Current and Potential Applications of Bioelectromagnetics in Medicine

Introduction

Several epidemiological studies that suggest links between exposure to electromagnetic fields and various harmful effects (for example, Nordström *et al*. 1983, 1987, Wertheimer, and Leeper, 1986, Brown and Chattopadhyay, 1988, EPA 1990, and Thériault 1990). The plausibility of such a causal link is underscored by experimental data showing that such fields can affect a wide range of biological processes, including growth and development (Goodman *et al*., 1989, Levengood 1967, Tsoneva, 1975, Khalil and Qassem, 1991, Stith *et al*., 1985, Ceccherelli *et al*., 1987, Kholodov, 1971, Delgado *et al*., 1981, Delgado *et al*., 1982).

However, it is also reasonably clear that the current focus on deleterious effects is a product of our poor current understanding of the mechanisms of bioelectromagnetic interactions (and in many cases, of the normal workings of the system being affected). After all, if one doesn't have a good understanding on how a complex system works, any energetic perturbations (such as applied EM fields) are much more likely to adversely affect function than to be helpful. There is nothing inherently destructive in electromagnetic energy; it can be a medium for delivering signals (with a wide variety of effects) to biosystems. With this in mind, I would like to provide a brief perspective on current and future applications of bioelectromagnetics in medicine. Needless to say, much of the future applications described below are speculative at this point.

Current Applications

A passive technique (detection of endogenous magnetic fields) is in use for diagnostic purposes (Erne *et al*. 1981, Williamson *et al*., 1983, Sato, 1990). It is possible to get valuable information about the functioning of various organs by analysis of the magnetic fields which they emit (these are extremely weak fields and are detected by SQUID devices).

The only active application of bioelectromagnetics in therapeutic use right now (that I am aware of) is ELF magnetic field treatment for bone non-unions (Christel *et al*., 1979, Barker *et al*., 1984, and all of the BRAGS proceedings volumes). Basically, the rate of bone growth and increase of mechanical integrity of knitted fractures can be accelerated non-invasively by placing a coil around the area, and creating a milli-Tesla AC or square-wave magnetic field by putting cur-

rent through the coil. A portable version of this device, most often used for fractures that are not healing by themselves, is used in hospitals right now. There are also cases of applied electric fields being used to enhance wound healing (Carley and Wainapel, 1985). Applications are like-wise being developed for treatment of ligament damage, osteoporosis, chronic skin ulcers, and tendenitis (Bassett, 1993).

Near-future applications

It is likely that the next advances in therapeutic uses for EM fields will be in the areas of regeneration and mitotic control. Applied electric fields have been shown to enhance nerve regeneration in mammals and other organisms (Borgens *et al*., 1981, Pomeranz, 1986, 1987, Borgens *et al*., 1987, McDevitt *et al*., 1987, Rusovan and Kanje, 1991, Kerns and Lucchinetti, 1992). Stimulated neurite outgrowth is likely to be responsible for this effect (sisken *et al*., 1993). These studies have obvious potential for use in medicine, since nerve damage can have grave consequences.

An even more exciting application involves whole limb regeneration. It has been hypothesized that limb regeneration (in normally regenerating species) is causally influenced by an endogenous electric field (Borgens *et al*., 1989). It has also been shown that applied fields of the type found *in vivo* can accelerate regeneration in such species, and more interestingly, effect regeneration in normally non-regenerating animals such as adult mammals (Smith, 1967, Smith, 1974, Becker and Sparado, 1972, Becker 1972, Borgens *et al*., 1979, Borgens, 1986, several papers in Borgens *et al*., 1989). Since human children exhibit fingertip regeneration (Illingworth, 1974, Borgens, 1982), a further study of the natural fields present at regeneration (Illingworth and Barker, 1980, Borgens *et al*., 1984) and a better molecular understanding of regeneration in other species may culminate in the ability to produce limb regeneration for limbs lost to trauma or surgical amputation.

Another potential near-future application involves mitotic control of tissues and cells in culture. It has been shown that applied ELF magnetic fields can enhance cell proliferation and accelerate the rate of cell division in tissue culture cells and embryos (Levin, in press, Saha *et al*., 1981, Saha, 1982, Rooze *et al*., 1982, Kaneko *et al*., 1984, Akamine *et al*., 1984, Falugi *et al*., 1987, Leon *et al*., 1992). This has potential applications for accelerating the growth rates of valuable cell cultures (such as skin for skin grafts, and other tissues used for transplantation).

Distant-future applications

More remote, and necessarily more speculative, applications of

bioelectromagnetics suggest themselves when one studies the literature on endogenous fields within organisms, and on the relationship of the biosphere with the geomagnetic and geoelectric fields.

There are a wide range of electric fields present within organisms (Marshall and Meader 1937, Becker, 1974, Robinson, 1983, Nuccitelli, 1984, Nuccitelli and Wiley, 1985). There are also a variety of magnetic fields (Erne *et al*. 1981, Williamson *et al*., 1983, Pohl, 1981, 1984, Sato, 1990), electromagnetic waves (Fröhlich, 1981, Fröhlich, 1983), and ultra-weak photons (Chwirot 1986, Schauf *et al.*, 1992) being emitted by cells, tissues, and organisms. These are hypothesized to be mediators of inter- and intra-cellular information (Galle *et al.* 1991, Popp and Nagl 1983a, 1983b, Nagl, 1988, Popp *et al.*, 1993). An understanding of the role of these endogenous fields is likely to have great pay-offs in our ability to obtain information from, and to affect, living systems in beneficial ways.

Other advances look promising in the area of cancer research. It appears likely that malignant tissue has electromagnetic characteristics which are different from those of normal tissues (Burr and Lane, 1935, Burr, 1952, Pyatenko and Tarusov, 1963, Mallard and Kent, 1966, Kim, 1976, Grasso *et al*., 1992, Scholz *et al*., 1988). Malignancy is often correlated with changes in the endogenous electric fields of the organism (Burr *et al*., 1938, Burr, 1941, Burr, 1952). Tumor tissue also appears to differ in its response to applied fields (Liboff and Winters, 1988). All of this offers potential uses in early and minimally-invasive diagnosis of malignancy.

Likewise, data suggesting that applied fields can preferentially affect malignant tissue (Gosset *et al*. 1924, Barnothy, 1969, Presman, 1970, Kim, 1976, Sheppard and Eisenbud, 1977, König *et al*., 1981, Jones *et al*., 1986), and studies showing that applied field effects can prolong the lives of animals with cancer (Humphrey and Seal, 1959, Indumati *et al*., 1965, Kholodov, 1971, 1973, Shauble *et al.*, 1977, Norton *et al*., 1983, Bellossi and Desplaces, 1991) makes plausible the possibility of cancer treatments based on bioelectromagnetics.

There has been some evidence that applied magnetic fields can ameliorate the harmful effects of ionizing radiation (Barnothy 1963, Amer and Tobias, 1965, Feola and Smith, 1984, Chiabrera *et al*., 1984a). This offers possibilities for magnetic radiation trauma treatment. This will have to wait for a good understanding of the effects, since other studies find increased damage caused by pulsed magnetic field application after exposure of mice to X-rays (Cadossi *et al*., 1989).

Finally, there are several studies which point to an interaction between living systems and the electromagnetic fields and radiations of the earth and atmosphere. For example, natural alterations in the geo-magnetic field are correlated with pa-

tient behavior in psychiatric wards (Friedman *et al*., 1965) and to various psychological disturbances (Persinger, 1987). Rajaram and Mitra (1981) find that convulsive seizures are correlated with geomagnetic activity, modified by solar activity. Persinger (1988) finds a correlation between geomagnetic activity and incidence of bereavement hallucinations. An understanding of the effects' mechanisms is likely to result in applications if these fields turn out to be important ecological parameters.

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