ALTERNATIVE MEDICINE

Bioelectromagnetics

by Robert O. Becker

Electricity and magnetism have fascinated mankind since their discovery. The mysterious unseen force of the lodestone and the spark and sting of static electricity were ideal candidates for the imagined "life force" that animated living things and whose absence brought death. By the 18th century, devices for the generation and storage of static electricity, the only kind then known, were in the laboratory of every natural philosopher.

In 1781, Luigi Galvani, a physician and Professor of Anatomy and Surgery at the University of Bologna, found that a freshly dissected frog would kick if a leg nerve was connected to its corresponding muscle by a wire made of two different metals joined end to end. Galvani thought the kick was caused by "animal electricity" made in the brain, conducted by the nerves, and stored in the muscles.

Alessandro Volta, a contemporary of Galvani's and a physicist, not an anatomist, argued that the electricity was generated in the bimetallic wire and was merely detected by the frog, more sensitive to electrical potential than any measuring device then known. Volta's subsequent "galvanic pile" consisted of stacks of paired silver coins and zinc discs with the pairs separated by paper soaked in salt water. With enough coins and discs, an electric current was generated. By inventing the battery, Volta established that an electromotive force could be produced by chemical action.

During the fruitless search for the "life force," many observations showed that continuously flowing electricity could stimulate nerve and muscle activity. In the mid 19th century, Emil Heinrich DuBois-Reymond in Berlin discovered the nerve impulse and postulated that its variations rather than continuous current constituted the stimulus. However, the speed of the nerve impulse was orders of magnitude slower than that of an electrical impulse in a wire.

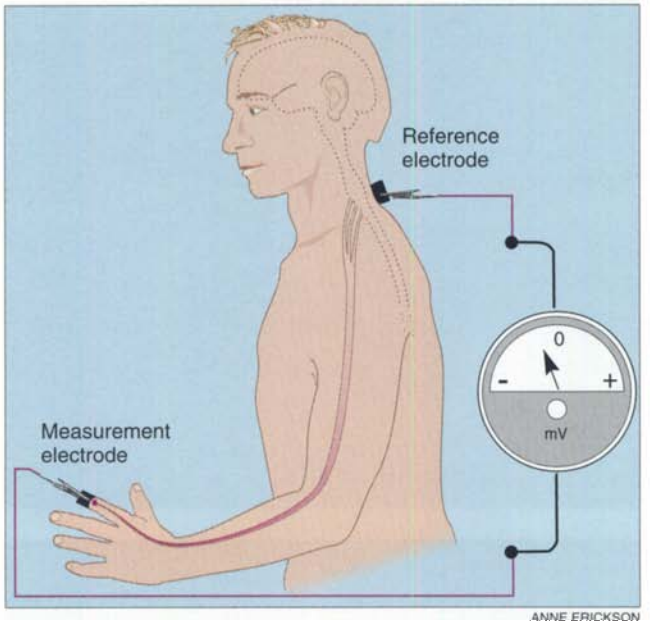
The death of electrical vitalism took place in 1868, when a student of DuBois-Reymond's proposed that the nerve cell membrane was semipermeable and permitted potassium ions to accumulate inside the cell, producing a transmembrane electrical potential. The nerve impulse was then a local breakdown in this potential, which was self-propagating along the nerve fiber. Although it could be detected electrically, the nerve impulse actually represented a flow of ions across the cell membrane.

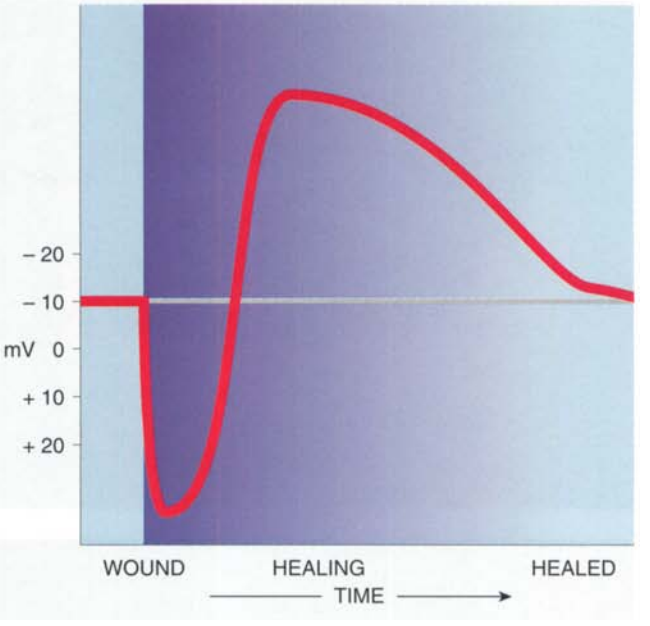
Galvani's animal electricity is real in one respect: measurable DC activity is produced in wounds. But it is generally accepted that the "current of injury" is simply the leakage of ions through injured cell membranes, a local by-product. More recent attempts to involve electricity or magnetism in any life process have been discredited as vitalistic nonsense.

Early in this century, the discovery of methods to reliably detect and record small electrical impulses led to the invention of the electrocardiograph and electroencephalograph. In the beginning, these instruments showed underlying slow variations of DC electricity, "baseline shifts" that were assumed to be useless artifacts interfering with detection of the real physiological activity. They were eliminated from the recordings by the simple expedient of inserting a capacitor in the input wire from the body. Chemistry had become so dominant in biology and medicine that electromagnetic forces were purposefully excluded.

Still, for some, there remained a nagging doubt that perhaps Galvani's current of injury represented something more than injured cell membranes, particularly in the brain. During the 1930's and 1940's, several

Another contemporary of Galvani and Volta, incidentally, was the Austrian physician Franz Mesmer, who thought his method of hypnosis was a manipulation of the body's magnetic field. Interest in "animal magnetism" waned after the discovery of chemically induced anesthesia in the middle of the 19th century.





Electrical potentials in the periphery are normally slightly negative with respect to the spinal cord. Following injury in the human, the sequence of polarity changes illustrated here and obtained with electrodes positioned as shown is identical to that in the salamander during limb regeneration. The different results come about because the salamander's cells are dedifferentiated by the electric current, whereas human cells do not have this ability.

prominent American neurophysiologists clearly demonstrated that real direct currents were present in the brain, where they appeared to control the level of excitability and the synchronization of activity in large collections of neurons.

Most of this work came to a halt during World War II. After the war, only a low level of support for work in bioelectromagnetics continued in this country, though studies continued elsewhere, particularly behind the Iron Curtain. Reports reaching the United States were largely ignored. By 1950, working on bioelectromagnetics was considered not only foolish but hazardous to a scientist's reputation. When Frank Brown at Northwestern University showed that magnetic fields of very low strength altered biological cycles in a reproducible fashion, his experiments were ridiculed.

Because I had been fascinated by the phenomenon of limb regeneration in the salamander since my undergraduate days, I undertook a simple research project to measure the current of injury in salamanders and in frogs, which do not regenerate limbs. There was a clear difference between the two amphibians, salamanders demonstrating a high negative potential during regenerative growth while frogs became positive during scarring.

When my report on the experiment was published in a clinical orthopedics journal in 1961, I found that other researchers had leanings similar to my own, and work began to be done anew on the relationship between electromagnetic forces and a variety of physiological activities. The connection between direct current and regeneration in the salamander was confirmed, and evidence appears to indicate that limb regrowth is caused by electrically induced dedifferentiation of mature cells at the amputation site. This process produces the blastema, a mass of primitive cells that basically recapitulate the original embryonic growth of the limb.

The salamander is able to regenerate any tissue or organ, as long as a portion remains to start from. The process begins with production of negative polarity at the site of injury. Many if not all salamander cell types respond by dedifferentiating.

The frog has lost almost all ability to regenerate. Amputations or wounds show positive polarity, and cellular dedifferentiation does not occur. Stephen Smith at the University of Kentucky caused a frog's hind leg to

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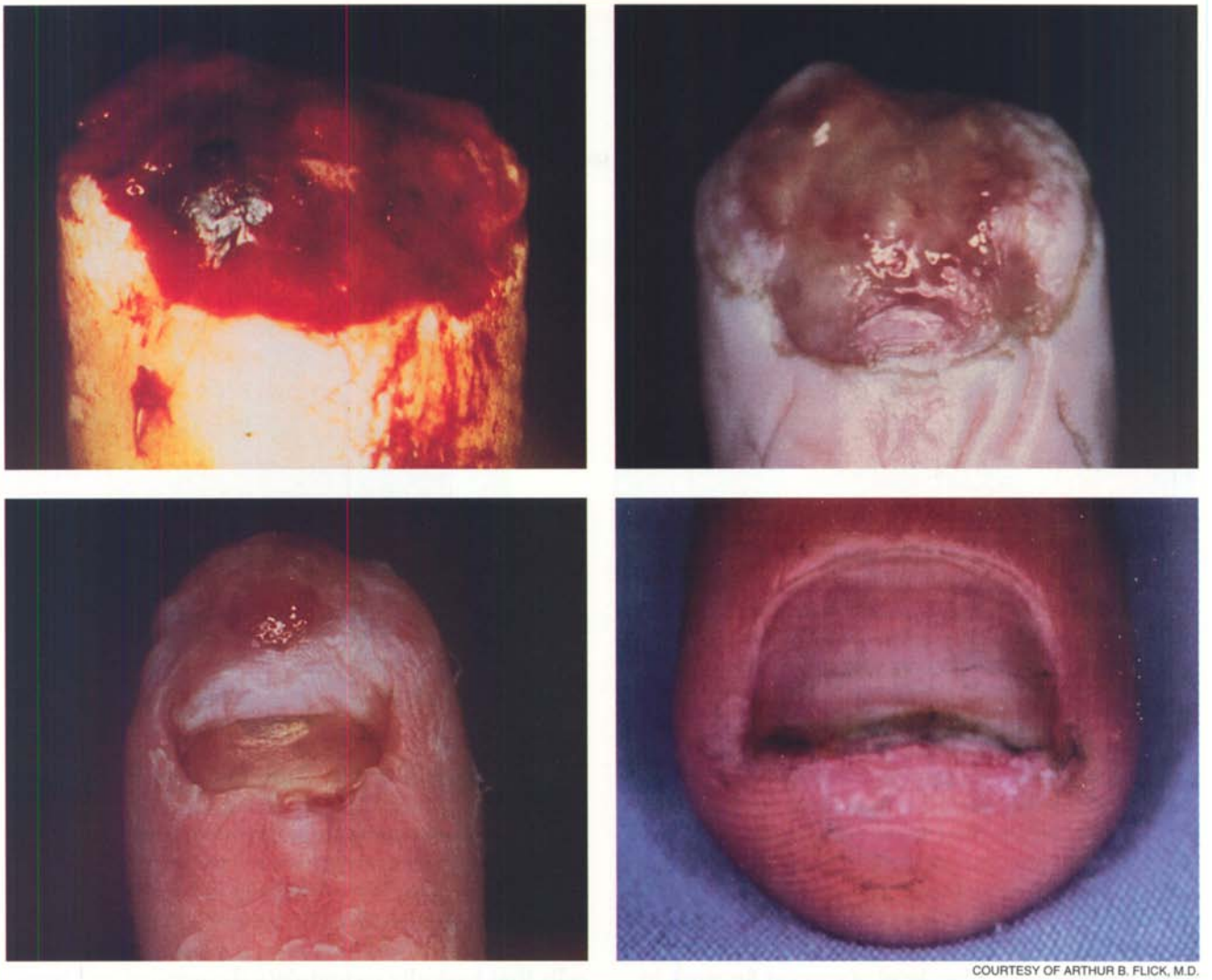
This series is edited by John D. Young and explains the basis for alternative and complementary therapies.



COURTESY OF ARTHUR B. FLICK, M.D.

A 21 year old man lost the distal phalanx of his forefinger in a crush injury (*top left*). Silver iontophoresis was begun within two hours of injury. Sixteen days later, a structure resembling a blastema had formed, and the proximal portion of the distal phalanx had been restored (*top right*). After 23 days, distal structures including the nailbed had reformed (*bottom left*). Regeneration was essentially complete by 60 days post injury. On follow-up a month later, regeneration was complete, including normal dermatoglyphic line patterns (*bottom right*). Regeneration occurs spontaneously in humans up to age 6 or 8 if the injury is not surgically treated, but to the best of my knowledge has not been reported at the age of this patient.

regenerate by implanting a small bimetallic junction, which produced a negative potential at the amputation site. Fractures in frogs heal by a process similar to regeneration: there is negative polarity at the fracture site which causes cells in the fracture blood clot to dedifferentiate. Amphibian erythrocytes have nuclei and are probably the cells responsible for this result.

Human wounds have the same negative polarity as in the salamander, but human cells do not dedifferentiate in response to an electric current. In electrically negative fractures, stem cells in bone are stimulated to begin the healing process. Human fractures that have failed to unite can often be healed by applying an electric current.

Since my original report on the relationship between direct current and limb regeneration in the salamander, my colleagues and I have been successful in demonstrating that intrinsic, neurally related DC potentials are involved in the stimulation of wound healing in mammals. Using small bimetallic junctions implanted at an amputation site between the shoulder and elbow of weanling rats, we succeeded in stimulating regeneration of the distal humerus but not structures below the elbow. Further, application of a wide variety of direct currents to human wounds resulted in no discernible increase in healing rates or efficiency. Now we know that the modest success in the rat model was caused by stimulation of the small population of stem cells in the bone marrow, whereas

failure in human wounds was probably caused by the paucity of such cells in human soft tissues.

Regeneration in the salamander is accomplished by electrically induced dedifferentiation of mature cells in the wound, but this process is not available to mammals, whose cells have lost the ability to dedifferentiate. Because the production of an adequate blastema is impossible without a source of primitive cells, regeneration in the human is not possible without a method to induce dedifferentiation or to harvest and expand the modest population of human stem cells. A variety of approaches to the stem cell concept are now under intense study, though the use of fetal tissue raises major ethical questions.

Bioelectromagnetics may have made available a method to induce dedifferentation in mature human cells as a result of research on a totally unrelated clinical problem. As a practicing orthopedic surgeon, I had long recognized that bone infections were difficult to treat because a limited blood supply prevents an adequate antibiotic level from being achieved in bone. Increasing bacterial resistance to antibiotics had, by the early 1970's, made this problem more acute.

I postulated that an iontophoretic direct current could drive antibiotics directly into infected bone. What was needed was an antibiotic substance of very small size and an electric charge that could be driven with a voltage low enough to be harmless. In vitro experiments confirmed that silver ions could be driven to depths of 1 to 2 cm with an electromotive force below 1 volt. Clinical use was cautiously begun with a simple system consisting of a flexible, silvered nylon fabric as the anode applied directly to the infected bone and with a battery-powered circuit of less than 1 volt. There was excellent antibacterial action with no overt side effects.

As the method was refined with further clinical experience, an unexpected phenomenon appeared. The treated wounds healed more than twice as quickly as expected, with rapid replacement of missing bone and soft tissue and with regrowth of normal, full-thickness skin. Accompanying this was the appearance of a profuse exudate that was found to consist of many immature cells with cytological characteristics of stem cells.

Was this recruitment and expansion of the modest pre-existing stem cell population or the electrically induced dedifferentiation of some mature cell type in the wound? When mammalian fibroblasts were exposed in vitro to the same silver application, they were similarly altered. Explants of silver-treated human wound tissue in culture demonstrated profuse clonal expansion of cytologically primitive cells. The present evidence appears to indicate that the electrically driven silver ion therapy works by producing dedifferentiation of normal, mature human cells in a wound, leading to rapid and complete healing by local tissue regeneration.

This is an ongoing project involving several laboratories and a continuing clinical evaluation. Other orthopedic surgeons have used the technique in the treatment of infected wounds. No untoward side effects have been identified, although the treatment has been found to be ineffective in a subgroup of diabetic patients, whose wounds show positive polarity and do not heal. Whether this method lives up to its obvious potential or not, it has shown that the capabilities of mammalian cells to respond to electrical energy at either the gross level of fields or the atomic level of electron carriers are incompletely understood.

It is my belief that electromagnetic energy plays a much greater role in the functional activities of living organisms than is generally accepted. My experiments over the past four decades have led me to postulate that DC electrical activity is present in humans and functions in such basic activities as growth, wound healing, cyclic functions including sleep, and the overall level of brain activity. My evidence indicates that this DC system resides in perineural cells, namely the peripheral Schwann cells and the glial cells of the central nervous system.

DC electrical activity may have been the earliest data transmission and control system in living organisms. It survives today, hidden beneath the sophisticated action potential and chemical systems, where it acts at the most basic level of life processes. Exploration of this activity is a potentially fruitful approach to the authentication of some of the principles of alternative medicine.

FOR MORE INFORMATION

The International Society for Bioelectricity publishes the journal *Electro and Magnetobiology*, which has articles by researchers around the world. I consider it to be the premier unbiased publication in the field. Contact Dr. Stephen Smith, Department of Anatomy and Neurobiology, University of Kentucky Medical Center, Lexington KY 40502-2957. Website at www.dekker.com.

The Bioelectromagnetics Society, 7519 Ridge Road, Frederick MD 21702-3519, publishes the journal *Bioelectromagnetics*. Website at http://www.bioelectromagnetic.org.