FUNCTIONAL ELECTRICAL STIMULATION—NEURAL PROSTHESIS FOR THE DISABLED

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When the organ systems of the body are studied from an engineering point of view, electricity emerges as the essence of human life. In fact, life itself is now taken to exist only so long as the brain produces measurable electrical activity. It is not surprising, then, that medical practitioners have been fascinated by the effects of externally applied electricity since the beginning of medicine. New materials and increased understanding of their biological interface properties, both of the materials themselves and of living tissues in the presence of electrical current, now make it possible to influence minute natural electric currents in the body and to create substitute signals to reactivate lost functions or sensations.

Many human beings throughout the world are finding relief from chronic pain through electrical stimulation, while surgical pain is prevented by means of electroanesthesia; paralyzed patients breathe with their own muscles when the phrenic nerves are stimulated; hypertension is relieved by stimulating the carotid sinus nerves; skeletal muscles are stimulated from the skin and by means of implanted electrodes within the muscles or around or within peripheral nerves, to enable the disabled to regain function of their limbs; patients' muscles are strengthened and their contractures relieved; electrical stimulation can control the elimination of wastes; and the peripheral nerves of the amputee have been stimulated to produce the sensation of touch. Bone and tissue growth can be enhanced by electrical currents. Even the brain of man has been electrically stimulated to excite primitive patterns of phosphenes to produce rudimentary vision in the blind, and to suppress epileptic seizures as well as uncontrolled spasticity in cerebral palsy; auditory nerves are stimulated to enable the deaf to "hear" simple sounds; and what is
somewhat frightening to contemplate, in some cases the behavior and personality of a subject have been altered through stimulation of the "pleasure" and other centers of the brain. This is truly the beginning of a whole new world of medicine.

The list of therapeutic and assistive applications of electricity to the organ systems of the body already demonstrated to be effective is long and encompassing.

Let me make a few predictions based on present applications of electrical stimulation of skeletal muscles and their nerves. Major progress will be achieved in the early 1980's in the development of assistive devices to enable the paraplegic to walk. The first practical application of electrical stimulation to aid in walking was made by W.T. Liberson and reported in the Annals of Physical Medicine in 1957. His pioneering work at the VA Hospital, Hines, Illinois, paved the way for many others throughout the world. The problem at present is not so much the technique of phasic stimulation of leg and hip muscles—this can be done now—as it is to provide the patient with an artificial sensory system to give him feedback as to where his legs are and also signals necessary to maintain balance. While the vestibular and visual functions are important for references to maintain balance, equally important in a normal human being are the proprioceptive signals sensed through the legs, hips, and trunk. I foresee early solution to these problems, probably in the form of either surface or direct nerve stimulation wherein appropriate signals to maintain balance are continuously provided to the paraplegic. The first walking systems will probably employ modifications of KAFO's (knee-ankle-foot orthoses) and trunk supports now familiar to the orthotist, along with canes instrumented to generate additional feedback signals. The leg and hip muscles will be phasically stimulated to produce walking patterns to be superimposed on basic algorithms for balance. A small computer worn on the belt will produce these signals. As patients begin to walk with such hybrid systems, I would expect increases in sophistication of electrical stimulation and of control principles gradually to minimize the necessity for external orthotic support.

At the same time that lower limbs are made more useful to the paraplegic, I expect to see much progress in assisting the quadriplegic and hemiplegic to regain control of their upper limbs. At present, prehensile function has been achieved. The problem of upper-limb function is more difficult than lower-limb because of the myriad patterns involved and the possible presence of lower motor neuron lesions. The control problem is difficult because signal sources from a high-level quadriplegic are limited, but much attention is being given to these matters in the ancillary fields of remote manipulation and teleoperators. For example, a present joint project among the Jet Propulsion Laboratory, the Veterans Administration Prosthetics Center, and Rancho Los Amigos Hospital has produced a remote manipulator, for use by a quadriplegic, which is operated
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solely by voice controls. It is reasonable to assume that if such a control system can effectively govern the complex movements of a remote manipulator, it could equally govern the complex movements of a human arm itself, as special groups of muscles are electrically stimulated in patterns similar to those of individual servomechanisms in the remote manipulator.

The previous examples relate to replacing lost functions as a result of paralysis. The use of electrical stimulation in therapy to promote the return of natural function may have an even larger impact. When human joints and muscles remain unmoved and idle, an insidious reversal of function rapidly ensues. An unmoved joint will stiffen and an unmoved muscle will atrophy. When the neuromuscular control system goes out of balance, certain muscles may spontaneously contract, producing serious contractual deformities that may be painful and difficult to straighten. The development of uncontrolled scar tissue following burn therapy often leads to a joint with severely restricted function. All of these problems are now most often dealt with through surgery and physical therapy. The time, and consequent cost, of physical therapists to maintain range of motion when stiffness and contractures threaten is very great. I foresee a major increase in the use of electrical stimulation with electrodes applied at the surface of the skin, or through percutaneous devices, used with automatic programmable cyclers at the patient’s bedside in the hospital or home to take over effectively much of the work of the physical therapist. These systems will be important not only in paralysis and burn treatment, but they will become a part of the therapy following implanted prosthetic joints where immediate, gradually increasing range of motion following surgery will assist the growth of new tissues most compatible with free movement of the joints.

I predict that the use of fine wire electrodes implanted in individual fascicles of human peripheral nerves will become widespread. Such wires can be connected to implanted stimulators or carried through the skin by means of biocompatible percutaneous devices for external electrical connections. The first patients are now being so treated at Rancho Los Amigos Hospital for contracture relief and sensory feedback. The possibility of identifying particular motor functions within certain nerve bundles in a peripheral nerve is very real. One can foresee a peripheral nerve implanted with a number of electrodes, combinations of which will control individual movements, say in the hand of a paralyzed patient. It may be unnecessary to determine the individual nerve-muscle actions a priori, for one can visualize an adaptive computer control system constructed of microminiature logic elements that discovers by trial and error which electrodes produce a useful function, in a manner similar to that of the infant as he learns to control his limbs. Or one can equally visualize such electrodes providing sensory feedback to amputees, giving them an artificial sense of touch and position from their prosthetic limbs.
This possibility has already been demonstrated at Duke University and at Rancho Los Amigos Hospital under Veterans Administration projects. In addition to peripheral nerves, the possibility of moving back to the roots of the nerves as they leave the spinal cord also exists. Professor Pierre Rabischong in Montpellier, France, has demonstrated this in animal studies using electrodes of pure carbon.

The use of electricity to restore lost functions in man by means of neuroprostheses, both in commercially available equipment and in advanced research projects, gives promise that indeed the blind will see, the deaf will hear, the lame will walk and use their arms, seizures will be predicted and suppressed, palsy will be controlled and pain will be suppressed through the application of externally generated electrical signals to modify those which are distorted or to replace those which have disappeared in a disabled person. These are the true functions of an orthosis or prosthesis.