated noninvasively by pulsed 30-Hz, 60-G PEMFs showed the treatment group improved substantially more than the placebo group (Trock et al., 1993). It is believed that applied magnetic fields act to suppress inflammatory responses at the cell membrane level (O'Connor et al., 1990).

Electroacupuncture

Electrical stimulation via acupuncture needles is often used as an enhancement or replacement for manual needling. Clinical benefits have been demonstrated for the use of electrical stimulation (electrostimulation) in combination with acupuncture as well as for electrostimulation applied directly to acupuncture points.

As an enhancement of acupuncture, a small-scale study showed electrostimulation with acupuncture to be beneficial in the treatment of post-operative pain (Christensen and Noreng, 1989). Other controlled studies have shown good success in using electrostimulation with acupuncture in the treatment of chemotherapy-induced sickness in cancer patients (Dundee and Ghaly, 1989). In addition, electrical stimulation with acupuncture was recently shown to be beneficial in the treatment of renal colic (Lee et al., 1992).

As a replacement for acupuncture, electrostimulation applied in a controlled study to acupuncture points by a

TENS unit was effective in inducing uterine contractions in postterm pregnant women (Dunn and Rogers, 1989). Further, research with rats has shown that electrostimulation at such points can enhance peripheral motor nerve regeneration (McDevitt et al., 1987) and sensory nerve sprouting (Pomeranz et al., 1984).

Regeneration

Animal research in this area indicates that the body's endogenous EM fields are involved in growth processes and that modifications of these fields can lead to modest regeneration of severed limbs (Becker, 1987; Becker and Spadero, 1972; Smith, 1967). Russian research and clinical applications, along with studies now under way in the United States, indicate that low-intensity microwaves apparently stimulate bone marrow stem cell division and may be useful in enhancing the effects of chemotherapy by maintaining the formation and development, or hematopoiesis, of various types of blood cells (Devyatkov et al., 1991).

The following studies are also relevant to the use of BEM for regeneration:

* PEMF applications to promote peripheral nerve regeneration (Orgel et al., 1992; Sisken, 1992).

* The "diapulse" method of using pulsed, high-frequency EM fields for human wrist nerve regeneration (Wilson et al., 1974).

* DC applications to promote rat spinal cord regeneration (Fehlings et al., 1992; Hurlbert and Tator, 1992).

* Swedish work showing that BEM promotes rat sciatic nerve regeneration (Kanje and Rusovan, 1992; Rusovan and Kanje, 1991, 1992; Rusovan et al., 1992).

Immune System

During the past two decades, the effects of EM exposure on the immune system and its components have been extensively studied. While early studies indicated that long-term exposure to EM fields might negatively affect the immune system, there is promising new research showing that applied EM fields may be able to beneficially modulate immune responses. For example, studies with human lymphocytes show that exogenous EM or magnetic fields can produce changes in calcium transport (Walleczek, 1992) and cause mediation of the mitogenic response (i.e., the stimulation of the division of cellular nuclei; certain types of immune cells begin to divide and reproduce rapidly in response to certain stimuli, or mitogens). This finding has led to research investigating the possible augmentation by applied EM fields of a type of immune cell population called natural killer cells, which are important in helping the body fight against cancer and viruses (Cadossi et al., 1988a, 1988b; Cossarizza et al., 1989a, 1989b, 1989c).

Potential Neuroendocrine Modulations

Low-level PEMFs have typically been shown to suppress levels of melatonin, which is secreted by the pineal gland and is believed to regulate the body's inner clock (Lerchl et al., 1990; Wilson et al., 1990b). Melatonin, as a hormone, is oncostatic (i.e., it stops cancer growth). Thus, if melatonin can be suppressed by certain magnetic fields, it also may be possible to employ magnetic fields with different characteristics to stimulate melatonin secretion for the treatment of cancer. Other applications may include use of EM fields to affect melatonin secretion to normalize circadian rhythms in people with jet lag and sleep cycle disturbances.

Table 2 provides an overview of selected citations to the refereed literature for these applications.

Future Research Opportunities

Although to date there is an extensive base of literature on the use of BEM for medical applications, the overall research strategy into this phenomenon has been quite fragmented. Because of BEM's potential for the treatment of a wide range of conditions, an integrated research program is needed that includes both basic and clinical research in BEM. These two approaches should be pursued vigorously and simultaneously along parallel tracks.

Basic research is needed to refine or develop new BEM technologies with the aim of establishing the fundamental knowledge about the body's endogenous EM fields and how they interact with clinically applied EM fields. A basic understanding of the BEM of the human body might provide insight into the scientific bioenergetic or bioinformational principles by which other areas of alternative medicine, such as homeopathy, acupuncture, and energetic therapies, may function. Furthermore, fundamental knowledge of BEM principles in the human body, in conjunction with psychophysiological states, might help facilitate understanding of mind-body regulation.

Clinical research, including preclinical assessments, is also essential, with the aim of bringing the most promising BEM treatments and diagnostics from limited use into widespread use as quickly as possible. Although a number of BEM devices show promise as new diagnostics or therapeutics, they must be tested on humans to show exactly when they are effective and when they are not. Moreover, measures of clinical effectiveness and safety are required for FDA approval of BEM medical devices. Ultimately, knowledge about the safety of new BEM medical devices can be ascertained only from the appropriate clinical trials.

Basic

The current status of basic research in BEM may be summarized as follows:

* Nonionizing, nonthermal exogenous EM fields exert measurable bioeffects in living organisms. In general, the organism's response to applied EM fields is highly frequency specific and the dose-response curve is nonlinear (i.e., application of an additional amount of the EM field does not elicit a response of equal magnitude; the response eventually diminishes no matter how additional EM stimuli are applied). Extremely weak EM fields may, at the proper frequency and site of application, produce large effects that are either clinically beneficial or harmful.

* The cell membrane has been proposed as the primary site of transduction of EM field bioeffects. Relevant mechanisms may include changes in cell-membrane binding and transport processes, displacement or deformation of polarized molecules, modifications in the conformation of biological water (i.e., water that comprises organisms), and others.

* The physical mechanisms by which EM fields may act on biomolecules are far too complex to discuss here. However, the following references propose such physical mechanisms: Grundler et al., in press; Liboff, 1985, 1991; and Liboff et al., 1991.

* Endogenous nonthermal EM fields ranging from DC to the visible spectral region may be intimately involved in regulating physiological and biochemical processes.

Consequently, the following pressing needs should be addressed in developing a basic BEM research program:

* Standardized protocols for measuring dosages for therapeutically applied EM fields should be established and followed uniformly in BEM research. Protocols are needed for characterizing (i.e., defining and measuring) EM field sources (both exogenous and endogenous) and EM parameters of biological subjects. Such variables must be characterized in greater detail than is commonly practiced in clinical research. Artifacts caused by ambient EM fields in the laboratory environment (e.g., from power lines and laboratory equipment) must be avoided.

* In general, a balanced, strategic approach to basic research--including studies in humans, animals, and cells along with theoretical modeling and close collaboration with other investigators in alternative medicine--will produce the most valuable results in the long run.

* Many independent parameters characterize nonthermal nonionizing EM fields, including pulsed vs. nonpulsed and sinusoidal vs. other waveforms; frequency; phase; intensity (as a function of spatial position); voltage; and current. If multiple fields are combined, these parameters must be specified for each component. Additional parameters necessary for characterizing the medical application of EM fields include the site of application and the time course of exposure. All of these can be experimentally varied, producing an enormous range of possibilities. To date, there has been little systematic research to explore the potential biological effects of this vast array of applied field parameter characteristics.

Clinical

Clinical trials of BEM-based treatments for the following conditions may yield useful results relatively soon: arthritis, psychophysiological states (including drug dependence and epilepsy), wound healing and regeneration, intractable pain, Parkinson's disease, spinal cord injury, closed head injury, cerebral palsy (spasticity reduction), learning disabilities, headache, degenerative conditions associated with aging, cancer, and acquired immunodeficiency syndrome (AIDS).

EM fields may be applied clinically as the primary therapy or as adjuvant therapy along with other treatments in the conditions listed above. Effectiveness can be measured via the following clinical markers:

* In arthritis, the usual clinical criteria, including decrease of pain, less swelling, and thus a greater potential for mobility.

* In psychophysiological problems, relief from symptoms of drug withdrawal and alleviation of depressive anxiety and its symptoms.

* In epilepsy, return to greater normality in EEG, more normal sleep patterns, and reduction in required drug dosages.

* In wound healing and regeneration, repair of soft tissue and reduction of collagenous tissue in scar formation; regrowth via blastemal (primitive cell) formation and increase in tensile strength of surgical wounds; alleviation of decubitus chronic ulcers (bedsores); increased angiogenesis (regrowth of vascular tissue such as blood vessels); and healing of recalcitrant (i.e., unresponsive to treatment) chronic venous ulcers.

For instance, a short-term, double-blind clinical trial of magnetic field therapy could be based on the protocol of Trock et al. (1993) for osteoarthritis of the knee or elbow. This protocol is as follows:

* A suitable patient population is divided into treatment and control groups. Individual assignments are coded and remain unknown to patients, clinicians, and operators until treatment and assessment are complete.

* Pretreatment clinical markers are assessed by clinicians or by patients themselves or both.

* Treatments consist of 3 to 5 half-hour sessions each week for a total of 18 treatments over 5-6 weeks.

* During treatment, each patient inserts the affected limb into the opening of a Helmholtz coil (a solenoid about 12 inches in diameter and 6 inches long) and rests while appropriate currents are applied to the coil via a preset program.

* The treatment is noninvasive and painless; the patient feels nothing; there is no measurable transfer of heat to the patient.

* The control group follows the same procedure except that, unknown to operator and patient, a "dummy" apparatus (altered internally so that no current flows in the coil) is used.

* Patients' posttreatment clinical markers are assessed.

* Appropriate data reduction (scoring of assessments, decoding of the treatment and control groups, and statistical analysis) is performed.

Clinical trials of BEM-based treatments for a variety of other conditions could follow a similar general outline.

Key Issues

Certain key issues or controversies surrounding BEM have inhibited progress in this field. These issues fall into several distinct areas: medical controversy, scientific controversy, barriers, and other issues.

Medical Controversy

A number of uncharacterized "black box" medical treatment and diagnostic devices--some legal and some illegal--have been associated with EM medical treatment. Whether they operate on the basis of BEM principles is unknown. Among these devices are the following: radionics devices, Lakhovsky multiple-wave oscillator, Priore's machine, Rife's inert gas discharge tubes, violet ray tubes, Reich's orgone energy devices, EAV machines, and biocircuit devices. There are at least six alternative explanations for how these and other such devices operate: (1) They are ineffectual and are based on erroneous application of physical principles. (2) They may be operating on BEM principles, but they are uncharacterized. (3) They may operate on acoustic principles (sound or ultrasound waves) rather than BEM. (4) In the case of diagnostic devices, they may work by focusing the intuitive capacity of the practitioner. (5) In the case of long-distance applications, they may operate by means of nonlocal properties of consciousness of patient and practitioner. (6) They may be operating on the energy of some domain that is uncharacterized at present.

A recent survey (Eisenberg et al., 1993) showed that about 1 percent of the U.S. population used energy healing techniques that included a variety of EM devices. Indeed, more of the respondents in this 1990 survey used energy healing techniques than used homeopathy and acupuncture in the treatment of either serious or chronic disease. In addition to the use of devices by practitioners, a plethora of consumer medical products that use magnetic energy are purported to promote relaxation or to treat a variety of illnesses. For example, for the bed there are mattress pads impregnated with magnets; there are magnets to attach to the site of an athletic injury; and there are small pelletlike magnets to place over specific points on the body. Most of these so-called therapeutic magnets, also called biomagnets, come from Japan. However, no known published journal articles demonstrating effectiveness via clinical trials exist.

Some of the medical modalities discussed in this report, although presently accepted medically or legally in the United States, have not necessarily passed the most recent requirements of safety or effectiveness. FDA approval of a significant number of BEM-based devices, primarily those used in bone repair and neurostimulation, was "grandfathered." That is, medical devices sold in the United States prior to the Medical Device Law of the late 1970s automatically received FDA approval for use in the same manner and for the same medical conditions for which they were used prior to the law's enactment. Grandfathering by the FDA applies not only to BEM devices but to all devices covered by the Medical Device Law. However, neither the safety nor the effectiveness of grandfathered devices is established (i.e., they are approved on the basis of a "presumption" by the FDA, but they usually remain incompletely studied). Reexamination of devices in use, whether grandfathered or not, may be warranted.

There are three possible ways of resolving controversies associated with BEM and its application: (1) elucidating the fundamental principles underlying the device, or at least the historical basis for the development of the device; (2) conducting properly designed case control studies and clinical trials to validate effects that have been reported or claimed for BEM-based treatments; and (3) increasing the medical community's awareness of well-documented, controlled clinical trials that indicate the effectiveness of specific BEM applications (see table 2).

Scientific Controversy

Some physicists claim that low-intensity, nonionizing EM fields have no bioeffects other than resistive (joule) heating of tissue. One such argument is based on a physical model in which the only EM field parameter considered relevant to biological systems is power density (Adair, 1991). The argument asserts that measurable nonthermal bioeffects of EM fields are "impossible" because they contradict known physical laws or would require a "new physics" to explain them.

However, numerous independent experiments reported in the refereed-journal research literature conclusively establish that nonthermal bioeffects of low-intensity EM fields do indeed exist. Moreover, the experimental results lend support to certain new approaches in theoretical modeling of the interactions between EM fields and biological matter. Most researchers now feel that BEM bioeffects will become comprehensible not by forsaking physics but rather by developing more sophisticated, detailed models based on known physical laws, in which additional parameters (e.g., frequency, intensity, waveform, and field directionality) are taken into account.

Barriers

The following barriers to BEM research exist:

* Members of NIH review panels in medical applications might not be adequately knowledgeable about alternative medical practices or BEM. This is the most serious barrier.

* Funding in BEM research is weighted heavily toward the study of hazards of EM fields; there is little funding for potential beneficial medical applications or the study of basic mechanisms of EM interactions with life processes. Also, the bulk of EM field research is administered by the Department of Defense and the Department of Energy, agencies with missions unrelated to medical research. The small amount of BEM work funded by NIH thus far has addressed mostly the hazards of EM fields. In late 1993 the National Institute of Environmental Health Sciences issued requests for grant application in the areas of (1) cellular effects of low-frequency EM fields and (2) effects of 60-Hz EM fields in vivo. The latter project is concerned solely with safety in power line and appliance exposures. However, the former apparently does not rule out the investigation of possible beneficial effects from low-frequency fields, although the focus is clearly on assessing previously reported effects of 60-Hz EM fields on cellular processes.

* Regulatory barriers to making new BEM devices available to practitioners are formidable. The approval process is slow and exorbitantly expensive even for conventional medical devices.

* Barriers in education include the following: (1) basic education in biological science is weak in physics, (2) undergraduate-and graduate-level programs in BEM are virtually nonexistent, and (3) multidisciplinary training is lacking in medicine and biology.

* The mainstream scientific and medical communities are basically conservative and respond to emerging disciplines, such as BEM, with reactions ranging from ignorance and apathy to open hostility. Consequently, accomplished senior researchers may not be aware of the opportunities for fruitful work in (or in collaboration with others in) BEM, while junior researchers may be reluctant to enter a field perceived by some as detrimental to career advancement.

Other Issues

Other key issues that need to be considered in developing a comprehensive research and development agenda for BEM include the following:

* Separate studies prepared for the Office of Technology Assessment, the National Institute of Occupational Safety and Health, and the Environmental Protection Agency have recommended independently that research on fundamental mechanisms of EM field interactions in humans receive high priority (Bierbaum and Peters, 1991; Nair et al., 1989; U.S. EPA, 1991). Moreover, a 1985 report prepared by scientists at the Centers for Devices and Radiological Health recommended that future research on EM field interactions with living systems "be directed at exploring beneficial medical applications of EMR (electromagnetic radiation) modulation of immune responses" (Budd and Czerski, 1985).

* Elucidation of the physical mechanisms of BEM medical modalities is the single most powerful key to developing efficient and optimal clinical intervention. Even a relatively small advance beyond present knowledge of fundamental mechanisms would be of considerable practical value. In addition, progress in the development of a mechanistic explanation of the effects of alternative medicine could increase its acceptability in the eyes of mainstream medicine and science.

* BEM potentially offers a powerful new approach to understanding the neuroendocrine and immunological bases of certain major medical problems (e.g., wound healing, cancer, and AIDS). However, substantial funding and time are required to perform the basic research needed in developing this approach.

* BEM may provide a comprehensive biophysical framework grounded in fundamental science, through which many alternative medical practices can be studied. BEM offers a promising starting point for scientifically exploring various traditional alternative medical systems (Becker and Marino, 1982).

Basic Research Priorities

The most fruitful topics for future basic research investigations of BEM may include the following:

* Developing assay methods based on EM field interactions in cells (e.g., for potassium transport, calcium transport, and cytotoxicity). These assays could then be applied to existing studies of such phenomena in cellular systems.

* Developing BEM-based treatments for osteoporosis, on basis of the large body of existing work on EM bone repair and other research (e.g., Brighton et al., 1985; Cruess and Bassett, 1983; Liboff et al., 1992a; MadroZero, 1990; Magee et al., 1991; Skerry et al., 1991). NASA researchers have already expressed interest in collaborative work to develop BEM treatments for weightlessness-induced osteoporosis.

* Measuring neurobiochemical changes in the blood in response to microcurrent skin stimulation in animals or humans with different frequencies, waveforms, and carrier waves. Such measurements should be made for preclinical evaluation of neurostimulation devices.

* Furthering studies of mechanisms of EM field interactions in cells and tissues with emphasis on coherent or cooperative states and resonant phenomena in biomolecules; and on coherent brainwave states and other long-range interactions in biological systems.

* Studying the role of water as a mediator in biological interactions with emphasis on the quantum EM aspects of

its conformation (i.e., "structure," as implied in some forms of homeopathy). The response of biologic water to EM fields should be studied experimentally. A novel informational capacity of water in relation to EM bioeffects may provide insights into homeopathy and healer interactions (i.e., "laying on of hands").

* Studying in detail the role of the body's internally generated (endogenous) EM fields and the body's other natural electromagnetic parameters (see the "Manual Healing Methods" chapter). Knowledge of such processes should be applied to develop novel diagnostic methods and to understand alternative medical treatments such as acupuncture, electroacupuncture, and biofield therapies. Furthermore, exploratory research on the role of the body's energy fields in relation to the role of states of consciousness in health and healing should be launched.

* Establishing a knowledge base (an intelligent database) to provide convenient access to all significant BEM work in both basic and clinical research.

* Performing systematic reviews as well as meta-analytic reviews of existing BEM studies to identify the frequency and quality of research concerning BEM as well as most promising clinical end points for BEM treatments in humans.

Summary

Just as exposure to high-energy radiation has unquestioned hazards, radiation has long been a key weapon in the fight against many types of cancers. Likewise, although there are indications that some EM fields may be hazardous, there is now increasing evidence that there are beneficial bioeffects of certain low-intensity nonthermal EM fields.

In clinical practice, BEM applications offer the possibility of more economical and more effective diagnostics and new noninvasive therapies for medical problems, including those considered intractable or recalcitrant to conventional treatments. The sizable body of recent work cited in this chapter has established the feasibility of treatments based on BEM, although the mainstream medical community is largely unaware of this work.

In biomedical research, BEM can provide a better understanding of fundamental mechanisms of communication and regulation at levels ranging from intracellular to organismic. Improved knowledge of fundamental mechanisms of EM field interactions could lead directly to major advances in diagnostic and treatment methods.

In the study of other alternative medical modalities, BEM offers a unified conceptual framework that may help explain how certain diagnostic and therapeutic techniques (e.g., acupuncture, homeopathy, certain types of ethnomedicine, and healer effects) may produce results that are difficult to understand from a more conventional viewpoint. These areas of alternative medicine are currently based entirely on empirical (i.e., experimentation and observation rather than theory) and phenomenological (i.e., the classification and description of any fact, circumstance, or experience without any attempt at explanation) approaches. Thus, their future development could be accelerated as a scientific understanding if their mechanisms of action are ascertained.

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Table 1. Electromagnetic Spectrum

Frequency range (Hz)* Classification Biological effect

0 Direct current Nonionizing

0 - 300 Extremely low frequency Nonionizing

300 - 104 Low frequency Nonionizing

104 - 109 Radio frequency Nonionizing

109 - 1012 Microwave and radar bands Nonionizing

1012 - 4 x 1014 Infrared band Nonionizing

4 x 1014 - 7 x 1014 Visible light Weakly ionizing

7 x 1014 - 1018 Ultraviolet band Weakly ionizing

1018 - 1020 X rays Strongly ionizing

Over 1020 Gamma rays Strongly ionizing

* Division of the EM spectrum into frequency bands is based on conventional but arbitrary usage in various disciplines.

Table 2. Selected Literature Citations on Biomedical Effects of Nonthermal EM Fields

Frequency range of EM fields

Location or type of bioeffect_

DC_ELF, including sinusoidal, pulsed, and mixed_

RF and microwave_

IR, visible, and UV light_

Review articles and monographs___

Bone and cartilage, including treatments for bone repair and osteoporosis_Brighton et al., 1981;

Baranowsi & Black, 1987;

Papatheofanis, 1989_Bassett et al., 1982;

Barker et al., 1984;

Brighton et al., 1985;

Hinsenkamp et al., 1985;

Huraki et al., 1987;

Bassett, 1989;

MadroZero, 1990;

Sharrard, 1990;

Grande et al., 1991;

Magee et al., 1991;

Pollack et al., 1991;

Skerry et al., 1991;

Ryaby et al., 1992___Brighton et al., 1979__

Soft tissue, including wound healing, regeneratrion, and vascular-tissue effects_Becker, 1987;

Becker, 1990;

Becker, 1992;

Vodovnik & Karba, 1992_Gordon, 1986;

Herbst et al., 1988;

Mertz et al., 1988;

Yen-Patton et al., 1988;

Albertini et al., 1990;

Ieran et al., 1990;

Im & Hoopes, 1991;

Kraus, 1992;

Liboff et al., 1992b;

Stiller et al., 1992;

Vodovnik & Karba, 1992_Devyatkov et al., 1991__Vodovnik & Karba, 1992__

Neural tissue, including nerve growth and regeneration__Wilson et al., 1974;

Rusovan & Kanje, 1991;

Subramanian et al., 1991;

Horton et al., 1992;

Rusovan & Kanje, 1992;

Rusovan et al., 1992_____

Neural stimulation effects, including TENS and TCES__Hagfors & Hyme, 1975;

Hallett & Cohen, 1989;

Anninos & Tsagas, 1991;

Klawansky et al., 1992_____

Psychophysiological and behavioral effects___Pasche et al., 1989;

Devyatkov et al., 1991;

Hajdukovic et al., 1992_Thomas et al., 1986_O'Connor & Lovely, 1988__

Electroacupuncture_McDevitt et al., 1987_Pomeranz et al., 1984;

Christensen & Noreng, 1989;

Dundee & Ghaly, 1989;

Lee et al., 1992_____

Neuroendocrine effects, including melatonin modifications_Feinendegen & Muhlensiepen, 1987_Lerchl et al., 1990;

Wilson et al., 1990a, 1990b___O'Connor & Lovely, 1988__

Immune system effects__Cadossi et al., 1988a;

Cadossi et al., 1988b;

Cossarizza et al., 1989a;

Cossarizza et al., 1989b;

Rosenthal & Obe, 1989;

Phillips & McChesney, 1991;

Walleczek, 1992_____

Arthritis treatments__Grande et al., 1991;

Trock et al., 1993_Devyatkov et al., 1991____

Cellular and subcellular effects, including effects on cell membrane, genetic system, and tumors_Easterly, 1982;

Liburdy & Tenforde, 1986;

Foxall et al., 1991;

Miklavcic et al., 1991;

Short et al., 1992_Cohen et al., 1986;

Takahashi et al., 1987;

Adey, 1992;

Marron et al., 1988;

Onuma & Hui, 1988;

Brayman & Miller, 1989;

Cossarizza et al., 1989a, 1989b;

De Loecker et al., 1989;

Goodman et al., 1989;

Rodemann et al., 1989;

Brayman & Miller, 1990;

Lerchl et al., 1990;

Omote et al., 1990;

Greene et al., 1991;

Liboff et al., 1991_Guy, 1987;

Chen & Ghandi, 1989;

Brown & Chattpadhyay, 1991;

Devyatkov et al., 1991__Adey & Lawrence, 1984;

Marino, 1988;

Blank & Findl, 1987;

Ramel & Norden, 1991;

Grundler et al., in press__

Endogenous EM fields, including biophotons__Mathew & Rumar, in press_Mathew & Rumar, in press_Popp et al., 1984;

Chwirot et al., 1987;

Chwirot, 1988;

Popp et al., 1988_Wijk & Schamhart, 1988;

Popp et al., 1992__

Note: Reports listed in table 2 are selected from refereed medical and scientific journals, multiauthor monographs, conference proceedings, and patents. See References for identification of sources. This is a representative selection from a large body of relevant sources and is not meant to be exhaustive or definitive.

A more detailed introduction to the field of BEM and an overview of research progress is available in the following monographs and conference proceedings: Adey, 1992; Adey and Lawrence, 1984; Becker and Marino, 1982; Blank, 1993; Blank and Findl, 1987; Brighton and Pollack, 1991; Brighton et al., 1979; Liboff and Rinaldi, 1974; Marino, 1988; O'Connor et al., 1990; O'Connor and Lovely, 1988; Popp et al., 1992; and Ramel and Norden, 1991.

Gauss is a unit of magnetic flux density. For comparison, a typical magnet used to hold papers vertically on a refrigerator is 200 G.