THE BASIC BIOLOGICAL DATA TRANSMISSION AND CONTROL SYSTEM INFLUENCED BY ELECTRICAL FORCES*

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Over the past decade, there has been a growing awareness that electrical and magnetic forces have specific effects on living organisms. These effects are produced by forces of very low magnitude and are not explainable in such simplistic terms as Joule heating. They appear to indicate sensitivities on the part of living organisms several orders of magnitude greater than predictable by present concepts of cellular or organismal physiology.

The effects are apparently separable into two broad categories: those that involve general or specialized functions of the central nervous system (CNS) and those that involve postembryonic growth and healing processes. CNS effects include the production of general anesthesia by electrical currents that traverse the brain,[1] the production of local or regional anesthesia by currents injected at classical acupuncture sites,[2] the direction of migratory behavior of the Atlantic eel by the earth's electrostatic field,[3] the navigational aid furnished the homing pigeon by the earth's magnetic field,[4] the apparent cue for the timing of biological cycles by the earth's magnetic field,[5] and the direct relationship between reversals of the earth's magnetic field and the extinction of whole species in the geological past.[6] Growth effects include the stimulation of bone growth by direct current injection,[7] the stimulation of cartilage regeneration by similar means,[8] the restoration of partial limb regeneration to mammals by small direct currents,[9] the stimulation of bone growth by electrical fields,[10] the inhibition of growth of implanted tumors in mammals by electrical currents with a polarity dependence[11] and by exposure to nonuniform magnetic fields,[12] the effect upon cephalocaudal axis development in the regenerating flatworm in a polarity-dependent fashion by applied direct currents,[13] and the production of morphological alterations in embryonic development by manipulation of the electrochemical species present in the environment.[14]

The lists are not intended to be all inclusive but were chosen to illustrate the great variety of effects produced. It should be noted that several of the effects are clinically applicable, and, indeed, some are in clinical use today. Unfortunately, none of the effects (except possibly bone growth stimulation) are based on an adequate foundation of biological theory, and, in fact, the key proposition of these effects, namely, that cells are capable of sensing and responding, in a specific fashion, to levels of electrical current voltage or electrical or magnetic fields, is hardly universally accepted.

I should like to consider, not the question of what effects occur or how they occur,

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but rather why they occur at all. Present physiological theories deal with growth and healing and nerve function quite adequately, and there is no valid reason to postulate that nanoampere currents or electric fields of strengths little removed from the naturally occurring one would have any effect upon cells. If electrotherapy of any type is to be accepted, not to fall into the hands of the quacks and charlatans, and to develop its potential to the utmost, we shall have to provide a framework upon which to explain our present observations, predict the existence of other effects, and provide a valid biological rationale for further work and exploration. In my opinion, the present seemingly unrelated observations do lend themselves to analysis and to the development of a logical theory that provides for experimental verification.

All of the reported effects appear to have one factor in common. They are all dealing with effects upon basic functions of the living material, functions that distinguish living from nonliving matter. All living organisms demonstrate the property of self repair to varying extents and capabilities, and all demonstrate certain cyclic patterns of behavior and activity, which are known as biological cycles. Finally, all of the reported effects are either directly upon nerve functions of some type or are upon activities, such as growth and repair, that are under some degree of neural control.[15] Most of these effects are upon biological functions that are under remarkably precise control by mechanisms that have, to date, eluded description by solution biochemistry. It would appear that what we are dealing with is something basic that resides in the organization of the living material itself, which is responsible for initiating, directing, and controlling the responses to trauma and is sensitive to alterations in the electromagnetic parameters of the environment. This postulate possesses several associated implications. First, the property must be well organized, but the mechanisms used must be simple. Second, the property must have been present in the first living organisms.

Without discussing the background of biogenesis in detail, there appear to be two main concepts at present. The first, which is derived from solution biochemistry, postulates an origin in an aqueous environment, with the development of complex molecules. and their subsequent sequestration from the environment by membraneous structures.[16] The second, which is derived from the concepts of the bio- logical solid state,[17] proposes an origin in complex crystalline structures that possess such properties as semiconductivity, photoconductivity, and piezoelectricity.[18] All of the reported effects of electromagnetic forces seem to lend support to the latter hypothesis. It is certainly not too difficult to conceive of an organized crystal structure with self-organizing and self-repairing properties based upon semiconductivity. Signals that indicate trauma would be transmitted by electron flow within the matrix, accompanied by perturbations in the electrical field pattern. Such a unit would demonstrate cyclic patterns in its activity produced by the interaction between lattice electron movement and cyclic variations in the electromagnetic field. It is furthermore not too difficult to imagine structures of this nature being the basis for subsequent organization of complex organic molecules and the gradual sequestration from the environment with the acquisition of aqueous-based energenic reactions. This unit would, then, approximate our concepts of a primitive living cell. Subsequent development could well be related to continuously increasing complexity in the solution-based chemical reactions. Nevertheless, the basic solid-state electronic material would perforce not have been discarded. Equally possible is the further development and specialization of the solid-state system to permit its continuing function into the metazoan state.

Accepting this premise, what characteristics would such a system have today and what would its functions be? Its presence should be grossly manifest by an organized

pattern of electrical potentials that would alter in a predictable fashion with trauma and subsequent repair processes. It should also be detectable as solid-state properties of various types associated with cells, cellular subunits, and cellular products. It should demonstrate characteristics of a control system, with identifiable input-output and transducer mechanisms. Finally, exposure to the various electromagnetic parameters should produce alterations in the functions controlled by this system.

Evidence that supports these concepts has been slowly accumulating for several decades. Standing dc potential patterns were described nearly 20 years ago.[19] More recently, the fields have been mapped with some precision, and the pattern has been found to be roughly parallel to the gross anatomical arrangement of the CNS.[20] Trauma produces alterations in the field pattern detectable as the current of injury,[21] which in turn shows a relationship to the duration and efficiency of the healing process.[22] Proteins,[23] collagen,[24] and cell membranes[25] have been shown to have various solid-state properties. Some data have been presented for semiconducting properties of nerve or related components.[26] Bone growth response to mechanical stress[27] and to fracture[28] have both been demonstrated to have characteristics of control systems with electrical phenomena as control system signals. Finally, there are now many reports of growth stimulation by low-level electrical phenomena, as listed above.

While our general concepts of this system hold that many, if not all, cells retain residual properties derived from the earliest living material, the metazoan complexity requires that certain cells or tissues specialize as data transmission and control channels for this modality. These channels should be carrying information in an electronic analog fashion and should deal with the basic biological activities I have discussed. It is apparent that there is some relationship between most of those functional phenomena and the CNS. Although the data transmission function of the CNS has been quite well described in terms of the action potential, no evidence has been found to link this property to the growth process per se.[29] In addition, the action potential system appears to be inadequate to explain the pain sensation.[30] Finally, on theoretical grounds, if we return once more to the concepts of biogenesis, the action potential system represents a sophisticated high-speed, high-capacity data transfer system. It seems highly unlikely that such a system originated early in metazoan development, yet animals that existed prior to its development must perforce have possessed a data transmission system capable of sensing trauma and initiating and controlling the repair process. I am therefore forced to conclude that two data transmission and control systems coexist in most present-day animals: one, the sophisticated, action potential, digital-type system, and the other, a more basic primitive analog-type system that antedated the former. Support for this concept is obtained from cybernetic analysis of the total function of the nervous system.[31] Either the nerves have two coexisting systems within themselves or a closely related tissue contains the primitive analog system. In this regard, it is interesting to note that the nervous tissue, wherever present, is invariably accompanied by the supportive or perineural tissue, the glial cells centrally and the Schwann cells peripherally. Further, morphological evidence exists for close communication between all of these cells, which makes possible their functioning as an anatomical unit,[32] and, finally, electrical activity of the analog type has been ascribed to these cells.[33] Evidence obtained in our laboratories in the past year has indicated that the retardation of fracture healing in peripherally denervated extremities is returned to normal when the transection gap in the peripheral nerve is bridged by these supporting cells, long before neural continuity itself is established.

I should like to propose in the light of the foregoing that all higher-order animals that exist today have two data transmission and control systems. The original, derived from the most ancient life forms, is analog in type and solid state in nature and deals with such

input parameters as the notification of trauma (perceived as pain) and the detection of alterations in the environmental electromagnetic field. The output parameter presently identified consists of regulation of reparative processes by control of the local electrical environment at the site of trauma. This system resides primarily in the supportive or perineural cells of the nervous system. It is further logical to postulate that the development of the nerve cells per se as high-speed data transmission devices was based upon and intimately related to the preexisting perineural cell system. There is much evidence for a steady state of slowly varying dc fields within the central[34] and peripheral[35] nervous systems. These have been shown to have a controlling function over the general level of activity of the digital action potential system.[36] I should therefore further postulate that the perineural system exercises a bias control over the functions of the neural action potential system, thereby setting its overall level of activity. Interaction between the solid-state data transmission system and the cyclic fluctuations in the ambient electromagnetic field would impress a similar cyclic fluctuation on the overall level of CNS activity.

This concept has the capability of explaining all of the reported phenomena at the present time. In addition, it provides a testable hypothesis that can be investigated by several methods. Particularly relevant to present interests is an analysis of the traditional technique of acupuncture. One of the problems overcome by the action potential system is the degradation of the dc signal by cable constants. Therefore, if the perineural cells function today as analog data transmission devices, the Schwann cells that accompany the peripheral nerves must employ some technique to prevent degradation of the de signal into the noise level with transmission over a distance. One such technique would be the establishment of the analogs of operational amplifiers along the peripheral channels. If these existed, one would then expect to observe dc voltage sources along the course of the peripheral data channels. These have been seen in our laboratory and coincide with the well-known acupuncture points. It is therefore understandable by these concepts how the insertion of a metallic needle into such a de source could cause a propagated perturbation along the data channel, which would thereafter produce functional results by direct action on the perineural system or indirectly via the bias control exerted by the perineural system on the nerve cells them selves.

Obviously, much remains to be done to explore this concept further and either prove or disprove the existence of a second data transmission system. In the interim, I believe it behooves all of us working in the area of the influences of low-level electromagnetic parameters on biological systems to recognize the existence of many parallel phenomena and to consider the possibility of an underlying biological control system of considerable import.

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DISCUSSION

DR. B. LOWENHAUPT: As I listened to Dr. Becker, I found myself unable to follow his central thesis of an electromagnetic signal system. It was puzzling that certainly the only force of biologic interest is electromagnetic. In all probability, the only force in nature is an electromagnetic force, so to say that there is an electromagnetic signal seemed to merely say that biochemical reactions occur.

DR. H. J. HAMBURY: Dr. Becker, I hesitate to take issue with you, because we have learned so much from you over the years, in fact, almost everything that we know about this field. However, did you state that there are no nerves in bones, because I'm sure there are?

DR. BECKER: Please let me explain that statement. When I said it, I knew that you and Dr. Johnson were here, and I expected one of you to say something about it. When I say there are no nerves in bone, it is from the viewpoint of bone per se, not the haversian canal, in which there is obviously a nerve, and not the periosteum, in which plenty of nerves are present; but, in bone structure itself, there are no nerves. This was a problem to Singer, because he stated regeneration and nerve are related and there are no explanations for this. I hope that answers your question.