ASSESSMENTS AND VIEWPOINTS ON THE BIOLOGICAL AND HUMAN HEALTH EFFECTS OF EXTREMELY LOW FREQUENCY (ELF) ELECTROMAGNETIC FIELDS.

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ELECTROMAGNETIC FIELDS AND PUBLIC HEALTH

Andrew A. Marino, Ph.D., J.D.
Louisiana State University Medical Center

INTRODUCTION

The roots of bioelectricity can be traced back past Galvani and Volta into antiquity, but bioelectricity was dormant, barely kept alive by the work of a few such as Lund (101), Burr (34, 35) and Szent-Gyorgyi (169), until its full flowering began in the 1950s and 1960s. Biological piezoelectricity was discovered in bone and subsequently found in many tissues (41, 56, 105, 109, 142, 159). These observations led to interest in the sensitivity of cells to electrical signals (6, 108, 110), and numerous studies showed that weak electrical currents (10^{-13} to 10^{-5} A) could cause bone growth in animals and human beings (7, 18, 24, 30, 31, 32, 54, 57, 73, 77, 84, 95, 96, 130, 137, 181, 186, 192, 193, 195). This phenomenon was patented as an effective therapy (174), approved by the Food and Drug Administration (FDA), and is now routinely used clinically for the treatment of bone nonunions and pseudarthroses.

A second approach to the treatment of the same disorders using magnetic fields began in the early 1970s and followed a similar course involving animal studies (8, 39, 140, 141), clinical trials (9), FDA approval, and consequent commercialization and clinical use (160). Electrical treatment procedures are being studied in connection with osteomyelitis (180), ligament healing (52), osteoporosis (10, 43, 86) joint fusion (23), acceleration of normal fracture healing (40, 71, 118), and other applications (74, 75, 78, 81, 85, 135, 168, 176, 177).

The door has been opened to a range of studies, approaches, and potential developments that were simply unimaginable only 20 years ago. Electrical factors have been shown to be intimately involved in the process of regeneration (15, 17, 20, 27, 28, 29, 44, 82, 83, 154, 165, 166), and we now have a hope of being able to restore this capacity in man as has been shown by many studies involving limb regeneration (19, 161, 163) and nerve regeneration

(45, 72, 79, 91, 126, 127, 132, 136, 149, 162, 164, 189, 190). Weak electrical signals have been used successfully for the treatment of drug addiction (137a), cancer (66, 128), pain (12, 13, 38, 47, 68, 88, 147), and for stimulation of normal healing (22). A broad range of organisms from bacteria to vertebrates have been shown to detect, exhibit, and respond to weak electric and magnetic fields (2, 5, 11, 25, 33, 48, 53, 61, 63, 80, 87, 94, 99, 102, 115, 116, 119, 125, 144, 148, 153, 156, 157, 167, 178, 179, 182, 183, 187, 188, 196).

Reports concerning the biological effects of weak electromagnetic signals can now be found in the 1iterature of virtually all surgical specialties, physical medicine, dentistry, neurology, anatomy, biochemistry, clinical ecology, and many other disciplines and specialties. A new science is being born, and it is bright with the promise of benefitting humanity. One of the brightest promises involves the deeper understanding of the origin of disease. It is becoming increasingly clear that much illness is environmentally induced (150, 151, 152). This awareness brings into sharp focus the question of the chemical and nonchemical composition of our environment. If electromagnetic energy can produce a therapeutic result in the hands of a clinician, if detection of electromagnetic fields is part of the primordial apparatus of living systems, if ultraweak electrical signals can initiate and regulate the body's growth systems, then it is reasonable to expect that uncontrolled application of electromagnetic energy to living organisms would have adverse effects. Does electromagnetic pollution belong on the list of established and accepted environmental contaminants capable of causing disease? The direct evidence that requires an affirmative answer is outlined in the next Section.

HEALTH RISK OF EXPOSURE TO SANGUINE/SEAFARER FIELDS

Introduction

Numerous laboratory studies have described biological effects following exposure to nonthermal electromagnetic fields (EMF). Some of the studies and an analysis of their significance are given below. A more complete description is given elsewhere (16).

Growth and Development

Giarola and Krueger (59), of Texas A & M University, found that exposure of one-day-old chicks to 1.3 G at 45 Hz for 28 days depressed their growth rate by 9 to 11% as compared with that of the unexposed birds; they observed a similar effect in an electric field of 3,500 V/m. In another study (92), they found that exposure of egg-laying hens to 1,600 V/m at 60 Hz for 16 weeks caused a decrease in egg production. Magnetic fields can also induce marked embryological changes (46).

We continuously exposed three generations of mice to a 60-Hz electric field and found that in the first and second generation, males and females reared in both fields were significantly smaller than the comparable control group when compared at 35 days after birth. In the third generation the males exposed to the vertical field were significantly smaller than the controls. In addition, the exposed mice exhibited a higher rate of mortality (114). In a follow-up study at 3,500 V/m (113), using an improved exposure system, we again found that the field caused an increased mortality in each generation; it also caused altered body weights in the third generation.

McElhaney and Stalnaker (104), of West Virginia University, applied 7,000 V/m, at 3 and 30Hz, to the immobilized but intact femurs of rats. They found that the electric field lessened the process of bone resorption that usually occurs in an unused limb; additionally, many of the exposed rats, but none of the controls, developed bone tumors. These results were partially confirmed by Martin and Gutman, of West Virginia University (117); they found that the bone loss which accompanies disuse was lowered by the electric field.

Grissett et al. (65), at the Naval Aerospace Medical Research Laboratory, exposed 30 monkeys to 20 V/m and 2 G at 76 Hz. After one year, the field-exposed males were significantly heavier than the control males.

We studied the effect of 60-Hz electric fields of 1,000 to 5,000 V/m on the rate of fracture healing in rats (111), and found retarded fracture healing in the exposed animals at 14 days postoperatively.

EMF exposure has a general debilating effect on reproduction (3, 4, 76, 133, 170, 173).

Central Nervous System

Extremely low frequency (ELF) fields have been examined from the viewpoint of their effect on the brain by direct means and, in other studies, by means of the behavior modification that results from the exposure.

Lott and McCain (100), at North Texas State University applied an electric field of 40 V/m at 640 Hz to rats; they found a significant increase in brain electrical activity during the 1-h exposure period. Similar changes in brain activity can occur at higher frequencies (36, 37, 49, 158, 194).

Fischer and colleagues at Graz University in Austria exposed rats to 5,300 V/m at 50 Hz for periods ranging from 15 min to 21 days (51). They found that the level of norepinephrine in the brain was significantly affected after as brief an exposure as 15 min. The norepinephrine level first rose above normal, then, by the 10th day of exposure, fell below normal. Similar results were reported following exposure to 50 to 500 microwatts/cm^2 at 2.4 GHz (64).

Noval et al. (131), at the Naval Research Laboratory in Warminister, Pennsylvania, and Bawin and Adey (14), at UCLA, each reported effects of ELF fields on brain metabolism. Noval's group exposed rats to 0.5 to 100 V/m at 45 Hz for 30 to 40 days and found decreased levels of brain choline acetyltransferase. Bawin's group reported that the exposure of chick and cat brain tissue to 5 to 100 V/m at 1 to 75 Hz for 20 min altered the tissue's binding of calcium. Hansson reported histopathological changes in rabbit brain following chronic exposure to ELF electric fields (69), and we have recently confirmed these observations in mice (70).

Friedman, Becker, and Bachman (55) at the Syracuse Veterans Administration Medical Center; Gibson and Moroney (60) at the Naval Aerospace Medical Research Laboratory; Hamer (67) at UCLA, Konig (90) at Technical University in Munich; and Persinger, Lafreniere, and Mainprize (139) at Laurentian University in Ontario, each reported a significant effect of ELF fields on the reaction time of human beings or monkeys. An effect of such fields on animal activity was reported by Moos (124) of the University of Illinois.

Neuroendocrine System

A variety of statistically significant effects, including depressed body weight, depressed water consumption, increased adrenal and pituitary weights, and altered serum levels of albumin and hydroxycorticosterone were found in rats exposed to 15,000 V/m for 1 month (112). The results indicated that exposure to the field produced a physiological stress response. Noval et al. (131) independently performed similar experiments at much lower field strengths and reached essentially the same conclusion. Magnetic fields produced a similar response (20).

Mathewson et al. (120), at the Armed Forces Radiobiology Institute, exposed rats for 28 days to 0.5 to 100 V/m at 45 Hz. Their data revealed a variety of statistically significant effects in the exposed animals, which included changes in blood glucose, hemoglobin and hematocrit, total lipids, triglycerides, and body weight (112).

Mathewson's study (120) tended to confirm the Noval et al. results, with the chief difference being the severity of the effects. This led to an attempt to delineate the differences in the conditions under which the studies were performed.

The Noval et al. study was performed inside a Faraday cage formed by the steel-wall construction of the facility at which the test and control animals were housed. The possible significance of the shielding was not recognized in the beginning, and it was, therefore, not incorporated into the design of the Mathewson study. To the extent that Faraday shielding can, of itself, produce biological changes, the shielding can account for the differences between the two studies. Such effects due to shielding have been found in human beings, guinea pigs, and mice.

In the most thorough study of the phenomenon, Wever (185a), at the Max Planck Institute in Germany, isolated volunteers in underground bunkers for 3 to 8 weeks and measured the daily periods of their body temperature and activity rhythms. He found that subjects that lived in a shielded bunker exhibited rhythms whose period was different from those of subjects living in the nonshielded bunker. He also reported that desynchronization—the rhythms no longer rising and falling together—occurred only in the subjects in the shielded bunker. Both effects ceased when Wever applied 2.5 V/m at 10 Hz; this indicated that both the normal electromagnetic environment and the ELF field had a similar influence on the human rhythms studied. Altman and Soltau (1), at the University of Saarbrucken in Germany, exposed guinea pigs to 240 V/m at 10 Hz and maintained parallel groups under Faraday conditions and under normal conditions (no field and no shielding respectively). They found that the shielding produced changes in the blood proteins compared to the normal conditions and that the ELF field caused these changes to disappear. Lang (93), also at the University of Saarbrucken, exposed mice to 3,500 V/m at

10 Hz and maintained parallel groups under Faraday and normal conditions. The shielding produced changes in body water content, hemoglobin, and blood sodium levels; the effects were eliminated by ELF fields.

Prokhvatilo (146), at the Mareyev Institute in Kiev, conducted experiments on the effects of 50-Hz electric fields of 1,000 to 5,000 V/m on the neuroendocrine system of rats. He found that after several months exposure iodine metabolism in the thyroid and ketosteroid metabolism in the adrenal gland were both altered. In addition, the microscopic appearance of the thyroid also changed because of the electric field. Similar effects on the alteration of thyroid function were reported by Dumanskii, Popovich, and Prokhvatilo (50), of the Kiev Scientific Research Institute; they also found a decrease in blood cholinesterase activity in the field-exposed rats.

Blood

Studies have demonstrated effects of ELF electric fields on the cells and other constituents of blood (29, 62, 107).

Cardiovascular Systems

Gann (58), at Johns Hopkins University, subjected dogs to a small controlled hemorrhage and examined the effects of 15,000 V/m at 60 Hz for 5 h on the dogs physiological response to the hemorrhage; he found that the blood pressure and heart rate were significantly different in the exposed dogs as compared to the controls (which also experienced the hemorrhage). Fischer, Waibel, and Richter (50a), at Graz University in Austria, found that brief exposure of rats to 5,300 V/m, 50 Hz, caused a significant drop in heart rate.

Beischer, Grissett, and Mitchell (21), at the Naval Aerospace Medical Research Laboratory, exposed volunteers to a magnetic field of 1 G at 45 Hz for 1 day; in 9 of the 10 subjects they observed a significant increase in the level of blood triglycerides following the exposure.

General Physiology

ELF electric fields have been reported to alter the rate of cell division in mice (106), alter the metabolism of rat sperm cells (3), affect muscle metabolism in rats (143), and slow the rate of tumor growth in mice (11).

Analysis

The reports described above may be summarized this way:

1. EMFs can alter the metabolism of all body systems, including the nervous, endocrine, cardiovascular, hematological, immune-response, and reproductive systems.
2. The effects on each tissue or system are largely independent of EMF frequency.
3. An organism's response to an EMF is determined in part by its physiological history and genetic predisposition; individual animals, even in an apparently homogeneous population, may exhibit changes in opposite directions in a dependent biological parameter.
4. EMF-induced biological effects are best characterized as adaptive or compensatory; they present the organism with an environmental factor to which it must accommodate.

If attention were restricted to EMF-related changes in individual body systems such as the brain or blood, it might be hypothesized that the action of the field involved certain enzymes, specific antibody regions of certain cells or particular organs. But the studies clearly showed that EMFs produce a complex interrelated series of physiological changes (Figure 1). It follows that the consequences of EMF exposure must be understood in terms of an integrative response of the entire organism. In my view, after the EMF is detected, information concerning it is communicated to the central nervous system which then activates the broad array of physiological mechanisms that are available to furnish a compensatory response. As is generally true of an adaptive response, the particular biological system that is invoked, and the nature of its response, will depend on numerous factors including the animal's internal conditioning and its external environment. The biological processes that follow detection of an EMF are similar to those associated with the response to any biological stressor. Thus, for example, the cellular or molecular mechanisms that operate in the adrenal following a cold stress to produce altered serum corticoid levels also operate following an electromagnetic stress, because adrenal activity is initiated by neuronal and hormonal signals, not by the actual presence of the stressor agent in the tissue.

If electric and magnetic fields are simply nonspecific biological stressors that can elicit a systemic adaptive response in the exposed organism, what kinds of effects will occur in exposed human beings? If an organism is subjected to,

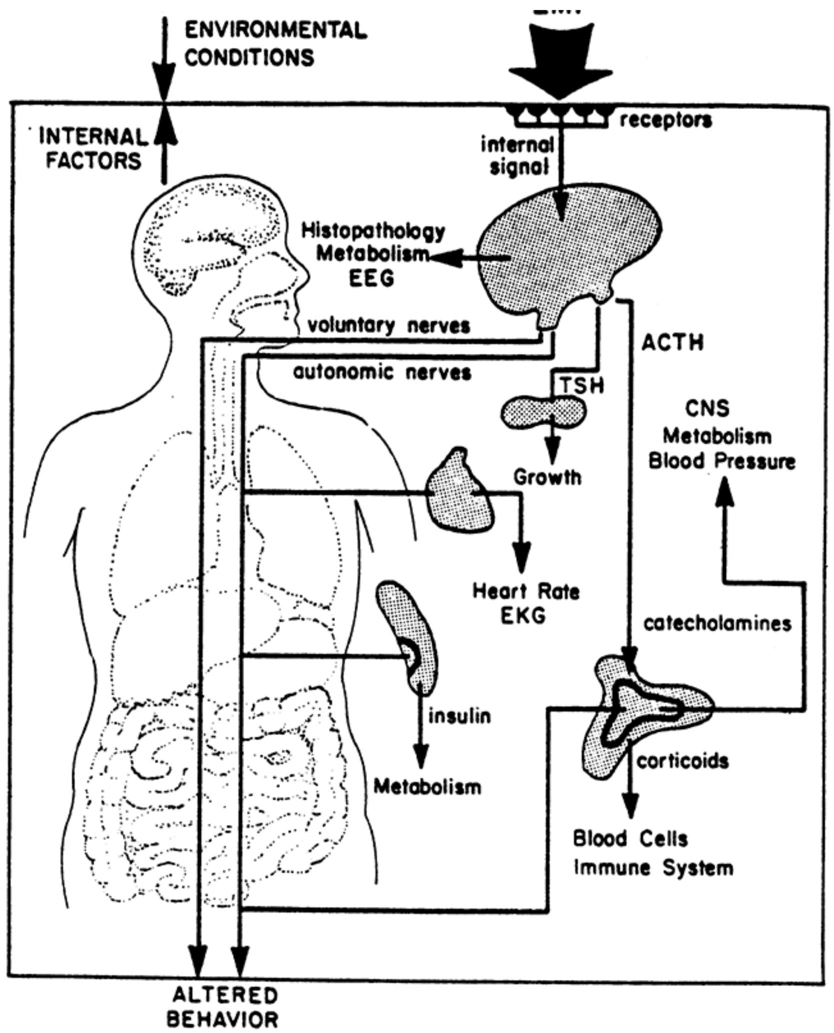

FIGURE 1

The physiological effects of applied electromagnetic fields.

for example, a cold stress, adaptive changes occur. If the stress is maintained, the animal's defenses break down, resulting in a diagnosable disease. But there is no signature disease for a cold stress. The animal could exhibit any of several diseases; infection (if a viral or bacterial agent were present in the environment) and pneumonia (if its respiratory system were already weakened for other reasons) are examples. The effects produced by environmental EMFs will depend on comparably diverse factors, and therefore will be manifested by an increase in all diseases.

In the example of the animal undergoing a cold stress, suppose that a second stress is applied (for example, that the animal is forced to live in cramped quarters). The expected result in an animal undergoing two stresses is that, whatever disease it is fated to develop when stressed beyond its limit, it will manifest that disease more quickly than if it experienced only one stressor. Thus, in general, EMFs will be a contributing factor, but not a strict cause, of disease.

If environmental EMFs are biological stressors, then epidemiological studies should show a correlation between EMF exposure and the incidence of disease. Many epidemiological studies have found this correlation (42, 89, 97, 98, 103, 123, 129, 138, 172, 175, 184, 185, 191).

HEALTH RISK OF SANGUINE/SEAFARER

The evidence shows that manmade EMFs are etiological factors in human disease. Many studies can be related to the health risk of high-voltage powerlines and it is possible to delineate zones of relative risk in their vicinity. But Sanguine/Seafarer electric and magnetic fields are significantly smaller than the corresponding fields of high-voltage powerlines, and the only indisputable method of evaluating the risk of Sanguine/Seafarer fields is to conduct biological experiments involving exposure to simulated Sanguine-strength fields as was recommended in 1973 (145).

Scientific studies will be needed if the environmental impact of Sanguine/Seafarer is to be rationally determined. Such studies should also address the potential global impact of Sanguine radiation in the magnetosphere. Helliwell had detected 60-Hz radiation in the magnetosphere from high-voltage powerlines (134). The radiated energy is amplified in the magnetosphere via an electron-wave interaction in which electrons precessing about the earth's field lines surrender energy to the electromagnetic wave. Sanguine/Seafarer, unlike powerlines, is intended to radiate and the physical and biological consequences, if any, of the Helliwell phenomenon as induced by Sanguine/Seafarer should be ascertained.

MECHANISMS OF DECISION

If our desire is to actually know the truth, what is the best way to evaluate the public health risk of Sanguine/Seafarer? The accumulated lessons gained in previous Federal level attempts to consider potential health dangers of exposure to environmental manmade EMFs provide the answer.

Shortly after the end of World War II, the Tri-Service program was initiated to determine safe exposure limits to EMFs. The concept of safety that evolved was based on the results of acute experiments: If a test animal's body was not overheated then (with a small safety margin) the corresponding EMF level was considered safe. Harm was equated to cooking, and safety to non-cooking. The decisions in the Tri-Service program were made by industry and the DOD.

About 10 years after Tri-Service, the Soviet Union began irradiating the American Embassy in Moscow with a microwave beam of 2 to 18 microwatts/cm^2 , a level approximately 5,000 times below the safe level of Tri-Service. For approximately 7 years the government studied the exposed workers for unusual disease incidences, and conducted microscopic studies of blood smears from embassy personnel looking for possible chromosomal aberrations. Sometime in the middle or late 1960s, a research program called Project Pandora was begun to complement these observations. The data from Pandora was destroyed without being published. The employees of the embassy were irradiated unknowingly, and had no opportunity to withdraw from the beam, nor to probe the expertise or impartiality of the people running the bioeffects studies.

In the late 1960s Sanguine/Seafarer was proposed and studies of the biological effects associated with the proposed antenna were funded by the Navy. The review group for the data thus obtained was a blue-ribbon panel (BRP) chosen by the Navy which met in December 1973 to consider the evidence. The BRP recommended continued and expanded research efforts (145). Despite this, most research was ended around 1975 when the Navy pronounced the antenna safe and pressed for its construction.

Within months of the public release of the BRP report (on the Senate floor) a second BRP was appointed at the behest of the Navy by the president of the National Academy of Sciences (NAS-BRP). The final report of the NAS-BRP tracked closely in form, content, and technique of analysis, as well as the testimony given by several panel members on behalf of the electric power industry in health and safety hearings concerning 765,000-V powerlines then being considered for construction in New York (26, 155).

The question to both the BRP and the NAS-BRP was nonspecific ("is it safe"). In both cases the Navy, or someone acting on its behalf, was the sole determiner of the expertise and credibility of the panel members. None of the panel members of either committee were ever tested regarding the bases of their views.

What does the history teach? First, that the naked conclusion of a blue-ribbon panel has no force of logic, claim to truth, or compelling reason to assent to its findings. Its conclusion merely reflects the unexposed bias and interests of its members. Blue-ribbon panels will be ignored by adversely affected parties, just as the Navy ignored the BRP, and others ignored the NAS-BRP. Second, there must be concrete issues for the scientists to consider. No one has urged that there is no risk from Sanguine/Seafarer, so it cannot be completely safe. Since the BRPs were not given concrete issues, they simply picked their own issues, and these bore no particular relation to the true societal problem. Third, the issues—once they are defined—will obviously be adversarial and cannot be settled by consensus. The Navy clearly wants the antenna and it supports the scientists who posit the notion that Sanguine/Seafarer will be safe. Some scientists disagree with this notion. The people who live in Wisconsin and Michigan who will actually be running the risk of exposure, whatever it will be, constitute still another interest group. The relations among these four groups are inherently adversarial.

There is a better way. The process must begin with a framing of issues, because there must be agreement on what actually constitutes the problem under discussion. Equally important is the direct involvement, or opportunity for involvement, of the people who would be impacted. They have a right to be heard. With issues and parties-in-interest, scientific talent must be made available to both sides, not one side as has been the case in most instances. The experts could then agree on the choice of judges, procedure, rules of evidence, and then the issues would be judged in the sunshine. Each witness could be specifically questioned by his adversary. This concept, the science court (121, 122, 171), follows the same principles and practices for the determination of truth and the pursuit of justice as are practiced in all other spheres in our society.

SUMMARY AND CONCLUSION

EMFs are in clinical use in many areas including the treatment of bone disorders, pain, and infection. Acceleration of the tempo of normal healing, and induction of regeneration in limbs and nerve have been demonstrated in animals following application of EMFs. A broad range of organisms from bacteria to vertebrates have been shown to detect and respond to EMFs. But not all biological responses to EMFs are therapeutic or otherwise beneficial. Numerous animal studies have shown that EMFs can elicit an adaptive syndrome—the stress response—mediated by the neuroendocrine system. Since the chronic application of any stressor can be inimical to health because it taxes adaptive capacity, it follows that chronic exposure to EMFs will be a risk to health. Consequently, EMF-exposed people will exhibit higher incidences of all diseases, not only higher cancer levels as have been reported.

The association between risk and the EMFs produced by specific emitters depends on the actual EMF level. For high-voltage powerlines the association is clear, but for Sanguine/Seafarer it cannot be rationally determined on the basis of the present evidence. The evidence that is needed is obvious (145).

An adequate assessment of the health risks of Sanguine/Seafarer cannot emerge from the present process.

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