Electrotherapy

The use of electric current to treat disease. Electrotherapy is based on principles developed during the nineteenth and twentieth centuries following the first demonstration of “animal electricity” by Luigi Galvani in the eighteenth century. This article covers low-frequency electrotherapy, diathermy and hyperthermia, and electroconvulsive therapy.

Low-Frequency Electrotherapy

Low-frequency electrotherapy uses relatively weak alternating electric currents. They are delivered by electrodes that are placed under or on the surface of the body and are connected to pulse-shaping circuits that are located inside or outside the body.

Excitable tissues

Electrodes that stimulate electrically excitable cells, such as those in muscle and nerve tissues, are usually placed directly in or on the tissue by surgery or are inserted through a vein by catheterization. There are many applications for electrode stimulation: irregular heart rhythms can be controlled by pacemakers; muscles, such as those of the diaphragm and urinary bladder, that become paralyzed can be made to contract electrically; and long-term pain can be relieved by implanting electrodes in the spinal canal. When coupled to appropriate braces, sensors, and programmed computers, electrodes in contact with the muscle groups of a lower extremity have been shown to help persons with spinal cord injury become ambulatory. Surface electrodes are widely used for temporary relief of pain, a technique known as transcutaneous electrical nerve stimulation; for preventing muscle atrophy after injury or immobilization; and for treatment of curvature of the spine, or scoliosis. See also: Cardiac electrophysiology; Muscle; Pain

Nonexcitable tissues

A wide variety—if not all—of the body's nonexcitable cells alter their function in specific ways and at specific times in response to appropriate, very weak electrical stimuli. (That observation reemphasizes the central roles of physics in all living processes and the interaction of electric charges as the basis of the chemical aspects of those processes.) Much of the progress in electrotherapy has evolved from the observation that both hard and soft tissues, such as bone and arteries, become electrically charged when they are cyclically deformed by mechanical or hydrodynamic forces. Weak voltages, in the range of microvolts to millivolts per centimeter, occur because both cells and tissues contain piezoelectric molecules that respond to deforming forces by becoming electrically polarized. Furthermore, electrically charged entities such as ions, cells, and molecules are transported by hydrodynamic forces past sites of structurally fixed electric charge and, in the process, create a voltage. That phenomenon is an example of an electrokinetic event.

By establishing the patterns and values of those stress-generated voltages in bone, researchers have been able to develop three methods of influencing the behavior of nonexcitable cells that are involved in the repair of nonunited fractures. The oldest method was an invasive procedure, and was followed by two noninvasive procedures. See also: Bone

Electrode implantation

The first clinical method for treating nonunited fractures employed surgically implanted electrodes. Once placed at the fracture site, they delivered constant, direct currents similar in amplitude to those that occur naturally in bone after fracture, known as injury potentials, or as a response to mechanical deformation. Unfortunately, surgical methods carry a risk of infection, and direct currents can result in adverse electrochemical reactions around the electrodes.

Pulsed electromagnetic fields (PEMFs)

Two noninvasive electrical methods have proved effective in altering cellular behavior. The first involves the placement of dynamically charged, insulated plates outside tissue-culture vessels or the fractured limbs of animals. Broad-scale application has not yet proven practical in humans, however. The second method uses one or more coils of wire coupled to a pulse generator to create a weak time-varying magnetic field that penetrates the body, much as radio waves enter a closed building. The field characteristics are designed to induce pulsing electric currents in the tissue, with waveforms, frequencies, and amplitudes similar to those produced normally by skeletal tissues during high-impact exercise. The waveforms of pulsed electromagnetic fields are quite asymmetrical and contain a broad range of frequencies, which are characteristics that distinguish them from power-line, radio-frequency, and microwave fields.

Depending upon the energy patterns generated by the magnetic fields in tissue, the function of cells involved in abnormal processes can be changed without producing heat. In nonunited fractures, the normal repair has been interrupted at an intermediate stage of healing, and soft, rather than hard, tissue forms a bridge between the bone fragments. The final stages of bony repair are not achieved until the soft tissues undergo calcification. Certain types of pulsed electromagnetic fields can initiate calcification, aid in the ingrowth of new blood vessels, and increase bone formation, each of which is important in restarting the healing process and ultimately achieving successful union. Pulsed electromagnetic fields have been widely used to treat nonunited fractures, many of which had failed to heal after one or more operations and the person faced amputation of the affected part. In contrast to other electromagnetic fields, the pulse types do not carry any known risks, and hospitalization and a surgical procedure are usually unnecessary, since pulsed electromagnetic fields are applied in the doctor's office. The method, therefore, is substantially less costly than most other treatments available.

As the understanding of their mechanisms of action at the cellular and subcellular levels has increased, pulsed electromagnetic fields have been used successfully to treat other problems of bone and its surrounding soft tissue. For example, when avascular necrosis of the hip in young adults results in bone tissue death, revitalization has been achieved and hip function restored following pulsed electromagnetic field therapy. In older persons, shoulder pain from chronic inflammation of tendons that has proved resistant to classical forms of treatment has responded to pulsed electromagnetic fields. Therapeutic requirements for selective cellular effects appear to parallel those involved in the treatment of disease states with drugs. Future success will lie in encoding the appropriate physical (as opposed to chemical or drug) “information” in the pulsed electromagnetic field waveform to produce changes in cell function and thereby control or correct specific pathologic processes. Other medical applications for pulsed electromagnetic field, such as in cardiology, remain to be explored.

C. Andrew L. Bassett

Diathermy and Hyperthermia

The therapeutic benefits of heat have been known for centuries, and modern medicine has used technology to provide controlled heat to diseased tissues.

Diathermy

Therapy for afflicted deep tissues that do not respond to conventional methods, such as infrared heating or heating pads, can often be achieved with diathermy. Heating results from the electrical resistance of tissue to high-frequency or microwave currents. Increasing the tissue temperature to a range of 106–113°F (41– 45°C) increases the physiologic response and therapeutic benefit, which includes increased extensibility of collagen tissues in joint contractures, decreased joint stiffness in rheumatoid arthritis, and pain relief and reduction of muscle spasms through the local action of heat on nerve endings and receptors. Warming can also resolve inflammatory infiltrates, edema, and exudates and increase blood flow in diseased or damaged tissue. Heating has been used in cancer therapy under proper temperature control.

Various instruments have been developed to accommodate placement of the heating element on the body. They include (1) coupling of 13.56- or 27.12-MHz shortwave currents from electric fields by way of insulated or noncontacting capacitor plates or specially shaped electrodes for placement in natural body cavities; (2) induction of 13.56- or 27.12-MHz electric currents by magnetic fields from solenoidal coils that enclose the afflicted body member or from flat coils that are placed near the surface of the afflicted tissues; and (3) transmission of 433-, 915-, or 2450-MHz microwave energy into the tissues by radiation from dipole or cavity antennae. The shortwave magnetic and the 433- or 915-MHz microwave applicators are superior to the shortwave capacitive and 2450-MHz microwave applicators for treating tissues beneath subcutaneous fat layers, because they minimize the undesirable selective heating of the fat and the variation in heating levels between patients. Diathermy is contraindicated for areas that are anesthetized or noninnervated, for areas with inadequate vascular supply, in the presence of acute inflammation accompanied by the formation of pus and fever, whenever there is a possibility of hemorrhage, and with malignancies, when there is inadequate monitoring of tissue temperature.

Hyperthermia

Hyperthermia is an experimental method of treating malignant tumors that uses heat alone, heat in combination with ionizing (x-ray) radiation, or heat with chemotherapy. One form of heating involves the application of radio-frequency energy by using methods similar to—but more sophisticated and more carefully controlled than—those in diathermy treatment. The effective temperature range of hyperthermia is very narrow, 108–111°F (42.5–44°C); the benefits are minimal at lower temp eratures, and damage to normal cells is probable at higher temperatures. Several mechanisms are thought to account for the selective destruction of tumor cells: (1) selective heating caused by the lower rate of blood flow in tumor tissues; (2) greater sensitivity of tumor cells to heat due to their hypoxic, acidic, and poor nutritional state; (3) synergism of ionizing radiation and hyperthermia due to thermal killing of cells that are hypoxic and are at those critical stages of growth when they are most resistant to radiation; and (4) increase in cell membrane permeability and sensitivity to chemotherapeutic drugs.

Exposures at frequencies other than those authorized for diathermy are performed in shielded rooms to prevent interference with radio communication facilities. The selective heating of tumor tissues uses the same basic techniques as those for diathermy: shortwave capacitive, shortwave inductive, and microwave applicators. However, because of the potentially life-threatening nature of malignant disease, more drastic measures can be justified, including the application of low-frequency currents by surface-contact and invasive electrodes and the implantation of magnetic seeds that can be heated by low-frequency magnetic fields. These approaches enhance the localization of tumor heating and minimize the destruction of normal tissues.

The frequencies used exceed 100 kHz to prevent excitation of nerves and muscles. Heating may be further localized through use of additional frequencies and more sophisticated applicators, such as phased-antenna arrays and cylindrical antennae designed for positioning in natural body cavities. Extensive multipoint temperature-measuring equipment with automatic feedback power-control systems is necessary to maintain a sufficiently high temperature in the tumor without destructive temperature changes in normal tissues. See also: Thermotherapy

Arthur W. Guy

Electroconvulsive Therapy

Electroconvulsive therapy is a procedure for treating severe psychiatric disorders. It is usually given as a series of treatments, typically numbering between 6 and 12, over a period of a few weeks. Each 10-min treatment is preceded by the administration of an anesthetic agent, to render the patient unconscious throughout the procedure, and a drug that blocks muscle movement in the body, to confine the provoked seizure to the brain and prevent convulsive movements in the body. Electrodes are then placed on the scalp and a small jolt of electricity is applied. The electric current provokes a generalized brain seizure, much like that experienced spontaneously by patients with grand mal epilepsy. The patient's brain waves are usually monitored with electroencephalography during the seizures, which typically last about 1 min.

In use since about 1940, electroconvulsive therapy has been shown to be effective in treating a specific set of psychiatric disorders, the most common of which is depressive illness. Depressed patients often undergo electroconvulsive therapy after failing to respond to other forms of therapy, particularly antidepressant medications. For others, electroconvulsive therapy is preferred because the medical risks associated with drug treatment are too great: in some elderly patients, the frequency of medical injury and death from antidepressants is believed to exceed that with electroconvulsive therapy. The fact that electroconvulsive therapy produces rapid improvement and has a high probability of success is another reason for its use. In patients at risk for death from suicide or medical conditions associated with depressive illness, electroconvulsive therapy may be preferred over other therapeutic methods. It has also been shown to be an effective treatment for patients with acute mania and schizophrenia. Less common uses are the treatment of a small set of medical and neurological disorders that are resistant to conventional therapies, such as Parkinson's disease, intractable epilepsy, and psychosis associated with toxic states. See also: Affective disorders; Parkinson's disease; Schizophrenia

Electroconvulsive therapy has a characteristic set of side effects. Following each treatment, patients experience a period of confusion that may last from several minutes to several hours, and immediately following the complete course of treatments, they frequently have memory difficulties. Memory problems include difficulty in remembering newly learned information and in recalling events from the recent past. At the same time, other aspects of intellectual functioning, such as the ability to perform a task and solve a problem, are unchanged or show improvement over that displayed before electroconvulsive therapy. The improvements can be attributed to the beneficial effects of electroconvulsive therapy on the psychiatric conditions that caused the diminished intellectual performance. Objective evidence of persistent difficulties in learning or recalling new information is difficult to obtain several weeks after treatment, but some patients may experience permanent gaps in their memory for events that occurred in the weeks prior to, during, and following the treatment course. The beneficial and adverse effects of electroconvulsive therapy can likely be traced to changes in brain physiology and biochemistry. Studies in humans and animals indicate it is unlikely that electroconvulsive therapy causes structural damage to the brain, but the precise ways in which it produces beneficial and adverse effects are unknown. See also: Electroconvulsive therapy

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