Stony Brook. . . . **Paul D. Minton**, chairman, statistics department, Southern Methodist University, to dean, School of Arts and Sciences, Virginia Commonwealth University. . . . **Allen G. Debus**, professor of history, biological sciences division, University of Chicago, to first director, Morris Fishbein Center for the Study of the History of Science and Medicine at the university. . . . **Neil G. McCluskey**, dean-director, Institute for Studies in Education, University of Notre Dame, to dean of education, Herbert H. Lehman College, City University of New York. . . . **Wesley J. Matson**, assistant dean, School of Education, University of Wisconsin, Milwaukee, to dean of education, Winona State College. . . . **Thomas R. Tephly**, associate professor of pharmacology, College of Medicine, University of Michigan, Ann Arbor, to director, Center for Toxicology and Biochemical Pharmacology, University of Iowa. . . **Roland H. Good, Jr.**, professor of physics, Iowa State University, to head, physics department, Pennsylvania State University. . . . **Robert L. Williams**, chairman, psychiatry department, University of Florida College of Medicine, Gainesville, to chairman, psychiatry department, Baylor College of Medicine. . . . **Harry J. Lowe**, acting chairman, anesthesiology department, biological sciences division, University of Chicago, elevated to chairman of the department.

RECENT DEATHS

John D. Akerman, 74; professor emeritus of aeronautics, University of Minnesota; 8 January.

Paul M. Althouse, 55; provost, Pennsylvania State University; 4 February.

George M. Bateman, 74; professor emeritus of chemistry, Arizona State University; 28 January.

Allan A. Blatherwick, 57; professor of aerospace engineering and mechanics, University of Minnesota; 31 December.

Walter H. Boone, 66; chairman, chemistry department, Potomac State College; 15 January.

Ng. Ph. Buu-Hoi, 56; director of research, Centre National de la Recherche Scientifique, Paris, and former director-general, Office of Atomic Energy of Vietnam; 28 January.

Carlton M. Carson, 73; retired micropaleontologist, Tidewater Oil Company, California; 7 January.

Antonio Ciocco, 63; professor of biostatistics, University of Pittsburgh; 5 January.

Andre G. Clavier, 77; electrical engineer and technical consultant, International Telephone and Telegraph Corporation; 9 January.

Richard Courant, 84; founder and former director, New York University Institute for Mathematics and Mechanics; 27 January.

Albert E. Dimond, 57; chief, plant pathology and botany department, Connecticut Agricultural Experiment Station; 4 February.

Franklin G. Ebaugh, 76; professor emeritus of psychiatry, University of Colorado; 4 January.

Earle J. Fennell, 66; retired associate chief topographic engineer, U.S. Geological Survey; 22 January.

Raymond L. Garner, 66; first chairman, biochemistry department, New Jersey College of Medicine and Dentistry; 13 November.

Chester S. Keefer, 74; professor emeritus of medicine, Boston University School of Medicine; 3 February.

Edgar B. Keemer, 93; former professor of pharmacy, chemistry and bacteriology, Howard University; 15 January.

Jacob Priman, 79; professor emeritus of anatomy, University of Pittsburgh; 23 November.

Richard B. Turner, 55; professor of chemistry, Rice University; 22 December.

Richard A. Waterman, 57; professor of anthropology, University of South Florida; 7 November.

Orland E. White, 85; director emeritus, Blandy Experiment Farm, University of Virginia; 10 January.

George C. Williams, 97; former president, Ithaca College; 28 December.

RESEARCH NEWS

Bioengineering: "Drop Foot" Corrected by Electrical Stimulation

More than 400 stroke victims in Yugoslavia and the United States have used an electrical device that eliminates "drop foot" and enables them to walk almost normally. Not all can use the new procedure, called functional neuromuscular stimulation, to overcome the spasticity of the calf muscles that normally accompanies a stroke, nor do all patients who try muscle control by electrical stimulation continue to use it. However, some patients have used the device for more than 3 years, still like it, and report no unpleasant side effects. One type of device for electrical stimulation is being evaluated at clinical rehabilitation centers in the United States by investigators who hope to see it widely distributed. Preliminary estimates indicate that, if the devices are manufactured in large numbers, they may be as cheap as some leg braces.

The leg stimulator is just one example of the marriage of artificial devices with natural limbs and organs. Doctors and engineers working together have perfected many substitutes for parts of the human body, ranging from artificial blood vessels to pacemakers. For example, a very large effort is being undertaken by many federal agencies (with 99 research contracts outstanding) to produce an effective artificial heart. Electrical stimulation of groups of muscles is an extremely attractive potential method for rehabilitating hemiplegics and paraplegics because usually the neuromuscular systems in the extremities of these patients are intact. Optimistic researchers even talk about the ambitious goal of programming a paraplegic to walk under the control of a set of carefully orchestrated electrical stimuli.

For the past 6 years the leading figures in research on functional stimulation of muscles have been investigators at the University of Ljubljana (Yugoslavia). The Ljubljana rehabilitation center has a strong program in clinical, theoretical, and engineering aspects of functional muscle stimulation. Its researchers are credited by many American physicians with developing the technique to the point that extensive clinical trials are feasible.

The Ljubljana program has been funded under the provisions of Public Law 480, which allows U.S. agencies to award research contracts to foreign countries out of monies (P.L. 480 funds) from the sale of U.S. agricultural products to these countries. Although eight or ten countries receive contracts for rehabilitation research under Public Law 480, the Yugoslavian program is one of the few that have produced extensive results. In an American medical community that can be extremely critical of research done in other parts of the country, much less abroad, these contributions are particularly well accepted. For grants that become available as a by-product of foreign aid, the contracts awarded to Yugoslavia appear to have paid off handsomely. Not only has functional stimulation been studied, but also many advanced rehabilitation procedures have been developed for patients other than stroke victims.

A stroke may impair several motor functions; one of the more common consequences is an inability of the patient to raise his foot normally, called drop foot. The desire for any movement of an extremity originates in the cerebral motor area. It is relayed through the corticospinal tract to the spinal cord, the motor neuron, and finally the muscle fibers. If this neural pathway is damaged or interrupted in the brain by inflammation or injury, part or all of the opposite side of the body becomes paralyzed. A patient with such a condition is called hemiplegic. Many muscle functions are recovered after a stroke, either spontaneously or with the aid of physical medicine, but some disabilities remain. Drop foot is the most common residual problem. This condition results in a rather clumsy gait, and an exaggerated, twisted posture. The next most typical disability is a weak knee joint. A significant number of patients also have weak hips.

These patients not only suffer the loss of voluntary movement, but they also have pronounced spasticity. Pulses of electrical current, delivered to the peroneal nerve through two surface electrodes placed behind the knee (Fig. 1), can inhibit spasticity and cause a normal flexion of the paralyzed muscles.

One particular stimulator that has been rather extensively tested was developed by Franjo Gracanin and colleagues at Ljubljana. Two electrodes are positioned on the skin above the peroneal nerve (upper electrode) and above the head of the fibula (lower electrode), and held in place by an elastic sleeve. The stimulation consists of a string of short pulses. As soon as the patient lifts his heel, the sequence of pulses is started. A switch in an innersole of the shoe provides the starting signal and a small battery-operated power supply strapped about the waist provides the current. The duration of each short electrical pulse is about 0.3 millisecond, and the pulses occur at a rate of about 20 to 50 per second. The selected duration of each individual pulse is a compromise between comfort and conservation of battery power; shorter pulses give the sensation of

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Speaking of Science

The Frontiers of Physics, or Some

Forecasting the future of science is an intermittently popular pastime that seems to be enjoying a revival just now. Physics, in particular, has been the subject of several recent, informal attempts at prognostication. In recent years physicists have come on hard times, and it is not difficult to find those whose outlook for the future is bleak. Some will venture the opinion that, compared to the biological sciences, physics is largely "mined out," and others will go so far as to describe the more esoteric fields of physics as a luxury that can no longer be afforded.

Despite such gloomy sentiments, and despite some public and private soul-searching, physicists at one recent gathering appeared to be taking a more optimistic view of the future in at least a few subfields of that science. The occasion was the dedication of a new physics building on the campus of New York University, and speakers talking about the "frontiers of physics" included Nobel laureate C. N. Yang of the State University of New York at Stony Brook, John Wheeler of Princeton University, and Bruno Zumino of the European Organizaiton for Nuclear Research. The consensus appeared to be that research in physics still deserves the intellectual and practical attention of the world, and those present had a number of examples to back up this contention.

Speaking of high energy physics, Zumino pointed out that there exists no adequate theory of the fundamental particles of matter and that present descriptions of these particles and their high energy collisions are almost entirely phenomenological. He emphasized the need for a better understanding of the relations and mutual interactions of the four fundamental forces of nature—the strong interaction, the weak interaction, the electromagnetic force, and the gravitational force. Zumino told of new efforts to form a unified theory of weak and electromagnetic interactions, and he said that these efforts might well lead to a more universal theory in the near future. He held out less hope for theoretical work on the nature of the strong interaction, for which, as he put it, "we are in the hands of the experimentalists."

Dealing with the more pragmatic field of solid state and condensed matter physics, Walter Kohn of the University of California at San Diego proposed a somewhat longer list of research frontiers in which he foresees the likelihood of major advances. Heading this list is the physics of surfaces, a subject that he considers ripe for harvesting with techniques such as electron diffraction and molecular beams, and a field with practical applications in metallurgy, catalysis, and microcircuitry. Noting that much solid state work in the past has focused on the properties of idealized, crystalline materials, he staked out the properties of amorphous, disordered materials as a second key area for the future. Kohn described still other frontiers such as phase transitions and the properties of matter under the influence of extremely high electric fields, and he mentioned new techniques, ranging from the use of lasers to very low temperatures (millidegrees A) or very high pressures (megabars), that touch but longer pulses give the sensation of pain.

Different durations for the entire string of pulses may be needed for different walking rates, but the basic Ljubljana device must be fixed at some value (between 0.4 and 1.8 seconds). The voltage of the stimulator, however, can be changed by turning a knob on the power box. Patients may need more voltage when general tension changes the tone of muscles, for instance at lunch hour on a crowded sidewalk, or when more accurate flexion of the foot is needed to overcome friction from a rough walking surface. As patients aided by functional stimulation improve, usually less voltage is needed.

Although functional neuromuscular stimulation (FNS) of the peroneal nerve eliminates drop foot and significantly improves the posture of many patients, it is by no means suitable for all. Often FNS cannot be used by diabetics because the threshold voltage increases day after day until it becomes dangerous, nor can it apparently be used by the many patients who have strokes resulting from arteriosclerosis because mental capacities and psychological attitudes of patients must be considered in deciding whether FNS is a suitable approach to rehabilitation.

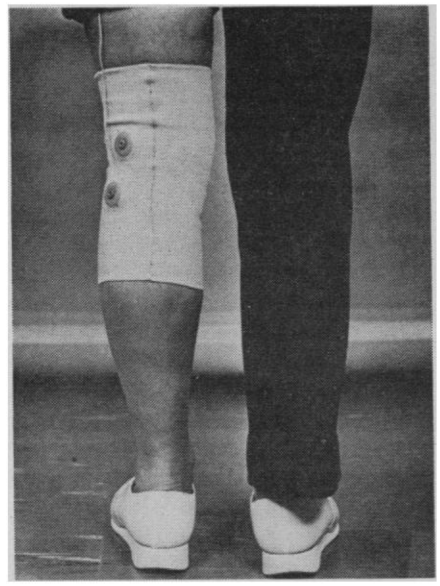

Fig. 1. Two electrodes fixed with an elastic sleeve behind the knee of this patient conduct the stimulus to correct drop foot.

Another disability that could possibly be corrected by FNS is cerebral palsy. Dr. Leon Sternfield of the United Cerebral Palsy Research and Education Foundation in New York is hopeful that clinical studies of these patients (750,000 in the United States) may begin. However, he points out that the proportion of cerebral palsy patients who could use functional stimulation is expected to be much smaller than that for stroke victims.

Of the 480,000 stroke victims in the United States, E. E. Harris of the Committee on Prosthetics Research and Development of the National Academy of Sciences estimates that only 5 percent of these could use FNS to correct drop foot. The Yugoslav researchers contend that the fraction could be as large as 30 percent. In the end, however, the clinical medical staff will determine which and how many patients are fitted with FNS devices. According to Gracanin, the most important problem is to educate physicians and particularly physical therapists in the methodology of functional stimulation.

Speculations on the Future of the Science

may help to open up these areas. He forecasts much greater use of computer simulation.

In addition, Kohn cited the need for solid state physicists to become more involved with interdisciplinary studies and with the practical problems faced by the society at large. He picked out chemistry as the critical border area in which much would be gained by bringing together the differing points of view of the physicist and the chemist. While emphasizing the importance of pure research, Kohn gave two examples of areas in which solid state physicists might aid in solving urgent problems—namely, catalytic mufflers for controlling auto emissions and materials capable of withstanding high neutron irradiation in fusion reactors.

A third subfield of physics in which there is currently great activity and high expectations for the future is astrophysics. John Wheeler described these expectations by comparing the efforts of physicists in the early years of this century to explain why atoms do not collapse—a dilemma that was resolved by the advent of quantum mechanics—with current efforts to explain why the universe does not undergo gravitational collapse. He noted that astrophysicists are investigating the expansion, collapse, and reexpansion of the universe, as suggested by a theory of general relativity, as well as the more localized collapse of matter into a black hole, which is thought to occur in certain old stars. Among the topics that Wheeler described as important for the future are an understanding of how energy is produced in quasi-stellar objects, the dynamics of stellar collapse, and the emission of gravitational radiation. Wheeler went on to speculate that some of the fundamental constants of the present universe are a consequence not of the laws of physics, per se, but of prevailing conditions at the time of the last contraction and expansion of the universe. He raised the possibility that other "initial conditions" might well have led to a universe with no stars of the sun's type, no planets, and no life. The exploration of such questions, he said, could unite particle physics, astrophysics, cosmology, and the search for an understanding of life.

A more prosaic view of the future of physics is that given by C. N. Yang, who said that physics today faces no sharply defined problems—in contrast to the situation in earlier years. He also pointed out the difficulties of performing large, cooperative experiments and the lack of new mathematical tools to handle the complex problems of modern physics. His nomination, therefore, for the central problem in physics is the development of new theoretical techniques for dealing with systems of infinitely many degrees of freedom, a subject not far from his current research efforts. Another Nobel laureate, Alfred Kastler of the École Normale Supérieure in Paris, told of some intriguing possibilities in quantum optics.

Clearly there are many different opinions about the future of physics, ranging from the disparaging to the optimistic. Indeed, the very diversity of opinions would seem to argue for the intellectual health and fertility of the field. Forecasters take note.—Allen L. Hammond

Other problems of a practical nature occur with the use of surface electrodes. A few patients experience skin irritation at the electrode sites. Heel switches tend to break easily, and wires connecting the heel switch to the power supply (not shown in Fig. 1) are unattractive. As with many prostheses, a patient may refuse an FNS device even though it functions satisfactorily if it is too awkward, unreliable, or unsightly.

Although electrical stimulation has been used for diagnostic and limited therapeutic purposes since World War I, electrical stimulation to cause a normal function was first introduced in 1961 by Vladimar T. Liberson who is now at the Veterans Administration Hospital in Miami, Florida. Stimulators similar to Liberson's have been built by research teams at the Texas Institute for Rehabilitation Research in Houston, and at the Case Western Reserve University in Cleveland, Ohio, in addition to the one at Ljubljana. All these devices have surface electrodes.

Several research teams, encouraged by the success of the basic FNS device, have been experimenting with more elaborate modifications. The Ljubljana group has developed one in which the duration of stimulation can change with the patient's walking speed. A simple memory in the power circuit recalls the duration of the "swing phase" of the previous step and adjusts the length of time for stimulation to a certain fraction (usually 0.7) of the swing time. Dr. Lojze Vodovnik of Ljubljana has tried a system that stimulates three groups of muscles with surface electrodes, rather than one group. According to Vodovnik, the multisite stimulation makes a smoother gait possible, but the walking speed and length of step are fixed by the relative timing of the various signals and cannot be varied. The multisite stimulator has only been used by patients in a rehabilitation center; it has not yet been released for patients to use without supervision.

Alternatives to surface electrodes are electrodes that penetrate the skin and electrodes that are implanted near the nerve or directly in the muscle. Because electrodes that cross the skin usually cause irritation and infection, they have not been used often for FNS. Researchers at Ljubljana, and the Rancho Los Amigos Hospital in Downey, California, have successfully corrected drop foot with small implanted electrodes. The Ljubljana team has a bullet-shaped electrode which it places next to the peroneal nerve; the Rancho team has an electrode that wraps around the peroneal nerve near the head of the fibula but receives its power through a lead to a receiver in the thigh. Implanted electrodes have fixed positions, which can be an advantage, as well as low energy consumption and improved appearance for the patient.

Neither the Ljubljana nor Rancho electrodes need batteries. The electrodes receive power from radio-frequency waves (1.3 megahertz) transmitted from an antenna on the leg. The frequency and duration of the pulses are completely determined by the transmitter, so that in theory no adjustments of the implanted devices need ever be made. However, implanted devices also have disadvantages, such as the necessity of a surgical procedure and the possibility of a negative reaction to a foreign body. For some patients, the freedom to move surface electrodes is desirable because muscle functions change over a period of time. Gracanin and his colleagues at present think that implanted electrodes are better for some patients and surface electrodes are better for others.

Muscle Fatigue

For getting a strong signal to the hip muscles implanted stimulators appear to be the only feasible devices. Unlike the peroneal muscles, the hip muscles must support the body weight. Fatigue has not impaired the effectiveness of FNS for the peroneal muscles, but some doctors fear that it may quickly reduce the strength of the hip muscles until they are no longer functional. Vodovnik and others at Ljubljana have shown that in paraplegics a muscle exerting continuous pressure as a result of FNS fatigues to 50 percent of its original strength in minutes. If the stimulation is cyclic rather than continuous, the fatigue is substantially reduced. According to Gracanin, it is impossible to produce the same force with FNS as with voluntary contraction. Other investigators do not agree. Nevertheless further reduction of the force by fatigue could make FNS functionally impractical in hip muscle control.

Jim Reswick of Rancho Los Amigos Hospital is among those who suggest that stimulation of a muscle by several electrodes fired in sequence may considerably reduce fatigue. Though there is some disagreement about its importance, research about fatigue is being pursued by many doctors for various reasons, not the least of which is the prospect of learning more about the basic characteristics of muscle fibers.

Another phenomenon called "carry over" raises basic questions about the way the neuromuscular system works. For as long as 30 minutes after the stimulator has been turned off, many hemiplegics can continue to flex their feet even though the electrical stimulus is absent. This phenomenon was first observed by Liberson and has since been noted by many clinicians. Apparently some conditioning has occurred that changes the organization (at least for a short time) of either the motor reflex mechanisms or higher centers in the central nervous system. Originally many researchers had hoped that permanent restoration of the function might occur, but the effect appears to be transitory. Don McNeal of Rancho Los Amigos Hospital has compared it to a "ringing" in the corticospinal system, rather than to a long-term reorganization.

The Ljubljana peroneal stimulator is being manufactured commercially, and 60 units are being evaluated in U.S. hospitals for possible recommendation to the Social and Rehabilitation Service of the Department of Health, Education, and Welfare. A final recommendation is expected in April 1973. If approved, the FNS device would become a normal rehabilitation tool and would be made widely available.

At the same time as the prototype FNS device is approaching the final stage of the engineering process, researchers seem to have some difficult decisions to make about the course of future FNS research and development. Dr. Wen Ko and colleagues at Case Western Reserve University have recently completed an engineering study for a device that would multiplex individually controlled signals to 64 implanted electrodes with three radio-frequency channels. Multisite stimulation, because of its inevitable complexity, could introduce many problems. Fatigue may be a limiting factor and some feedback may be necessary to coordinate many muscles. McNeal has suggested that possibly the problems of controlling larger sets of muscles will be overcome by introducing electrical stimulation higher in the central nervous system rather than at many peripheral sites.

Whatever direction the investigators of functional stimulation choose for their future inquiries, it is clear that they have already made a sure first step toward the goal of rehabilitating paralyzed limbs by engineering.

—William D. Metz