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Charge transfer in the living matrix

James L. Oschman, Ph.D.[*]

Nature's Own Research Association, P.O. Box 1935, Dover New Hampshire, USA

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Nuclear matrix

Summary The living matrix is defined as the continuous molecular fabric of the organism, consisting of fascia, the other connective tissues, extracellular matrices, integrins, cytoskeletons, nuclear matrices and DNA. The extracellular, cellular and nuclear biopolymers or ground substances constitute a body-wide reservoir of charge that can maintain electrical homeostasis and "inflammatory preparedness" throughout the organism. Recent research has emphasized the significance of charge transfer in relation to the scavenging or neutralization of free radicals delivered to sites of injury during and after the oxidative burst. Evidence comes from studies of the role of electrons in mitigating the consequences of inflammation when living systems are connected to the earth (earthing). The phenomenon helps explain how bodywork and movement therapies can facilitate the resolution of acute or chronic injuries, and how patients with inflammatory conditions may "deplete" a therapist during hands-on treatments. It is suggested that barefoot contact with the earth as well as hands-on and hands-off therapies facilitate healing by stimulating the migration of charges into sites of acute or chronic inflammation. One hypothesis to explain the effects of earthing is that charges from the ground substance reservoir prevent "collateral damage" to healthy tissues in the vicinity of an injury. A second hypothesis is that earthing allows electrons to replenish charge in the ground substance reservoirs, making electrons available throughout the body.

Introduction: barefoot and charge transfer

Recent research has documented a variety of benefits from the transfer of charge from the earth to a barefoot organism (Ober, 2003; Ober and Coghill, 2003; Ghaly and Teplitz, 2004; Chevalier et al., 2006; Oschman, 2007, 2008a; Chevalier and Mori, 2008). These benefits are revealed by improved sleep, pain reduction and rapid effects on inflammation as negative charges (free electrons) neutralize free radicals that contribute to chronic health problems. Such health issues can arise from either "silent inflammation" from old injuries that have not fully resolved, or from the

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[*] Tel.: +1 603 742 3789; fax: +1 603 742 4695.
E-mail address: joschman@aol.com

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observable symptoms of inflammation: heat (measurable by medical infrared imaging), redness, pain, reduced range of motion at joints and swelling. Note, however, an important caveat, shown in the text box.

Inflammation: a caveat

Repeated observations are revealing that the classic signs of inflammation, heat, redness, pain, reduced range of motion and swelling are greatly reduced or even absent when the body is electrically coupled to the earth as soon as possible after an injury. This has been dramatically and repeatedly confirmed during several recent athletic events in which earthings have been used to treat acute injuries. If verified, these observations will have profound implications for our understanding of the functioning of the immune system.

The barefoot phenomenon has raised questions about the ways charge can be transferred within the body. While a variety of possible pathways exist, this report focuses on the living connective tissue matrix. We therefore define the living matrix and explore its potential to mediate charge transfer from the bare feet or other part of the body surface to sites of injury. We will see that the properties of the matrix identified by Pischinger and his colleagues provide a mechanism for the whole organism to store charge and therefore to react virtually immediately to injury to any part. Specifically, it is proposed that electrons are stored throughout the body in the extracellular ground substance and can be transferred via ionic conduction, semiconduction, drift and other methods to the vicinity of an injury. This charge transfer will occur because of the gradient in charge density created as of free radicals are neutralized.

The significance of charge transfer extends beyond consideration of the response to injury, as most physiological and biochemical processes in the body involve electrons in one way or another. Recent studies have shown that barefoot contact with the earth produces virtually instantaneous changes in a variety of physiological measures (Chevalier et al., 2006; Oschman, 2007, 2008a; Chevalier and Mori, 2008). This report focuses on the possible roles of electrons in the injury response. Another article will look at biochemical and physiological aspects of charge transfer. We begin by summarizing the research of others who have contributed parts of the picture.

The electrocardiogram

Charge transfer became a major issue in physiology and medicine with the discovery of the electrocardiogram about a century ago. A question arose as to precisely how the electrical fields produced during the beating of the heart travel to the surface of the body, where they can be detected with appropriate instruments. In 1913, Einthoven and colleagues made the simplifying assumption that the human body is a homogeneous "volume conductor" with the heart's electricity conducted through tissues, with dissolved electrolytes serving as the charge carriers (Einthoven et al., 1913). This overly simplistic model was useful in the early stages of research on the electrocardiogram. Unfortunately, the volume conductor assumption continues to dominate electrophysiology. For example, a recent treatise on electromagnetic field effects summarizes "electrical transport within tissues" as follows:

> The fundamental bioengineering perspective is that the human body is considered to be a compartmentalized (or lumped element) conducting dielectric. It consists of about 60% of water by weight, in which 33% is intracellular and 27% is extracellular. Body fluid in both the intracellular and the extracellular compartments is highly electrolytic, and these two compartments are separated by a relatively impermeable, highly resistive plasma membrane. Current within the body is carried by mobile ions in the body fluid (Lee et al., 2006).

Hence, when scientists think of charge transfer they immediately think of ions diffusing within a volume conductor. The various organs and layers of tissue are "lumped" together, essentially disregarding anatomy. This is a classic example of "meaning invariance" as was described previously (Oschman, 2008a). It is a problem that occurs again and again in science when tentative assumptions, useful in the early stages of an investigation are gradually taken as facts. Reliance on the volume conductor assumption has encouraged the use of approximations that affect virtually every aspect of physiology and medicine, and that pose barriers to the appreciation of complementary and alternative therapies. A closer look at the electronic aspects of biology will help everyone understand alternative approaches, and will require revision of many textbooks. Problems long considered solved will have to be reinvestigated. This step is necessary, and is overdue. For the diffusing hydrated ion and molecular charge transfer complex are simply too large to move fast enough through tissues to explain the speed and subtlety of living processes, including the electrocardiogram. Nor can they explain the rapid physiological changes that take place the instant barefoot contact is made with the surface of the earth.

The need for faster mechanisms of charge transfer also shows up dramatically in peak athletic or artistic performances involving perception and movement that is far too rapid to be explained by slow moving nerve impulses, diffusion of regulatory molecules and chemical reactions rate-limited by diffusion (Oschman, 2003). Moreover, demanding athletic events can result in acute injuries, and there is strong motivation for rapid healing so the athlete can re-enter the competition. Experience with elite athletes has repeatedly documented remarkably quick recovery when the injured part of the body is electrically coupled to the earth and when the athlete is subsequently connected to the earth during sleep and recovery (Spencer; see Oschman, 2008a). This appears to be true regardless of what part of the body has been injured.

It is often forgotten that controversy about the electrocardiogram began during the 1930's, when physiologists looked more carefully at the mechanisms of conduction of cardiac electricity. The standard electrocardiogram is often recorded from electrodes on the two wrists and left ankle, although other arrangements are used for specific purposes. It was soon realized that the electrical pathways through the body to the sensing electrodes are anatomically intricate, and that each tissue has a different conductivity (Eyster et al., 1933; Katz and Korey, 1935; Collin and Plonsey, 1978). These factors are neglected in the volume conductor model. Confusion about the precise nature of the electrocardiogram persists to this day, and extends to many other biological phenomena involving charge transfer.

Reversibility of conductive pathways

It is well known that the electrically conductive pathways in the body work in reverse, from the skin surface to the organs within the body. For example, electrical stimulation of the skin to affect the heart underlies external cardiac pacing and defibrillation. Likewise, electrical stimulation of the brain via electrodes on the scalp, in a method known as DC brain polarization, is being researched for effects on cognition and other aspects of brain function (e.g. Iyer et al., 2005). Finally, it has been known since the work of Duchenne, in 1867 (see Duchenne, 1959) that electrical stimulation at certain points on the skin surface can activate particular muscles. These discoveries document the presence and therapeutic significance of conductive pathways from the skin surface to the tissues and organs throughout the body, and in the opposite direction. While skin has a finite resistance, it is clearly not an insulator. Moreover, low impedance points have been identified on the skin. Some of these are acupoints, and there is evidence that some of these points are electrically coupled to specific organs (Chen, 1996; Major, 2007).

The living matrix

Evidence has accumulated that the living matrix (Figure 1) is a body-wide communication system that is essential to all living functions. The living matrix includes the extracellular sugar–protein biopolymers or ground substances, the collagens, water molecules, as well as the basement membranes, cytoskeletons, nuclear matrices and genetic material. Structural continuity between the extracellular, cytoskeletal and nuclear compartments was recognized and discussed by Hay (1981a, b), Berezney et al. (1982) and Oschman (1984), and even earlier by Pischinger and colleagues, beginning in 1975 (see below). Historically, the interstitial, cytoplasmic and nuclear or karyoplasmic elements of this continuous matrix have all been referred to as ground substances (Oschman, 1984). Because of their continuity, these matrices form a totally pervasive system, a major organ that reaches into every part and that forms all of the other tissues and organs. It is the only system that has direct contact with all of the parts of the body.

While it is the fundamental material that our bodies are made of, the matrix system has not been recognized by Western biomedicine as an actual organ because it is so intertwined with physiological regulations and living structures that it is challenging to identify it as a discrete system. Nonetheless the biophysical properties of the matrix and its components have profound significance in terms of biocommunication and other vital functions, and can help us understand many of the remarkable effects produced by bodywork and movement therapies as well as by barefoot contact with the surface of the earth.

When we think of body-wide communications, we usually think of the nervous and circulatory systems, as they support a variety of messaging functions, with signals carried by nerve impulses and hormones, respectively. However, as early as 1845, CB Reichert had recognized that nerves and blood vessels do not directly contact the cells in the

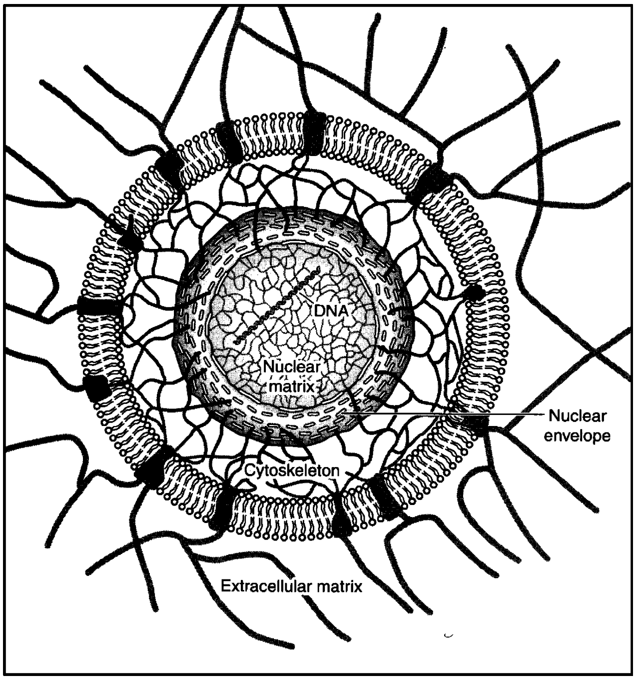

Figure 1 The living matrix is defined as the continuous molecular fabric of the organism, consisting of fascia, other connective tissues, extracellular matrices, integrins, cytoskeletons, nuclear matrices and DNA. This illustration from Oschman (2000) shows the continuity of the extracellular matrix, cytoskeleton and nuclear matrix.

body. Therefore, the influences of these important systems cannot be direct but must be mediated by and through the extracellular matrix. This and a subsequent paper (Oschman, 2008b) focus on these mediations. Here, the focus is on the conduction of electrons from the skin surface to parts of the body that have been injured. The following summarizes some of the research on the matrix system.

Alfred Pischinger

The role of the extracellular matrix in mediating a variety of important physiological functions was a major topic of the research of Alfred Pischinger and his colleagues in Austria and Germany beginning in 1975. Their research has been updated in a 10th edition of Pischingers classic text (Pischinger, 2007). The book is important for all therapists because it provides a holistic perspective founded on biomedical and clinical research. Pischinger recognized that the body-wide "ground regulation system" is responsible for all vital functions including nutrition of cells, removal of wastes, inflammation, defense and injury repair. Pischinger expanded on Virchow's "cellular pathology" model (Virchow, 1859) by stating that the smallest common denominator of life in the vertebrate organism is not the cell, but is a triad: capillary-matrix-cell.

Pischinger's work and that of his colleagues demonstrated more than any other that the extracellular matrix is not an inert filler substance or a passive mechanical filter, lying between the capillaries and the cells. Instead the matrix is a dynamic and vibrant and alive component of the organism with vital roles in the moment-by-moment operations of virtually all physiological processes. Under appropriate conditions, the matrix can react quickly as a unit. Signals can spread virtually instantly throughout the entire intermeshed system in an autocatalytic or chain-reaction manner. The proteoglycans in the ground substance in particular can react to stimulation of various kinds with a form of depolarization that can be rapidly propagated throughout the matrix system. This depolarization resembles the depolarization of a neuron in that it allows transmission of energy and information over great distances. Unlike the neuron, this depolarization is not "all or none" or digital in nature. Instead, it is an analog system, with the degree of depolarization proportional to the intensity of the stimulus. In a classic paper, Becker (1991) described the importance of this direct current analog system in regulating wound healing. What is being "depolarized" or "repolarized" are the epithelial layers at the surface of the skin or surrounding an organ (the so-called injury potential, reviewed by Borgens et al., 1989), as well as the basic electrostatic tonus established by the vast array of anionic ground substance molecules. Components of this ground substance network are shown in Figure 2 and include the following:

1. Glycoproteins are sugar–proteins with oligosaccharide chains (also called glycans) attached covalently to their polypeptide side chains. Integral membrane proteins and integrins are often glycoproteins with their glycosylated (carbohydrate) regions extending into the extracellular matrix.
2. Proteoglycans are a special kind of glycoproteins that are rich in carbohydrate polymers. They consist of a core protein with one or more glycosaminoglycan chains attached. Proteoglycans are the largest macromolecules found in biological systems.
3. Glycosaminoglcans or mucopolysaccharides are long linear carbohydrate polymers consisting of repeating disaccharide units. They are negatively charged under physiological conditions because they have a large number of hexose or hexuronic acid groups, either or both of which may be sulfated. The combination of the sulfate and carboxylate groups of uronic acid produces a very high density of negative charge. Examples of glycosaminoglycans include chrondroitin sulfate, dermatan sulfate, heparin, heparin sulfate and keratin sulfate. The glycosaminoglycans stand out straight from the proteoglycan backbones, and adjacent chains repel each other to form an arrangement like the bristles of a brush (Figure 2). The result of the charge density is a strong field or "domain" of negative charge (Hay, 1981a, b).
4. Hyaluronic acid or hyaluronan is a non-sulfated glycoaminoglycan that is found throughout the extracellular matrix.

The fundamental unit of the ground substance is called the matrisome (not to be confused with matrisomes in the brain, i.e. neural structures in the basal ganglia). Matrisomes in the extracellular matrix are oriented in a self-repetitive or redundant manner throughout the ground substance. While all matrisomes have the same basic pattern or organization, no two are alike (Figure 2).

The significance for the organism is that the proteoglycans and related molecules provide both local and systemic ionic, osmotic and electrical homeostasis. Electrical homeostasis, in turn, involves the concentration and distribution of free or mobile electrons and protons, as we shall see below. Because of the high density of negative charges on glycosaminoglycans (provided by sulfate and carboxylate groups of the uronic acid residues) the matrix is a vast whole-body redox system capable of absorbing and donating electrons at any point (Levine and Kidd, 1985). This electron transfer function extends to the interiors of cells as the cytoplasmic matrix is also strongly negatively charged (Ling, 1962). In other words, the entire extracellular and cellular matrix is a biophysical storage system or accumulator for electrical charge. One of the causes of the physiological shifts that take place when barefoot contact with the earth is established could therefore be a normalization of electrical homeostasis in the proteoglycan network in the living matrix and its extensions into cells and nuclei.

On the basis of thermodynamic, energetic and geometrical considerations, it has been concluded that the molecules of the ground substance form minimal physical and minimal electrical surfaces. The mathematics of minimal surfaces reveals that tiny changes in one area can cause large changes in distant areas of the ground substance (Karcher and Polthier, 1990). These concepts have implications for virtually all physiological and biochemical processes, membrane transport, antigen–antibody interactions, protein synthesis, oxidation reactions, actin–myosin interactions, sol to gel transformations in polysaccharides, and so on (Andersson et al., 1988). Subtle interactions with a living system, as minimal as the introduction of a single photon, can produce a cascade of changes that shift the physiological state of the entire organism. Such profound changes have been observed in many forms of complementary and alternative medicine, but have been difficult to comprehend on the basis of classical Newtonian physics, chemical laws of mass action, and Avogadro's or Loschmidt's number (discussed in detail by Heine (1997). As mentioned above, the volume conduction model has also limited the inquiry into biological energetics by over-emphasizing one of many possible methods of charge transfer.

Albert Szent-Györgyi

Albert Szent-Györgyi was certain that the random bumping about of molecules as envisioned in solution biochemistry was far too slow to explain the speed and subtlety of life. He looked for something that could move about rapidly within the living structures, and focused on electrons, protons and energy fields. Szent-Györgyi researched the insoluble scaffoldings that other biochemists routinely discarded when studying solution biochemistry.

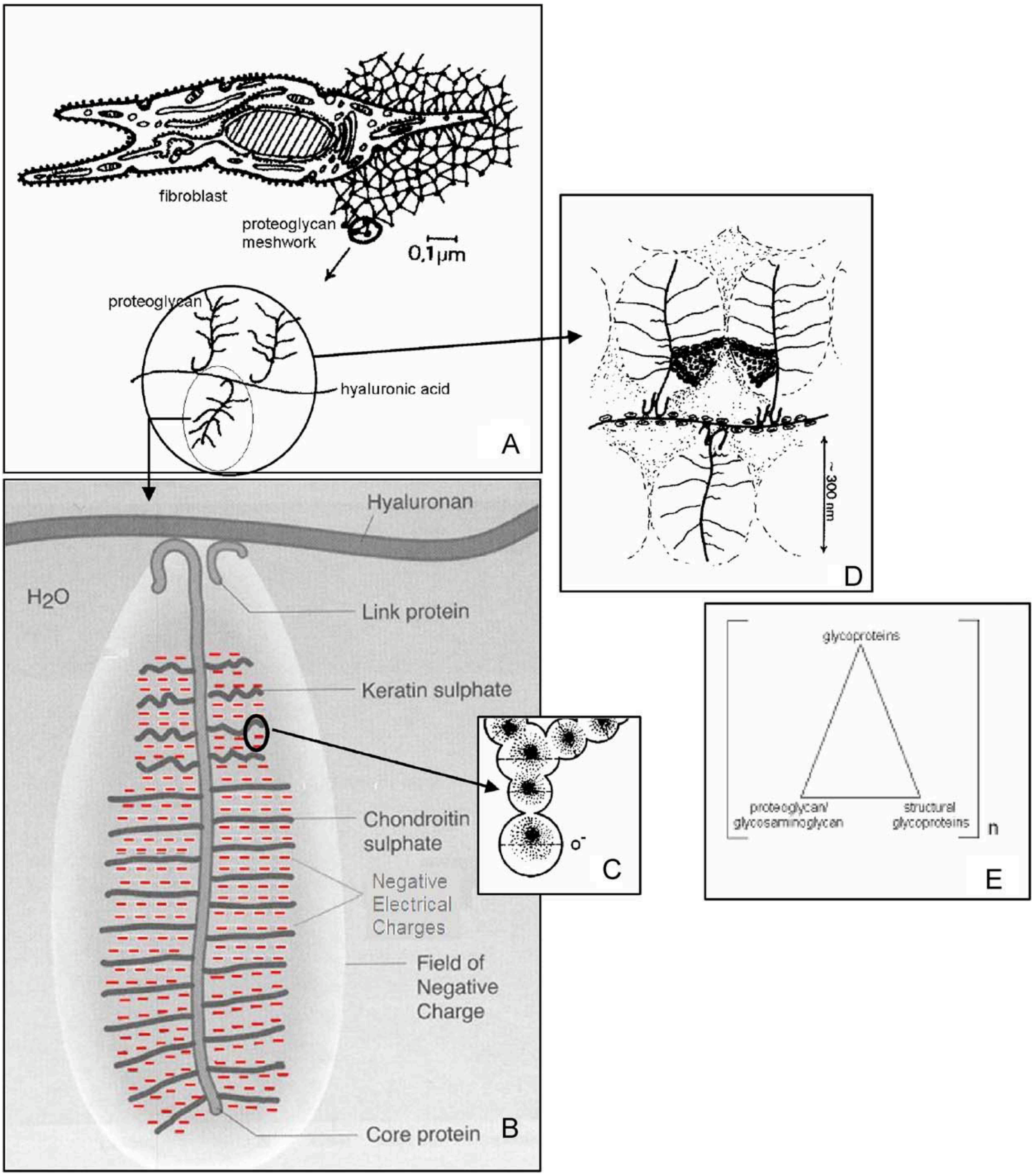

Figure 2 Details of the extracellular matrix: (A) The fibroblast embedded in the proteoglycan meshwork, along with details of the ways the proteoglycans attach to hyaluronic acid. The region in the circle represents one "matrisome" and is enlarged below. (B) The matrisome is a repeating proteoglycan unit consisting of the core protein linked to hyaluronan and glycosaminoglycan side chains. The glycosaminoglycans stand out straight from the proteoglycan backbones, and adjacent chains repel each other to form an arrangement like the bristles of a brush. The result of the charge density is a strong field or "domain" of negative charge. Original artwork is by Raychel Ciemma, and is reproduced from Lee (2005) with permission. (C) Details the origin of the negative charges on the glycosaminoglycan molecules. The dots represent the distribution of electrons in the atoms. From Ling (1962). (D) Detail from (A) showing close packing of proteoglycans (matrisomes) within tissues. The dotted lines depict the "domains" of the individual proteoglycan molecules. The double arrow shows the exchange of water and ions between the matrisome and the extracellular fluids. (E) A single matrisome unit within a bracket. This structure is repeated again and again (*n* is an extremely large number) to form a continuous ground substance reaching into every part of the organism. Figures A, D and E are from *The Extracellular Matrix* and *Ground Regulation: Basis for a Holistic Biological Medicine* by Alfred Pischinger, original German title *System der Grundregulation*, published by Karl F. Haug Verlag, copyright © 2004. English edition published by North Atlantic Books, copyright © 2007 by North Atlantic Books. Reprinted by permission of publisher.

Unknown to many physiologists is an extensive multi-disciplinary effort spanning some 70 years detailing non-electrolytic mechanisms of charge transfer in living systems. The early work was reported by Moglich and Schon (1938) and Jordan (1938). The subject was advanced dramatically by the publication in both *Science* and *Nature* of the Korányi Memorial Lecture given in Budapest on March 21, 1941 (Szent-Györgyi, 1941a, b). In these two papers, Szent-Györgyi proposed that proteins are semiconductors and are thereby capable of rapidly transferring free electrons from place to place within an organism:

> If a great number of atoms is arranged with regularity in close proximity, as for instance, in a crystal lattice, the terms of the single valency electrons may fuse into common bands. The electrons in this band cease to belong to one or two atoms only, and belong to the whole system.... A great number of molecules may join to form such energy continua, along which energy, viz., excited electrons, may travel a certain distance.

While this idea met with great skepticism, it was eventually shown to be entirely correct. It is now accepted that most if not all components of the living matrix have semiconductor properties (Rosenberg and Postow, 1969; Gutmann and Lyons, 1981; Gutmann et al., 1983). The Korányi Lecture is now recognized as seminal to the burgeoning global molecular-electronics industry, which makes extensive use of biomolecular semiconductors as components of nanoelectronic circuits. A recent review of this field (Hush, 2003) acknowledges the contributions of Albert Szent-Györgyi and his contemporary, Robert Milliken. It was Milliken who introduced the term "orbital" in 1932 and developed the molecular orbital theory that continues to be a cornerstone of quantum chemistry. Milliken received the Nobel Prize in Chemistry 1966 for his accomplishments.

At the end of the Korányi Lecture, Szent-Györgyi concluded:

> By means of our active substances we can produce the most astounding biological reactions, but we fail whenever a real explanation of molecular mechanisms is wanted. It looks as if some basic fact about life were still missing, without which any real understanding is impossible. It may be that the knowledge of common energy-levels will start a new period in biochemistry, taking this science into the realm of quantum mechanics.

In his trilogy, *Bioenergetics*, *Introduction to a Submolecular Biology*, and *Bioelectronics* (Szent-Györgyi, 1957, 1960, 1968), Szent-Györgyi continued to explore electronic conduction and charge transfer effects from the quantum perspective. The work of Szent-Györgyi's team at the Marine Biological Laboratory in Woods Hole, Massachusetts continued for another decade, with a primary focus on the details of charge transfer and the electronic aspects of cancer (Szent-Györgyi, 1976, 1978). Research in this field was thoroughly reviewed by Szent-Györgyi's associate, Ronald Pethig (1979). Since that time, a major portion of the study of organic semiconductors has shifted from academic settings to the nanoelectronics industry, as mentioned above. It is here that one finds the resources for basic research because of the enormous commercial value of increases in the speed of electron transfer processes in semiconductor devices. The basic goal of this rapidly evolving field is to use organic molecules or molecular aggregates as self-contained electronic devices in order to produce a new level of miniaturization that goes far beyond what can be achieved with circuits etched on a silicone wafer. The nanometer-scale building blocks include organic molecules, nanoparticles, nanocrystals, nanotubes and nanowires (Reed and Lee, 2003).

Szent-Györgyi (1988) stated that, "Molecules do not have to touch each other to interact. Energy can flow through ... the electromagnetic field." He continued, "The electromagnetic field, along with water, forms the matrix of life. Water ... can form structures that transmit energy." The structures he was referring to are the layers of water intimately associated with the surfaces of proteins, DNA and other molecules in the living matrix. This interfacial water is essential for the conformational stability and functioning of proteins and DNA. Thanks to contemporary research, we can now visualize the way water is organized in relationship to collagen, which is the major protein found in connective tissue (Cameron et al., 2007) and DNA (Corongiu and Clementi, 1981; Brovchenko et al., 2007). The importance of this interfacial water cannot be overestimated. Each fiber of the living matrix, both outside and inside cells and nuclei, and the genetic material, is surrounded by an organized layer of water that can serve as a channel of communication and energy flow. While electrons flow through the protein backbone (electricity), protons flow through the water layer. Mitchell (1976) referred to this proton flow as "proticity." Various degrees of coupling between electron and proton flows are possible.

Charge transfer has been studied in detail at relatively small levels of scale, such as in the electron transport chains found in chloroplasts and mitochondria. In these examples, what are designated as "long-range" charge transfers are measured in a few to hundreds of Ångstroms, and these are obviously much smaller distances than those involved in the transfer of an electron from, say, the bottoms of the feet to the brain or other tissue of an individual standing barefoot on the earth. Between the electron donor (the surface of the earth) and an electron acceptor (an inflammatory free radical, for example) are various tissues, membranes, epithelia and other boundaries. Of particular interest is the inflammatory barricade, a layer of connective tissue that is formed around a site of injury (Selye, 1953, 1984; also see Oschman, 2008a).

Kenneth J. Pienta and Donald S. Coffey

Pienta and Coffey (1991) published "Cellular harmonic information transfer through a tissue tensegrity-matrix system." The report combines the concepts of the living matrix, vibratory and resonant interactions, cellular and tissue continuity, piezoelectricity, solid-state biochemistry, coherence, and tensegrity to paint a picture of the regulation of living systems. The abstract of their report describes the matrix as a body-wide communication and regulatory system:

> Cells and intracellular elements are capable of vibrating in a dynamic manner with complex harmonics, the frequency of which can now be measured and analyzed in a quantitative manner by Fourier analysis [and by other methods]. Cellular events such as changes in shape, membrane ruffling, motility, and signal transduction occur within spatial and temporal harmonics that have potential regulatory importance. These vibrations can be altered by growth factors and the process of carcinogenesis. It is important to understand the mechanism by which this vibrational information is transferred directly throughout the cell [and throughout the organism]. From these observations we propose that vibrational information is transferred through a tissue tensegrity-matrix which acts as a coupled harmonic oscillator operating as a signal transducing system from the cell periphery to the nucleus and ultimately to the DNA. The vibrational interactions occur through a tissue matrix system consisting of the nuclear matrix, the cytoskeleton, and the extracellular matrix that is poised to couple the biological oscillations of the cell from the peripheral membrane to the DNA through a tensegrity-matrix structure. Tensegrity has been defined as a structural system composed of discontinuous compression elements connected by continuous tension cables, which interact in a dynamic fashion. A tensegrity tissue matrix system allows for specific transfer of information through the cell (and throughout the organism) by direct transmission of vibrational chemomechanical energy through harmonic wave motion. Pienta and Coffey, 1991) (Bracketed additions are author's.)

Thomas Hanna, Mae-Wan Ho, David P. Knight, Mark F. Barnes

In 1988, Thomas Hanna, Ph.D. (1928–1990) introduced the Greek term "soma" into the world of bodywork and movement therapies. Hanna created a school of "Somatics" and a set of simple exercises that enhance flexibility and ease of movement. According to Hanna, soma represents the body of life, the body experienced from within, the original cybernetic system. Hanna's reference to cybernetics is profoundly relevant to the study of the connective tissue and living matrix. Whether in an amoeba or in the human body, the matrix forms a self-regulating system that continually strives to achieve stability and balance by adapting the local cellular envronment as the external environment changes. The response to injury is one of these self-regulations.

A more recent conceptualization of somatic principles emerged from the work of Ho and Knight (1998). Taking into consideration semiconduction and proticity in the living matrix, they proposed that the acupuncture meridian system is a specialized information network, based on liquid crystalline resonant pathways that links and coordinates the various structures and functions within the organism, separate from or along with neural communications.

Barnes (2000) further synthesized these concepts in an effort to understand the deeper significance of changes in connective tissue brought about by Myofascial Release and other approaches. A key point he derived from Pischinger is that most vital activity, information exchange and primary regulation take place in the matrix, and not in the nervous system. Most importantly, if the matrix functions are interfered with, the defense and repair systems are compromised. The success of many of the manipulative therapies is due in part to their ability to restore the functions of the matrix. The barefoot phenomenon is revealing details of how the matrix functions in injury and repair processes.

Helene Langevin

In 2006, Helene Langevin published a study that explored the possibility that connective tissue is a "previously unrecognized" body-wide signaling network. At the same time, she pointed out the antiquity of the concept, as acupuncture theory is based on the idea that the body possesses a meridian system that functionally interconnects all parts of the body. Langevin and Yandow (2002) documented the close relationship between acupuncture points and connective tissue planes. There is evidence that at least some of the meridians represent low resistance pathways for the conduction of electricity; that stimulating a point on one meridian may affect the electrical properties both on the same and on other meridians; and that diseases and disorders can influence electrical properties at some points (summarized by Major, 2007, p. 57; Chen, 1996).

Langevin further stated that it remains unknown if the extensive *in vitro* research on the semiconductive, piezoelectric and photoconductive properties of biomolecules (e.g. the work of Albert Szent-Györgyi, Pethig, Mitchell and others cited above) has biological significance. However, there is substantial evidence that electric fields generated naturally by the piezoelectric effect and streaming potentials in bone and other tissues regulate bone and tendon remodeling, providing a biological basis for successful treatments of fracture non-unions (summarized by Bassett, 1968, 1995). There is also an extensive literature on the biological roles of photons (e.g. Pavesi and Fauchet, 2008; Shen and Van Wijk, 2006).

Langevin also raises the important issue that electronic charge transfer over a distance might require a gradient in charge density to give rise to diffusion current. Alternatively, a sustained potential difference would be needed give rise to a drift current. These are significant considerations in relation to injury and the injury potential. As free radicals are neutralized by mobile electrons, a gradient in electrons will be created that will favor the creation of a diffusion current, as Langevin suggests. However, there can also be a drift current, as drift currents in semiconductors can actually be independent of potential difference, particularly when the drift is across a PN junction (Physics Forum, 2007). We shall see next that there is evidence that semiconduction does take place *in vivo* and that PN junctions exist in living systems.

Robert O. Becker and the Hall effect

The Hall effect is named after E.H. Hall, who devised a method that can be used to distinguish between conductors, semiconductors and insulators (Hall, 1879). As shown in Figure 3, a magnetic field is set up at right angles to the direction of flow of charge through a material. The magnetic field exerts a force, called the Lorentz Force that deflects some of the charge carriers, producing a voltage perpendicular to the direction of current flow. This is called the transverse Hall voltage. The experiment works differently for different kinds of current flows. For any given strength of magnetic field, the Hall voltage is proportional to the mobility of the charge carriers. Ions in a solution are large and are barely deflected by a magnetic field. Free electrons are abundant in a metallic wire, but also have very low mobility. Electrons in semiconductors are fewer in number, but they are very free to move, and readily give rise to measurable Hall voltages, even with weak magnetic fields.

In his 1979 review, Pethig pointed out that matter exhibits a wide range of electronic conductivities. Metals are classified as conductors, and have conductivitiess of around 10^8 mho/m, whereas plastic is an insulator, with a conductivity of about 10^{-17} mho/m. This is an enormous range, extending over 25 decades of magnitude at room temperature. However, conductivity is not the only factor to consider in relation to the speed of charge transfer. The two quantities that dominate are the number of mobile charge carriers and their effective mobility. For example, diamond, which is a superb insulator, and germanium and silicon, which are semiconductors, have electron mobilities more than 25 times greater than that of metals such as copper. All materials contain electrons, but the ability of these electrons to move and their migration velocity is not easy to predict from theory and from measurements made on isolated molecules. Fortunately, the Hall effect can discriminate between simple conduction, ionic conduction and semiconduction.

In 1961, Robert O. Becker, MD conducted experiments on the limbs of intact salamanders (Becker, 1961). He was studying the pulsing direct current field that is set up by the brain waves and spreads throughout the body. In other studies, he had found that this field regulates growth and regeneration. Becker found that there was a significant transverse

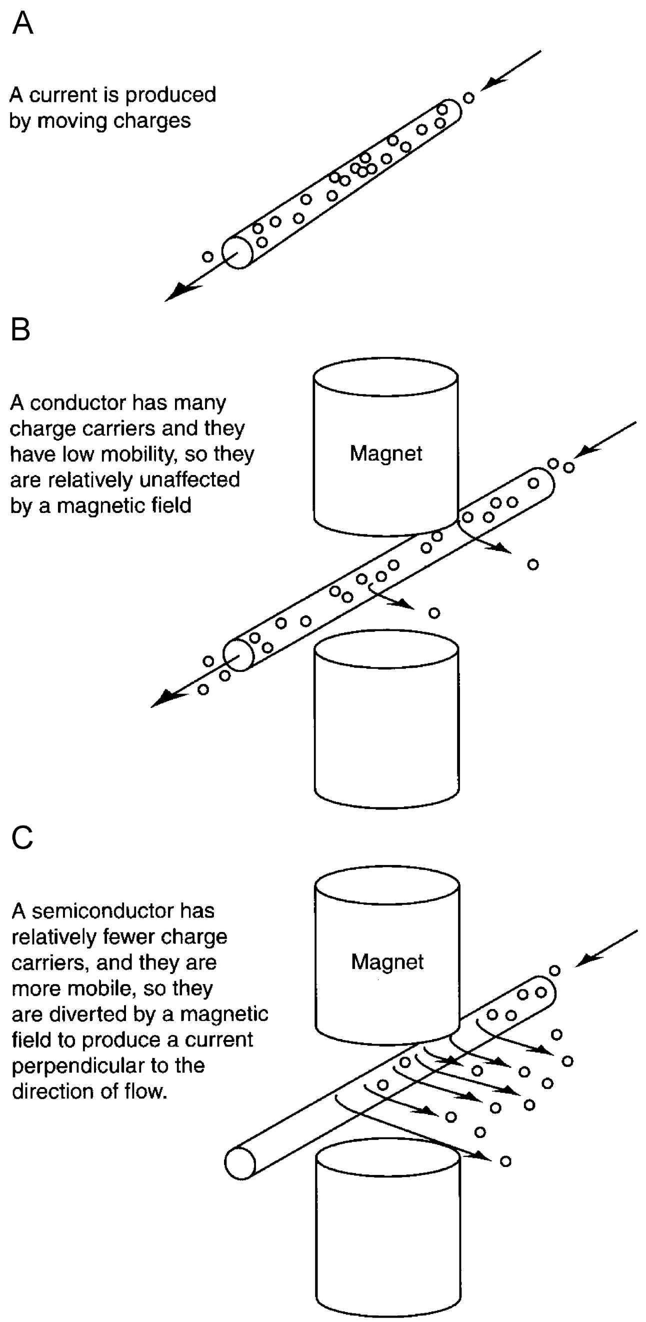

Figure 3 The Hall Effect can distinguish between conduction and semiconduction. (From Oschman (2000), after Becker and Selden, 1985, p. 113.)

Hall voltage across the salamander limb, and that it disappeared when the animal was anesthetized. This indicated two things. First, the pulsing fields are set up by the low-frequency oscillations of the brain, since they were reversibly eliminated by the anesthetic. When the brain fields cease to oscillate, consciousness is lost. Secondly, the Hall effect documented that the pulsing fields are semiconducted through the tissue. Becker suspected that the fields are set up in the fascial sheathes surrounding the nerves, called the perineurium. Becker's subsequent work showed that the two components of bone are semiconductors as well. Collagen is an N-type semiconductor and apatite is a P-type semiconductor (Becker and Selden, 1985).

Charge transfer: a variety of mechanisms

A wide variety of electrolytic charge transfer, donor–acceptor, semiconductive and redox reactions are taking place within an organism at any given time. Some of these processes involve ionic conduction; others involve charge transfer in and along the molecular fabric of the body, the living matrix, via semiconduction, quantum mechanical tunneling, resonant transfer, solitons and related processes. One description of the charge transfer process in the matrix is, "highly vectoral electron transport along biopolymer pathways" (Lewis, 1982). Still other mechanisms involve the body-wide clouds of negative charge created around the proteoglycans, as shown in Figure 2. Taken together, the insoluble semiconducting fabric of the body, the soluble and mobile charge transfer complexes in cells and tissues (e.g. Slifkin, 1971; Gutman, 1978; Mattay, 1994; Gutmann et al., 1997) and the protein–carbohydrate ground substance provide multiple opportunities and pathways for the movement of charge between the skin surface and the free radicals involved in the inflammatory response.

Electron flows from the skin surface to a site of injury or inflammation will follow the usual rules for electron flows in multi-component systems: the preferred route will be the pathway or pathways of least resistance and the gradients in charge density, as described above. Moreover, such charge transfers will be driven by the established principles of attraction between opposite charges. However, there is a fascinating and unexpected paradox in the relationship between the speed of electron transfer reactions and the "driving force". Rudolph A. Marcus of the California Institute of Technology predicted a phenomenon that was completely unexpected by the chemist's intuition and that was initially difficult to accept and confirm. When the driving force increases beyond a certain level, electron transfer will begin to slow down instead of speed up, as we would expect (Marcus, 1992). Odd as this may seem, the phenomenon was established experimentally and led to Marcus receiving a Nobel Prize in chemistry in 1992 for his contributions to the theory of electron transfer reactions in chemical systems. A consequence is that a vectoral electron transport process does not necessarily require a large potential gradient, and may actually be greater when the potential is small.

In addition, the precise pathways of charge transfer from the skin surface will depend on the location of a site of injury and the impedance and other properties of the various tissue layers and fluid compartments. These pathways will also depend on where on the skin surface the earth contact is made. Finally, the pathway will change from moment to moment as physiological and behavioral changes take place due to the localized reduction in inflammation produced by the charge transfer.

Conclusions

Study of the barefoot phenomenon is providing new insights into the ways the body responds to injury as well as the mechanisms by which earthing and other techniques can facilitate regeneration and repair. The following lists what is generally accepted about responses to injury, and the testable hypotheses that are under consideration. It worthwhile to emphasize that the schemes proposed here are mechanisms for quickly providing antioxidant electrons to any part of the body that is injured, without exception, in order to reduce collateral free radical damage to nearby healthy tissues. This is possible because of the ubiquity of the ground substance, which is a part of every living structure, including individual cells and nuclei. These concepts also provide a possible mechanism by which the body can restore its reserves of antioxidant electrons in order to maintain inflammatory preparedness:

1. *Established fact*: any injury, large or small, results in an oxidative burst in which neutrophils and other white blood cells deliver highly reactive oxygen and nitrogen species to the region to destroy pathogens and to break down damaged cells and tissues.
2. *Hypothesis*: when free electrons are readily available, they can reduce or prevent free radical "collateral damage" to healthy cells and tissues during and after the oxidative burst.
3. *Hypothesis*: Free electrons in the tissues are the ultimate antioxidants because they can traverse the inflammatory barricade that the body forms around an injury site.
4. *Hypothesis*: the classic signs of inflammation-heat, redness, pain, reduced range of motion and swelling—are largely avoidable if the tissues have sufficient free electrons to prevent free radical collateral damage to healthy tissues near a site of injury.
5. *Hypothesis*: free electrons from the earth can enter the body via the bare feet, and can be transferred to sites of injury.
6. *Established fact*: while skin tends to have a relatively high resistance to the flow of electricity, significant electrical coupling across the skin to the body interior is evidenced by the ability to record the electrocardiogram and the electroencephalogram from the heart

and brain, respectively, and is also evidenced by the ability of electrical fields applied to the skin to enter the body and influence the functioning of those organs.

7. *Established fact*: the foot has a major acupuncture point called Kidney 1.
8. *Hypothesis*: some of the acupuncture points have lower electrical resistance than non-points, and the points connect to meridians that extend throughout the extracellular matrix of the body, although there is debate about these issues.
9. *Hypothesis*: mobile electrons can enter the body via Kidney 1 and other areas on the skin surface and can be distributed throughout the organism via the ground substance, the meridian system and other methods of charge transfer.
10. *Established fact*: The extracellular sugar biopolymers or ground substance forms a body-wide reservoir or accumulator for electrical charge.
11. *Hypothesis*: the ground substance maintains electrical homeostasis and the "inflammatory preparedness" of the organism because of its capacity to store and transfer charge to sites of injury.
12. *Hypothesis*: charges stored in the matrix are attracted to sites of injury because of the gradient in charge density created as electrons are depleted by neutralizing free radicals.
13. *Hypothesis*: wearing shoes with insulating soles isolates the human body from the surface of the earth and thereby disturbs electrical homeostasis, depletes the reserves of charge in the ground substances and reduces the "inflammatory preparedness" of the organism.
14. *Hypothesis*: Electrons entering the body via the feet can replenish the charge in the ground substance reservoirs and thereby make antioxidant electrons readily available to injury sites anywhere in the body.
15. Hypothesis to be presented in the next report in this series: providing free or mobile electrons to tissues saturates the electron transport chains in mitochondria, thereby increasing the availability of adenosine triphosphate that energizes the activities of immune cells and other cells involved in tissue repair.
16. *Hypothesis*: electrical continuity between the human body and the surface of the earth allows geophysical electrical rhythms to cause rhythmic changes in the electrostatic tone of the matrix, which can set the organism's biological clocks.

On the basis of its system-wide distribution and its capacity for charge storage, the living matrix is ideally suited to provide electrons that can prevent "collateral damage" to healthy cells and tissues when the oxidative burst delivers free radicals to a site of injury. This conclusion arises from the observation that connecting the body to the earth immediately after an injury seems to reduce or prevent the classic signs of inflammation, and by the observation that all parts of the body are affected. Continuity of the anionic extracellular matrix with the anionic cellular and nuclear ground substances enables the protective effects to extend to the cell interior and nuclear matrix, including the DNA.

A physics description of the human body is that it is composed of matter which is, in turn, composed of electrons and protons. Some of the electrons are free electrons. These electrons can be described as particles, as a sort of electric fluid, as a cloud, or as a gas. Physicists and quantum physicists have used all of these terms: particles, delocalized electrons, fluid or quantum fluid, cloud, and gas to describe mobile electrons. The proteoglycans in the ground substances form a body-wide field of negative charge (see Figure 2B). The behavior of these electrons is significant in terms of physiology, behavior and therapeutics.

Inflammation has been associated with a wide variety of chronic diseases, and the various bodywork and movement therapies are especially effective in the treatment of chronic issues. We are learning that the earth is a rich source of free or mobile electrons and that most people are deficient free electrons because of infrequent barefoot contact with the earth. This information is relevant to our understandings of how various hands-on and hands-off therapies can stimulate the healing response. The laws of physics teach that electrical fields produced during touch (the piezoelectric effect and streaming potentials) and the biomagnetic fields introduced during hands-off therapies such as healing touch, therapeutic touch, polarity therapy, Reiki, and so on will influence the movements of charge within the body of a patient. When this information is viewed from the perspective of the inflammation hypothesis, it can explain how restoring the reservoirs of electrons in the ground substance and stirring of the clouds of electrons can produce healing effects for a wide range of acute and chronic injuries and diseases.

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References

Andersson, S., Hyde, S.T., Larsson, K., Lidin, S., 1988. Minimal surfaces and structures: from inorganic and metal crystals to cell membranes and biopolymers. Chemical Reviews 88, 221–242.

Barnes, M.F., 2000. Myofascial release—morphological change in the connective tissue. In: Charman, R.A. (Ed.), Complementary Therapies for Physical Therapists. Butterworth-Heinemann, Oxford, pp. 171–185 (Chapter 13).

Bassett, C.A.L., 1968. Biologic significance of piezoelectricity. Calcified Tissue Research 1, 252–272.

Bassett, C.A.L., 1995. Bioelectromagnetics in the service of medicine. In: Blank, M. (Ed.), Electromagnetic Fields: Biological Interactions and Mechanisms. Advances in Chemistry Series, vol. 250. American Chemical Society, Washington, DC, pp. 261–275.

Becker, R.O., 1961. Search for evidence of axial current flow in peripheral nerves of salamander. Science 134, 101–102.

Becker, R.O., 1991. Evidence for a primitive DC electrical analog system controlling brain function. Subtle Energies 2, 71–88.

Becker, R.O., Selden, G., 1985. The Body Electric. Electromagnetism and the Foundation of Life. William Morrow and Company, Inc., New York.

Berezney, R., Basler, J., Bucholtz, L.A., Smith, H.C., Siegel, A.J., 1982. Nuclear matrix and DNA replication. In: Maul, G.G. (Ed.), The Nuclear Envelope and the Nuclear Matrix. Alan R. Liss, New York, pp. 183–197.

Borgens, R.B., Robinson, K.R., Vanable Jr., J.W., McGinnis, M.E., McCaig, C.D., 1989. Electric Fields in Vertebrate Repair: Natural and Applied Voltages in Vertebrate Regeneration and Healing. Alan R. Liss, New York.

Brovchenko, I., Krukau, A., Oleinikova, A., Mazur, A., 2007. Water percolation governs polymorphic transition and conductivity of DNA, from computational biophysics to systems biology (CBSB07). In: Hansmann, U.H.E., Meinke, J., Mohanty, S., Zimmermann, O. (Eds.), Proceedings of the NIC Workshop 2007, John von Neumann Institute for Computing, Jülich, NIC Series, vol. 36, pp. 195–197.

Cameron, I.L., Short, N.J., Fullerton, G.D., 2007. Verification of simple hydration/dehydration methods to characterize multiple water compartments on Tendon Type 1 Collagen. Cell Biology International 31 (6), 531–539.

Chen, K.-G., 1996. Electrical properties of meridians. IEEE Engineering in Medicine and Biology, May/June, pp. 58–63, 66.

Chevalier, G., Mori, K., 2008. The effect of earthing on human physiology. Part 2: electrodermal measurements. Submitted for publication.

Chevalier, G., Mori, K., Oschman, J.L., 2006. The effect of earthing (grounding) on human physiology. European Biology and Bioelectromagnetics (January 31), 600–621.

Collin, R.E., Plonsey, R., 1978. A note on dipole sources in conducting biological tissues. Bulletin of Mathematical Biology 40, 201–209.

Corongiu, G., Clementi, E., 1981. Simulations of the solvent structure for macromolecules. II. Structure of water solvating Na^+-B-DNa at 300 K and a model for conformational transitions induced by solvent variations. Biopolymers 20, 2427–2483.

Duchenne, G.B.A., 1959. E.B. Kaplan's Translation from the First Edition of Physiologie des mouvements, First Published in 1867. W.B. Saunders, Philadelphia.

Einthoven, W., Fahr, G., de Waart, A., 1913. Über die Richtung und die manifeste Grösse der Potentialschwankungen im menschlichen Herzen und über den Einfluss der Herzlage auf die Form des Elektrokardiogramms. Pflugers Archiv fur die gesamte Physiologie 150, 275.

Eyster, J.A.E., Maresh, F., Krasno, M.R., 1933. The nature of the electric field around the heart. American Journal of Physiology 106, 574–598.

Ghaly, M., Teplitz, D., 2004. The biological effects of grounding the human body during sleep, as measured by cortisol levels and subjective reporting of sleep, pain and stress. Journal of Alternative and Complementary Medicine 10, 767–776.

Gutman, V., 1978. The Donor–Acceptor Approach to Molecular Interactions. Plenum Press, New York.

Gutmann, F., Lyons, L.E., 1981. Organic Semiconductors. Part A. Krieger, Malabar, Florida.

Gutmann, F., Keyzer, H., Lyons, L.E., 1983. Organic Semiconductors. Part B. Krieger, Malabar, Florida.

Gutmann, F., Johnson, C., Keyzer, H., Molnár, J., 1997. Charge Transfer Complexes in Biological Systems. Marcel Dekker, Inc., New York.

Hall, E., 1879. On a new action of the magnet on electric currents. American Journal of Mathematics 2 (3), 287–292.

Hanna, T., 1988. Somatics: Reawakening the Mind's Control of Movement, Flexibility and Health. Addison-Wesley, New York.

Hay, E.D., 1981a. Extracellular matrix. Journal of Cell Biology 91, 205s–223s.

Hay, E.D., 1981b. Cell Biology of Extracellular Matrix. Plenum, New York, p. 107.

Heine, H., 1997. Hehrbuch der biologischem Medizin, second ed. Hippokrates Verlag, Stuttgart.

Ho, M.-W., Knight, D.P., 1998. The acupuncture system and the liquid crystalline collagen fibers of the connective tissues. American Journal of Chinese Medicine 26, 251–263.

Hush, N.S., 2003. An overview of the first half-century of molecular electronics. Annals of the New York Academy of Sciences 1006, 1–20.

Iyer, M.B., Mattu, U., Grafman, J., Lomarev, M., Sato, S., Wassermann, E.M., 2005. Safety and cognitive effect of frontal DC brain polarization in healthy individuals. Neurology 64, 872–876.

Jordan, P., 1938. The physical structure of organic giant molecules. Naturwiss 26, 693–694.

Karcher, H., Polthier, K., 1990. Die geometrie von Minimalfachen. Spektrum d. Wissenchaft 10, 96–197.

Katz, L.N., Korey, H., 1935. The manner in which the electric currents generated by the heart are conducted away. American Journal of Physiology 111, 83.

Langevin, H.M., 2006. Connective tissue: a body-wide signaling network. Medical Hypotheses 66, 1074–1077.

Langevin, H.M., Yandow, J.A., 2002. Relationship of acupuncture points and meridians to connective tissue planes. The Anatomical Record 269, 257–265.

Lee, R.P., 2005. Interface. Mechanisms of spirit in osteopathy. Stillness Press, LLC, Portland, OR.

Lee, R.C., Bodnar, E.N., Betala, P., Bloom-Eberwein, S., 2006. Electrical Shock Trauma. In: Barnes, F.S., Greenbaum, B. (Eds.), Handbook of Biological Effects of Electromagnetic Fields, third ed. CRC Press, Boca Raton, FL (Chapter 10).

Levine, S.A., Kidd, M.P., 1985. Antioxidant Adaptation: Its Role in Free Radical Pathology. Biocurrent Division, San Leandro, CA.

Lewis, T.J., 1982. Electronic processes in biology. Physics in Medicine and Biology 27 (3), 335–352.

Ling, G.N., 1962. A Physical Theory of the Living State: The Association-Induction Hypothesis. Blaisdell, New York, p. 58.

Major, D.F., 2007. Electroacupuncture. A Practical Manual and Resource. Churchill Livingstone/Elsevier, Edinburgh.

Marcus, R.A., 1992. Electron transfer reactions in chemistry: theory and experiment. Nobel Lecture, December 8.

Mattay, J. (Ed.), 1994. Electron Transfer I. Springer, Berlin.

Mitchell, P., 1976. Vectorial chemistry and the molecular mechanics of chemiosmotic coupling: power transmission by proticity. Biochemical Society Transactions 4, 399–430.

Moglich, F., Schon, M., 1938. Energy of vibration in crystals and molecular complexes. Naturwiss 26, 199.

Ober, A.C., 2003. Grounding the human body to earth reduces chronic inflammation and related chronic pain. ESD Journal, July Issue.

Ober, A.C., Coghill, R.W., 2003. Does grounding the human body to earth reduce chronic inflammation and related chronic pain? In: Presented at the European Bioelectromagnetics Association Annual Meeting, November 12, 2003, Budapest, Hungary.

Oschman, J.L., 1984. Structure and properties of ground substances. American Zoologist 24, 199–215.

Oschman, J.L., 2000. Energy Medicine: the scientific basis. Churchill Livingstone, Edinburgh.

Oschman, J.L., 2003. Energy Medicine in Therapeutics and Human Performance. Butterworth Heinemann, Edinburgh.

Oschman, J.L., 2007. Can electrons act as antioxidants? A review and commentary. Journal of Alternative and Complementary Medicine 13 (9), 955–967.

Oschman, J.L., 2008a. Perspective: assume a spherical cow: the role of free or mobile electrons in bodywork, energetic and movement therapies. Journal of Bodywork and Movement Therapies 12, 40–57.

Oschman, J.L., 2008b. Mitochondria and cellular aging. Preparation for Anti-Aging Medical Therapeutics, vol. 11.

Pavesi, L., Fauchet, P.M., 2008. Biophotonics. Springer, New York.

Pethig, R., 1979. Dielectric and Electronic Properties of Biological Materials. Wiley, Chichester.

Physics Forum, 2007. 05.02.07. Why is drift current through a PN junction independent of applied bias voltages? On the web at ⟨http://www.physicsforums.com/showthread.php?t=168627⟩. Accessed on May 22, 2008.

Pienta, K.J., Coffey, D.S., 1991. Cellular harmonic information transfer through a tissue tensegrity-matrix system. Medical Hypotheses 34, 88–95.

Pischinger, A., 2007. Extracellular Matrix and Ground Regulation: Basis for a Holistic Biological Medicine. North Atlantic Books, Berkeley, CA (Revised and updated English translation of Das System der Grundregulation: Grundlagen für eine ganzheitsbiologische Theorie der Medizin. Originally published by K.F. Haug, Heidelberg, 1975).

Reed, M.A., Lee, T., 2003. Molecular Nanoelectronics. American Scientific Publishers, Stevenson Ranch, CA.

Reichert, C.B., 1845. Vergleichende Beobachtukngen über das Bindegwebe und die verwandten Gebilde. Dorpat 168.

Rosenberg, F., Postow, E., 1969. Semiconduction in proteins and lipids—its possible biological import. Annals of the New York Academy of Sciences 158, 161–190.

Selye, H., 1953. On the mechanism through which hydrocortisone affects the resistance of tissues to injury. Journal of the American Medical Association 152 (13), 1207–1213.

Selye, H., 1984. The Stress of Life, Revised Edition. The McGraw-Hill Companies, Inc., New York, pp. 218–219.

Shen, X., Van Wijk, R., 2006. Biophotonics: Optical Science and Engineering for the 21st Century. Springer, New York.

Slifkin, M.A., 1971. Charge transfer Interactions of Biomolecules. Academic Press, London.

Szent-Györgyi, A., 1941a. Towards a new biochemistry. Science 93 (2426), 609–611.

Szent-Györgyi, A., 1941b. The study of energy-levels in biochemistry. Nature 148 (3745), 157–159.

Szent-Györgyi, A., 1957. Bioenergetics. Academic Press, New York.

Szent-Györgyi, A., 1960. Introduction to a Submolecular Biology. Academic Press, New York.

Szent-Györgyi, A., 1968. Bioelectronics. Academic Press, New York.

Szent-Györgyi, A., 1976. Electronic Biology and Cancer. Marcel Dekker, Inc., New York.

Szent-Györgyi, A., 1978. The Living State and Cancer. Marcel Dekker, Inc., New York.

Szent-Györgyi, A., 1988. To see what everyone has seen, to think what no one has thought. Biological Bulletin 175, 191–240 (This symposium volume contains a complete listing of publications of Szent-Györgyi 1913–1987).

Virchow, R., 1859. Die Cellularpathologie. Hirschwald, Berlin (Cited from Picken, L., 1960. The Organization of Cells. Clarendon Press, Oxford, p. 582).