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This is a report of the current activities and recent progress in the 14 projects conducted at this REC. The long-term objectives of the projects were described in earlier issues of the BPR. The core area for this REC's research is neuromuscular control using sensory feedback systems. In addition, this REC has a long-standing record of concern for and contribution to communication disorders.

Monitoring, Modifying, and Testing Anterior Spinal Instrumentation
Project responsibility: Derek Rowell, Ph. D., and John Hall, M.D.

Research is proceeding in an effort to improve the results of surgical procedures for scoliosis correction. An accepted technique for handicapped children with certain types of spinal deformities is anterior spinal fusion stabilized by implantation of a Dwyer Cable. It is important to reduce, or preferably eliminate, postsurgical complications consisting of breakdown of the cable system and failure of fusion, which result in a loss of the correction. This might be accomplished if adequate biomechanical data were available with regard to the forces acting on the cable and the fusing spine. To obtain such data, a passive telemetry system has been designed for implantation at the time of the spinal fusion procedure.*

Current work is concerned with the assembly of devices for implantation and the design and construction of the associated telemetry receiver and analyzer.

Neurophysiological Feedback from Extremities
Project responsibility: Neville Hogan, Ph. D.

The object of this project is to enhance the intimacy of the union between an amputee and his prosthesis by providing as natural a means of control as possible given the limitations of current prosthesis technology. An essential subgoal is to implement in a prosthesis the most accurate transmission of commands which can be achieved using myoelectric signals. To this end, a microprocessor-based technique for improved myoelectric signal processing has recently been implemented. This microprocessor implementation has retained the high fidelity of the improved processing techniques reported previously in the Fall 1979 issue of BPR, and the convenience of digital implementation, while containing the entire processor in a package which is small and portable. In its current form, the processor could be readily applied to the control of assistive devices such as a powered wheelchair or a medical manipulator, but is as yet not small enough to be contained inside a prosthesis. Efforts continue to make this device as small and as practical as possible.

Use of a New Biofeedback and Gait Analysis System in Conjunction with the Microcomputer-Controlled Above-Knee Prosthesis
Project responsibility: Woodie Flowers, Ph. D.

Efforts are continuing to develop more versatile A/K prostheses through research on microcomputer-controlled knee mechanisms which allow prostheses to be custom tailored to their user. The activities range from clinical application of new prostheses and instrumentation systems for immediate postoperative training to evaluation of the efficacy of powered multimode A/K prostheses.

Three unique electronically-controlled prostheses have been built and used by amputees. The most versatile prosthesis, which is restricted to studies in the laboratory because of its electrohydraulic umbilical, was recently used to demonstrate that an A/K amputee could perform tasks such as foot-over-foot stair and ramp climbing, and could make smooth transitions through automatic gait mode changes using relatively straightforward knee controllers. Another of the new prostheses was used to show that electronically-augmented biofeedback can aid postoperative training.

Immediate goals include completion of smaller and more sophisticated controllers for the existing prototype prostheses, and completion of an all-new, passive-powered, regenerative, self-contained microcomputer-controlled prosthesis.

Evaluation of Gait and Posture in Selected Groups of Children with Cerebral Palsy, Myelomeningocele and Scoliosis
Project responsibility: Sheldon R. Simon, M.D.

Segmental Energy Analysis—The energy cost of gait is being measured to help determine how functional a patient will be as an ambulator or how effective a particular treatment (operation, orthoses, therapy program) has been in making gait more efficient. The change in mechanical energy per distance walked in one gait cycle is being used as the indication of energy cost. The potential and kinetic energies of 12 different segments of the body are calculated for the entire gait cycle from high-speed films taken of the patient walking. From this segmental information, the total body energy change during the gait cycle is calculated.
Our studies show that healthy subjects and patients tend to walk at a speed that minimizes their change in mechanical energy per distance walked. This is similar to the findings of other investigators which show that metabolic energy used per distance walked tends to be minimized at the chosen speed of walking. The exact relationship between these two parameters is yet to be defined. As efficiency increases, the amount of transfer of energy taking place within and between segments increases, reducing muscle energy needed. Our investigations of patients have demonstrated that improvement in gait, as shown by increases in efficiency, may not coincide with improvement in other commonly used measures of gait such as changes in velocity, or joint angles. This raises the question of whether gait improvement has multiple definitions.

Limb Segment Inertial Properties—
During the past year the development of regression equations to determine the moment of inertia of lower-extremity limb segments has been completed. In a series of 13 normal adults, the moment of inertia of the combined thigh, shank and foot and the combined shank and foot were measured using the free oscillation technique of Hatze. Moments of inertia were measured about an axis perpendicular to the sagittal plane and passing through the proximal joint of the system being considered. In addition, on each subject the limb diameters in the sagittal and coronal planes, and limb circumferences, were measured at six locations along the lower extremity, as were segment lengths and subject weight.

A linear multivariable correlation analysis was performed to determine which of the measured anthropometric parameters were the most effective predictors of the moment of inertia determined from the free oscillation. For the thigh-shank-foot system, the leg length squared and body mass were found to correlate most highly with the moment of inertia. For the shank-foot system, the shank length squared, body mass and the knee circumference were found to correlate most highly with the moment of inertia.

Relationship Between the Wire-Electrode Electromyographic Signal (EMG) and the Physical Behavior of Muscles—
In the past year we have explored relationships between muscle activity as measured by the electromyographic signal (EMG) and readily identifiable muscle mechanical variables: muscle lengths, lengthening velocities and joint moments.

Based on muscle length, lengthening velocity and EMG data, the following conclusions for normal gait were drawn:

(i) The tibialis anterior and hamstrings begin their electrical activity at their peak lengthening velocity. (ii) Two-joint muscles show less changes in length per unit length during gait than do one-joint muscles, due to the interaction of joint rotations. (iii) Motion of the knee joint is less influential than those of the ankle or hip joints to the length changes in two-joint muscles. (iv) Before the period of weight acceptance, vasti muscles are fully active and ready to work as a spring; functionally, the vasti are helping to smooth the impact of the foot at heel strike and could conceivably be storing energy (as a stretched spring) for release at a later time in the gait cycle. (v) The muscle lengths show differences as a function of walking speed, especially when muscles are actively shortening.

From the study of the relationship between muscle activity and external joint torques, the fact that two-joint muscles showed electrical activity in phase with the external joint torques at the distal joint was observed. Co-contraction appeared to be present whenever needed for stability of posture. Co-contraction across the hip and knee was found whenever the joint moments were small, i.e., whenever there was a possibility of a change from a flexion (extension) to an extension (flexion) moment even if the moment does not actually change direction. An exception is when the vasti muscles are preparing for weight acceptance by activating before heel strike.

Similar relationships have been investigated for three spastic patients: a 9-year-old female with left hemiplegic cerebral palsy; a 3½-year-old male with asymmetrical spastic quadriplegic cerebral palsy, and a 14-year-old male with left spastic hemiparesis secondary to early encephalopathy. In these subjects with equinus gait, reflex activity in the calf muscles after heel strike could be determined, i.e., as the calf muscles were rapidly lengthened the ankle joint torque increased with a 50 millisecond latency. Additionally, the spring action at the knee joint during the period of weight acceptance, as in the normal subject, was not seen. The knee joint was steadily extending from the beginning of this period by the extending torque at the hip joint.

Interactive Graphic Display of Gait—In order to provide an increased understanding of the complex pattern of gait, an interactive graphics system has been developed and added to the central computer system. Segmental relationships can be examined at any point in the gait cycle or the motion of the whole body or specific segments can be displayed dynamically. The operator has interactive control of the display through computer terminal input. An analog control in the form of a “joystick” is being added to allow the operator to sweep through motions or stop the display at any particular position or viewing angle. This type of representation will provide a means of examining the gait pattern that has been unavailable through film or hard-copy graphics.

EMG System—The evaluation of available techniques for recording electromyographic signals has continued. In the past year, electrode-preamplifier packages from other laboratories as well as those commercially available were extensively tested. No single type was found ideal for clinical purposes. The muscle examined and long leads without preamplification were the greatest factors generating noise, rather than postamplification cable motion. Many of the devices were unacceptably large, awkward to use, fragile, and expensive for use in a clinical setting. This led to the development of a miniaturized preamplifier system, which is located at the electrode site and provides greater flexibility in less than one fifth the volume and cost of commercially available units. Several prototypes of this device are now undergoing clinical trials with considerable success. Final versions, providing further size reduction with increased noise rejection, appear extremely easy to use—and inexpensive.
Motion System Modifications for Upper-Extremity Function—In the past year, the Gait Laboratory System has been modified to examine the kinematics of upper-extremity motion. In the current project, normal subjects were filmed as they reached to pick up objects from a table in front of them with their right hand. This research will provide important information about the motor control of the upper extremity and will serve as a foundation for the development of a clinical evaluation protocol. The software available in the laboratory has been used to derive and analyze the film data and determine the shoulder, elbow, and wrist joint angular changes and angular velocities. Other software was developed to examine the trajectory of the reach and the phasing of the grasp. The adaptation of the system for film analyses was successfully completed. Minimal intra- and inter-subject variability was found in most reaches to a particular object in a particular location. This consistency in normal performance is important for the evaluation of abnormal patterns of movement.

In the near future, we will begin developing a clinical evaluation protocol for teenagers and adults. Reaches to pick up objects and other tasks which represent the spectrum of activities of daily living, will be filmed. EMG activity of several arm and hand muscles will be collected simultaneously. Pilot testing of an adaptation of this methodology with infants has also been initiated.

Statistical Analysis of Gait of Persons with Cerebral Palsy—The objective of this ongoing study is to utilize mathematical pattern recognition programs for the evaluation of kinematic gait data. In the past year, a clustering procedure developed by Professor A. Wong (Sloan School of Management, M.I.T.) has been applied to the kinematic gait data of a random sample of 120 patients with cerebral palsy. Using the kth nearest neighbor clustering procedure, five subpopulations were identified from the modes of a uniformly consistent estimate of the underlying measurement-space density. Graphical profiles and F-ratios were used to identify individual measurements, which were most useful in distinguishing the membership of the various observed clusters.

It was found that the five resulting clusters can be identified with different severeness levels of abnormal gait. Walking velocity and patterns of hip and ankle movements were seen to be markedly different for each cluster rather than related to age (2–15) or to subdiagnosis (hemiplegia, diplegia, etc.). Traits associated with patients in two of the clusters were identified with severe gait pathologies, while the remaining three clusters exhibited characteristics more closely approximating normal gait. Most of the patients in the two poorest-walking groups (clusters 1 and 3) were diagnosed as having quadriplegia, while none of the patients in the best-walking group (cluster 2) had the same diagnosis. On the other hand, a patient diagnosed as having diplegia can be in any one of the five identified clusters; from these results the conclusion was reached that the present clinical diagnosis system is not suitable for indicating the functional status of a cerebral palsy patient.

The Friedman recursive partitioning decision rule was used to construct a classification scheme based on the groupings obtained by the clustering method. Use of this classification rule demonstrated that the effects of corrective measures such as surgery or assistive devices on the gait patterns of individual patients can be examined.


The construction of a system to gather information on the physiologic function of individual muscles about the ankle is nearly complete. The mechanical apparatus at M.I.T. has been integrated with the hydraulics and with the control circuitry to form a functional unit which can either generate torque or control the orientation of the subject's ankle. The frequency response has been measured and found to be adequate for projected experimental needs. Programs have been implemented, and a cable run to the system to allow versatile computer control. The force plate part of the apparatus has been constructed and calibrated. It can measure accurately the force vector and center of pressure during any experimental run. The electronics of the myoelectric processing system are complete and can monitor and store signals from 14 channels through either surface or needle electrodes. Goniometers and the associated electronics to measure the orientation of the limb segments have been integrated into the system. Some final calibration and the substitution of a new hydraulic power supply are needed before experiments can actually begin.

Dynamic Analysis of Myoelectrical Activity during Gait* Project responsibility: Neville Hogan, Ph. D., and Sheldon R. Simon, M.D.

Recent efforts have focused on a deeper understanding of the transmission of surface myoelectric signals from their origins deep in the muscle to their detection at the electrodes. Analysis and experiments have shown that the anisotropy of muscle due to the parallel arrangement of the muscle fibers and the inhomogeneity due to the difference in the electrical properties of muscle, fat, and skin have a large effect on the amplitude and frequency content of the detected myoelectric signal. An extremely useful aspect of this research has been the description of these effects as analogous to the familiar phenomena of optical distortion and refraction. These insights promise to be of great value in the design of improved electrode arrays. The results were presented at the Third Annual Conference of IEEE Engineering in Medicine and Biology Society, Houston, Texas, in September 1981.

Objective Measurement of Spasticity Project responsibility: Mark Hallett, M.D.

This project has focused on the nature of the short- and long-latency stretch reflexes produced in the triceps surae by phasic dorsiflexion stretch of the ankle. In the last 6 months we have completed an analysis comparing our normal subjects, 17 patients with rigidity from Parkinson's disease, and 47 patients with spastic increase in tone from a variety
of etiologies. These results are being prepared in manuscript form and for presentation at the World Congress of Neurophysiology in Kyoto, Japan in September, 1981. The results show that there are clear physiological differences between spasticity and rigidity and between different types of spasticity. Additionally, it is possible to quantify objectively certain aspects of the increased tone using phasic stretch reflexes. Our current plans are to incorporate this very interesting set of measurements into a more comprehensive battery of tests to analyze motor capability at the ankle joint.

Suppression of Abnormal Involuntary Movements by Application of Mechanical Loads and Biofeedback

Project responsibility: Michael J. Rosen, Ph. D.

WRIST TRACKING STUDIES

Data taken during pursuit tracking tasks performed by tremor-disabled subjects have been analyzed to establish implications for clinical management and theoretical mechanisms of tremor. Results show, in particular, the following:

1. Abnormal tremor measures based on peak power density or cumulative power were reduced by a statistically, and often clinically, significant amount by application of viscous damping loads.

2. This tremor alteration is selective in the sense that it is achieved, on average over all subjects, with insignificant decrease in voluntary tracking fidelity (with respect to amplitude and phase).

3. For two of three subjects who were tested in isometric force tracking as well as displacement, average tracking performance was substantially better for force production, suggesting the possible utility of isometric joysticks as tremor-adaptive interfaces to systems and vehicles.

4. Unlike normal physiological torque variance, pathological tremor torque oscillations under isometric conditions remained at a constant amplitude when the torque required for tracking was increased, so that signal-to-noise ratio was improved.

5. Tremor spectra of tremor-disabled subjects of diverse etiology were found uniformly to include one or two small peaks in the normal tremor range near 10 Hz in addition to the low frequency of pathological peak. This suggests co-existing but distinct mechanisms for physiological and abnormal intention tremor.

6. The difference between the two mechanisms is further indicated by the consistent observation that the peak torque of high frequency tremor increased proportionally to required voluntary torque, in contrast to the invariance of the peak torque at low frequency described above.

7. Abnormal tremor torque is also observed to be constant with respect to the change in experimental conditions from unloaded movement to isometric force production. This suggests a mechanism other than reflex instability since this change should radically alter reflex loop gain.

8. Abnormal tremor peak frequency is also invariant over unloaded, damped, and isometric conditions. This finding, that manipulation of peripheral parameters apparently leaves tremor frequency unchanged, strongly suggests a central oscillator as the source of the tremors observed in our subjects.

COMPLIANT ANKLE ORTHOSIS

Work has progressed considerably toward applying viscous or other compliant loading as a means of controlling manifestations of spasticity in gait. Specifically, the goal is to reduce equinus in cerebral palsied children by using an articulated brace (foot-ankle orthosis) which applies torque in opposition to ankle extension/flexion. If the clinical impression that hyperactive stretch reflexes induced by foot dorsiflexion have an abnormally accentuated rate dependence can be verified objectively, then a viscous loading function which limits the angular velocity of the ankle should reduce equinus-inducing reflexes. A gait improvement with respect to that allowed by rigid or elastically constrained orthoses is hypothesized.

At this point, a prototype orthosis has been fabricated with a small magnetic particle brake as the source of restraining torque. Control circuitry and on-line computer programs are being developed to allow for simulation of a variety of passive loading functions. The orthosis is instrumented to transduce standard gait timing events as well as applied torque. It permits adjustment for foot size and ankle axis location, and weighs approximately 2½ lb. including the shoe.

Testing of our first candidate for use of the prototype orthosis is complete. A spastic paraparetic juvenile subject has been monitored using the torque measurement capability of the ankle stretch instrument used in the Measurement of Spasticity project during ramps of dorsiflexion applied at rates ranging from 25 to 200 deg/sec. Preliminary data show a discontinuity in the torque vs. angular velocity curves at 75–100 deg/sec for one leg and 150–200 deg/sec for the other. Unrestrained gait testing of this subject with and without the prototype orthosis will begin shortly.

Automated Muscle-Fatigue Indicator

Project responsibility: Carlo J. De Luca, Ph. D.

A series of pilot studies have recently been initiated to obtain a variety of basic data directed at augmenting our understanding of the process of muscle fatigue. The pilot studies have specifically asked how muscle force, subject hand-edness, subject sex, and muscle fiber type relate to the process of localized muscle fatigue. Thus far, 31 normal subjects have been studied. The preliminary results show that the initial value of the median frequency of the EMG signal is apparently not directly correlated with the muscle force output. However, the initial median frequency for the same muscle was found to be significantly smaller in females than in males, and slightly smaller in the dominant limb than in the non-dominant limb. The results also show that muscles containing a relatively larger percentage of fast-twitch fibers display a relatively larger percentage change in the value of the initial median frequency during a contraction.

Application of objective measurement of localized muscle fatigue to disabled subjects has begun. Thus far, 8 patients with either Duchenne's Muscular Dystrophy or peripheral nerve injuries have been tested. Preliminary results are highly favorable and indicate that substantial changes in the initial median frequency can in fact be measured in both clinical conditions.
Communication Systems for the Severely Motor Handicapped

1. UNICOM

Project Responsibility: Derek Rowell, Ph. D.

The UNICOM (UNiversal COMMunicator) project has progressed with respect to new system features, evaluation by new handicapped users, and objective measurement of user performance. Examples are as follows:

1. The UNICOM scanning mode has been expanded from a system with a single “page” video character menu to one which permits scanning of multiple pages. The additional pages include one with a character matrix containing the necessary control commands and special characters. A third page was added as a transfer page and to assemble and send computer log-on messages and passwords. The original page was left intact with all UNICOM functions except that the cursor command “home” was replaced by the page selection command.

2. A new strategy—direct selection with a joystick controller—has been implemented. An input matrix is displayed as in the scanning or encoding modes, but the input cursor is directly controlled by a joystick. When the user steers the input cursor to the desired character and closes the “enter” switch, the character is added to the message display. This system will soon be tested by a disabled person.

3. During the past year a UNICOM used as a scanning communication device by a severely involved cerebral palsyed high school student has been extended into a computer terminal. He has used it with the school’s computer to take a programming course.

4. Four UNICOM users have had their “typing” speed measured, three using encoding and one with directed scan. Two of the encoding users used the sip and puff “harmonica” interface and typed familiar passages at 15 and 17 words per minute. Both are high quads. The other encoding user has spastic paralysis of all extremities with useful function only in the right arm. With the eight-key keyboard he typed at 1.9 words per minute. The fourth person tested can move only his left arm, which is paretic and ataxic. With the directed scan joystick, he can type at 1.1 words per minute.

2. Analysis of Factors Influencing Rate of Non-Vocal Communication

Project responsibility: Michael J. Rosen, Ph. D.

In collaboration with Dr. Cheryl Goodenough-Trepanier, a linguist at Research and Training Center 7 at Tufts-New England Medical Center, a number of theoretical studies have been conducted on non-vocal communication (NVC). Specifically, factors influencing the rate of communication of a NVC system user have been analyzed to provide a unified approach to diverse devices, to attempt clinically useful predictions, and to suggest further work. These analyses have been collected in a manuscript to be submitted under joint authorship. Selected results are listed below:

1. A simple formula has been derived which expresses average time per word, Y, as a product of three terms—

   \[ Y = C \cdot L \cdot T \]

   where:

   \[ C = \text{the average "cost" in linguistic units (letters, phonemes, syllables) of composing a word;} \]

   \[ L = \text{the average number of motor acts required to encode a unit (equal to 1 for direct selection systems);} \]

   \[ T = \text{the average time required for a single motor act.} \]

   This formula applies broadly to all encoded and direct selection NVC systems.

2. The form of the equation \[ Y = CLT \] and the dependence of individual terms on the independent variables N (number of units provided by a system menu) and B (number of distinct motor acts recognized) indicates two unavoidable tradeoffs. Larger inventories allow more efficient word formation, i.e., smaller C, but require longer act sequences for coding, i.e., larger L. Similarly, more switches in an interface allow shorter code sequences—while the necessity for smaller switches or large switch arrays implies more time per act, i.e., larger T.

3. A clinical implication of this is that, for a given non-vocal patient for whom a system is being prescribed or designed, selection of an optimal interface and an optimal language menu cannot be undertaken independently.

4. An algorithm has been outlined which operates on time and accuracy data taken during abstract target acquisition tests and predicts the communication rate to be expected with available or hypothetical NVC systems.

5. It can be demonstrated mathematically that codes relating sequences of acts to selection of language units will invariably have reduced L if sequences of multiple length (as opposed to three acts required for every unit, for example) are permitted. This is true in spite of the necessity for an independent “enter” command to notify the system that an act sequence is complete.

6. Expressions are derived for the average number of additional acts required for indication of word boundaries under conditions of different delimitation techniques. These expressions provide a rational means of choosing a technique, depending on the system code and characteristics of the inventory.

Evaluation and Application of Myoelectric Biofeedback

Project Responsibility: Carlo J. De Luca, Ph. D.

During the past 6 months, the myoelectric biofeedback project has entered a termination phase. We are currently in the process of compiling all previously accumulated data and performing the analysis in preparation for final evaluation. Emphasis is on a search for an appropriate manufacturing group to produce our version of the myoelectric biofeedback device. These latter efforts are proceeding very favorably; several groups have displayed and demonstrated active interest.

Refreshable Braille Data Display System

Project responsibility: Derek Rowell, Ph. D.

The two TSPS (Traffic Supervision Position System) refreshable braille displays, installed at the Southwestern Bell Telephone Company, Little Rock, Arkansas (BPR 10-33, pp. 108-110, Spring 1980), continue in service and enable two blind operators to be fully employed and competitive. The performance of one operator is just above the office average. That of the other is significantly above.

These two displays have accumu-
Clinical Engineering in Rehabilitation

Project responsibility: Philip A. Drinker, Ph. D.

A new non-vocal communication technique and display board, Eye-Link, that uses direct selection by eye contact between disabled sender and nondisabled receiver has been developed. The primary use of Eye-Link is seen in the early phases of hospitalization; however, it may also find application in the chronic-care setting as a low cost, indestructible backup to electronic communication systems. The advantages of Eye-Link include simplicity, ease of comprehension, and speed relative to scanning and encoding techniques.

The technique embodied in Eye-Link is based on the use of a transparent board on which the selections are displayed in a rectangular matrix. The receiver holds the board, facing the sender, so that they can see each other through it. The transmission technique is as follows:

1. the receiver asks the disabled sender, "word or spell?"
2. the sender responds with an eye movement to the upper left or upper right.
3. the receiver then instructs the sender to fix on the desired letter/word.
4. the receiver, watching the sender's eyes, moves the board until eye contact is made through an individual square, indicating the desired selection. (For the sender with disconjugate gaze, the receiver must ascertain and follow the dominant eye.)

Results of this research by Philip A. Drinker and Susan Kropoff were presented at the Rehabilitation Engineering Society of North America Conference in Washington, D.C. in August, 1981.

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Introduction

In July, 1978 the Bureau of Education of the Handicapped of the Department of Education awarded a 3-year demonstration grant to the Memphis City Schools—Division of Special Education. The primary objective of the project was to demonstrate that severely physically handicapped children could participate more meaningfully in their educational programs as a result of assistance from technical aids in the areas of seating, communication, mobility and personal care. The secondary objective was to evolve service delivery concepts that could be incorporated into a model that could be used for replication in other educational settings.

The need for this study was illuminated by the fact that more than half of the approximately 8 million handicapped children presently in the United States do not have access to quality educational opportunities. The BEH award permitted the formation of the cooperative agreement with the NIHR-sponsored Rehabilitation Engineering Center at the University of Tennessee, which has provided the technical consultation, device design, fabrication, and maintenance support. The cooperative effort was termed project TEACH—Technical Educational Aids for Children with Handicaps.

Three major need areas were identified for immediate study; (i) specialized seating and positioning to prolong attentive upright postures, (ii) augmentative communication aids to facilitate communication between teachers and students, and (iii) the refinement of educational goals to include the acquisition of skills of daily living, such as toileting, feeding, fine motor skills, and mobility.

Previous experience of the project staff, as well as those of colleagues working with handicapped children in other areas of the country, has led to the subjective observations that technical aids can make a significant contribution to the level of participation of severely handicapped children within educational settings. However, these most significant accomplishments have rarely been documented using quantitative measures, thereby diminishing their impact in terms of justifying the expendi-
tures involved. Therefore, it was deemed important that the methodology attempt to document quantitatively the individual results within the three aforementioned areas of priority.

It is the intent of this report to present in summary form the results of Project TEACH with emphasis on the Rehabilitation Engineering component.

Methodology

The core area of research focus at the University of Tennessee—Rehabilitation Engineering Center has been specialized seating and mobility for severely handicapped children. Therefore, Project TEACH was able to benefit from the dissemination of this research experience and results, as well as from the direct technical services provided by the center staff on a contractual basis. The cooperative staffing assigned to the project were a Speech Pathologist (50% time), Occupational Therapist (75% time), Rehabilitation Engineer (50% time), Technician (50% time), Parent Trainer, and a Project Coordinator.

The sample population consisted of 10 children, each exhibiting some form of cerebral palsy. All were nonverbal as a result of extensive motor damage to the speech mechanism. Each child also demonstrated serious motor impairments which affected their functioning in addition to speech; i.e., trunk instability, absence of head control, limitation in personal care skills, or dependency in mobility.

After selection of the study sample, the next step was to develop an assessment protocol which was used to obtain baseline data related to existing functional levels and needs for each child. It then became the challenge of the technical members of the team, working in cooperation with the therapists and educators, to derive solutions to meet the needs defined.

A significant number of diverse variables can affect the successful delivery of technical services in an educational setting. Therefore, a further goal reflected in the methodology was to identify the most significant steps and incorporate them into a generalized flow chart that could be refined to meet the needs of a unique educational setting. This was accomplished by empirically creating a delivery model which was refined as a result of experiences gained throughout the project.

Results

The following results emphasize the technical aspects of the project. However, it does not do justice to the less-tangible contributions of the therapists, educators, evaluators, parents, parent trainers, and children. Their efforts in the areas of needs assessment, fine and gross motor level assessment and training, parent and child intervention, coupled with the guidance necessary to keep the technical staff on course, are contributions that were essential elements for effective technical intervention. A more comprehensive publication on Project TEACH, which elaborates on these non-technical aspects of the project, is available from the Rehabilitation Engineering Center (1). Also, a sound/slide production, available on a loan basis, provides a general description of the project activities (2).

The Effects of Seating and Positioning Supports—In measuring the effects of therapeutic seating systems, three areas were considered: (i) maintaining head control, (ii) maintaining trunk control, and (iii) a student's ability to use the arms in a gross functional manner. Eight of the 10 students required custom fitted seating systems (Two students were ambulatory and therefore not included in this component of the study). Each child was therapeutically positioned by a seating support. Measurements were taken at three intervals within an 18-month period while performing activities with and without the seating systems. The results obtained in (i) and (ii) above are summarized in Figure 1.

When the students were pulled from lying supine to sitting, they were able to maintain their heads in alignment with their trunks (head control) for an average of 51.6 sec; they were able to hold their heads in alignment with their trunks, when prone on a wedge, for 106.9 sec; and when prone standing were able to hold their heads in alignment with their trunks, which were therapeutically positioned. However, when they were in their therapeutic seating systems, the students' ability to hold their heads in alignment with their trunks increased most significantly to at least 7 hours, which was the end of the school day. After use of therapeutic seating, most children continued to maintain upright alignment for varying periods during bus transport and also at home.

In measuring trunk control, defined as the ability to maintain the trunk in an upright midline posture, students were seated in four different positions—sitting cross-legged on the floor, sitting on a wedge, sitting on a standard chair, and sitting in a therapeutic seating system. The average time they could maintain trunk control in each position was recorded. The average time sitting cross-legged on the floor was 6.46 min; sitting on a wedge was an average of 10.7 min; they were able to sit unsupported on a standard chair for an average of 5.96 min; and in their seating system they were able to maintain the trunks in alignment for an average of at least 7 hours which again was the termination of the measurement period.

Arm control was measured by suspending a ball with an eight-inch diameter from the ceiling with a rope. The number of times a student could bat it in a 1-minute period was recorded. While in their seating systems students were able to bat the ball an average of 19.3 times in a 1-minute period. When not in their seats they had insufficient control to bat the ball at all. An obvious further step would be to initiate a study in which a comparison is made between seating support and changes in fine motor skills.

Mobility—Four students were chosen as candidates to be given powered mobility, which was compared with the baseline mobility performances using manual wheelchairs, or in one case ambulation with a walker. In the powered situation, one used an ABEC chair, two used E & J 3P Chairs, and the fourth used a modified Amigo Cart. Comparative tests were run and measures were taken by recording the time required for the student to traverse a distance of 125 feet (38.1 meters), first using manual propulsion when possible and then a powered device. The second series of tests involved the use of revolution counters added to both the manual and powered chairs to record the total distance covered in a normal 6-hour school day averaged over a period of a typical school week.

Three of the four children were unable to complete the manual propulsion speed test within an acceptable time frame due to the extent of their physical disabilities. The fourth child could walk the 125 feet distance with a modified walker in 89 seconds. Using their pow-
ened devices, all four children could traverse the test track in less than one minute. Individual variations were due to the control ability of each child and the type of powered chair and control system each was using.

The distance test revealed that the average distance traveled by each of the four children dependent on manual propulsion was 1184 feet (358.1 meters) over a typical 6-hour period; three of the children relied on random propulsion by others and the fourth ambulated with the use of a walker. Using powered mobility the average distance traveled within the 6-hour period was 2231 feet (680 meters).

Based on the subjects studied, it can be concluded that children with zero or very limited mobility can be given sufficient control over a powered device in order to permit them to safely mobilize themselves within a school environment within a practical time frame; i.e., traverse 125 feet in less than one minute. Secondly, when given the opportunity through powered mobility, the test subjects increased their overall mobility distance approximately two times the distance traveled when dependent on others for propulsion; or in one case on stressful ambulation with a walker.

Communication—Rate of communication is an important variable when considering which alternative communication system to prescribe. The slower the system, the less likely the listener will choose to wait for the complete message, resulting in frustration for both the sender and receiver (3). In the educational setting, the rate of communication has a direct bearing on the quality and quantity of time spent between student and teacher, and on the quantity of time required for students to complete work assignments that require output responses.

Directly bearing on the rate of communication is the rate of accessing the communication aid. In order to evaluate the relationship between alternate communication devices and speed of accessing the devices, it was decided to use symbolic units as a measure of comparing access rates between six different systems. That is, the selection of a Blissymbol by finger pointing, or an alpha-numeric character by eye gaze, or selection of keys on a keyboard were all given an equal value of one symbolic unit. All students were assessed by the Speech Pathologist as being functionally unintelligible as a result of Cerebral Palsy. Most could communicate only through facial expression and gross gestures. Two attempted speech but were almost never understood.

Three children used a lap tray incorporating a symbol board and pointed to the symbols with their hands. Three children used an eye gaze chart and pointed to symbols with their eyes. Two children used the Proscan, which was activated by an optical sensor mounted on the head (4). One child (LM) used a developmental device also activated by a head-mounted optical sensor but with an improved feedback panel. Measures were taken with the commercially available TRS-80 pocket computer and the
Canon Communicator, both of which required finger function. All measures were obtained after at least 7 months of training (with the exception of the new optical headpointer (LM) which was only used for 3 months and the TRS-80 which had been used only 2 months).

As shown in Table 1, mean access rates with lap trays and eye gaze charts using symbols were 7 and 8.45 symbolic units, respectively. The optical head pointer, the TRS-80, and the Canon yielded means of 38.8, 25.5, and 39.5 symbolic units respectively. Caution must be exercised in interpreting these results, especially since comparisons are being drawn between individuals with varying degrees of control ability. Also, the eye gaze and lap board devices communicate the equivalent of whole words through the use of symbols, while the remaining systems communicate only alpha-numeric characters, or word units. However, the cluster of access rates within a single device used by children with varying degrees of control ability is significant.

If one assumes that a symbol (Bliss-symbols) communicates the equivalent of a five-letter word, then the eye gaze and lap board approaches would have equivalent rates of 35 and 42.2 symbolic units respectively. However, the limitation of the simplified eye gaze and lap board approaches is in the practical size of the vocabulary that can be displayed, especially when portable configurations are required. However, the approach is certainly valid for young beginners, since at that stage size of vocabulary is usually not a priority factor. Electronic devices using alphanumeric characters have no limit to the vocabulary size. With the addition of stored words and whole-phrases prediction strategies, user program ability, etc., (features which are now available with microprocessor based systems) the communication rates have been drastically improved, especially when activated by direct access input modes. (The experimental prototype used by L.M. in this study has the stored word/phrases features, but was not used during the testing sessions.) It is further noted that Rosen and Trepagnier have recently published a suggested standardized methodology for measuring access rates for the purposes of comparing direct selection and encoding systems (3).

In summary, other things being equal, faster communication is better communication. These preliminary results suggest that electronic devices, especially when expanded to include stored words/phrases or symbols accessed through direct selection, can be an effective means of providing faster communication. However, it should be also stressed that the more simple (non-electronic) aids can be equally effective, especially for beginners who are at the stage of learning the prerequisite skills necessary for the effective use of more sophisticated (and expensive) electronic communication aids.

Personal Care—Feeding—Feeding was chosen as a personal care activity for documentation, since it has obvious significance for the child and also cost-saving implications within the educational setting.

Feeding skills measurement was taken with four students, all of whom were totally dependent in feeding, but possessed the potential for independence with the assistance of a technical aid. Since the technical solutions provided were so individualized, each will be briefly described.

<table>
<thead>
<tr>
<th>Student</th>
<th>Without equipment unassisted</th>
<th>Without equipment assisted (fed)</th>
<th>With equipment unassisted</th>
<th>With equipment assisted</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.D.</td>
<td>cannot eat</td>
<td>20 min.</td>
<td>30 min.</td>
<td></td>
</tr>
<tr>
<td>H.R.</td>
<td>cannot eat</td>
<td>15 min.</td>
<td>25 min.</td>
<td></td>
</tr>
<tr>
<td>S.R.</td>
<td>cannot eat</td>
<td>25 min.</td>
<td>cannot eat</td>
<td>17 min.</td>
</tr>
<tr>
<td>B.K.</td>
<td>cannot eat</td>
<td>20 min.</td>
<td>10 min.</td>
<td></td>
</tr>
</tbody>
</table>

1. DD was provided with a Winsford Feeder, a powered feeding device he operated with chin control with his arms restrained under his tray.
2. HR was provided with a C.P. feeder, as she has sufficient gross motor arm placement to hit the levers required to operate this mechanical feeder.
3. SR had a modification to her tray which restrained her arms, giving her more upper trunk stability during feeding.
4. BK was provided with a swivel plate because he could not reach the food at the far side of his tray. A built up spoon handle helped sustain grasp.

The time required for a teacher’s aide to feed a randomly selected school lunch was recorded. Then the feeding device was provided, a proficiency level obtained, and the time recorded for each child to eat independently; or in one case (SR) to be fed with the arms restrained.

As indicated in Table 2, feeders allowed three of the children to become independent during mealtime and to accomplish this within a practical time period (30, 25, and 10 minutes). Although in two cases the feeding time was increased by 10 minutes, it obviated the need for salaried aid through-

### Table 1. Rate of Accessing the Communication Aid.

<table>
<thead>
<tr>
<th>Device</th>
<th>Means of access/input</th>
<th>Symbols (units) per minute</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye gaze chart</td>
<td>Direct eye gaze/symbols</td>
<td>TR 7</td>
<td>x = 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SR 6</td>
<td>(35)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JM 8</td>
<td></td>
</tr>
<tr>
<td>Lap board</td>
<td>Direct pointing/symbols</td>
<td>AE 9.67</td>
<td>x = 8.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BK 7</td>
<td>(42.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HR 8.67</td>
<td></td>
</tr>
<tr>
<td>Proscan</td>
<td>Direct optical pointer/alphabet</td>
<td>DD 18.5</td>
<td>x = 38.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LM 34</td>
<td></td>
</tr>
<tr>
<td>*New optical pointer</td>
<td>Direct optical pointer/alphabet</td>
<td>LM 64</td>
<td></td>
</tr>
<tr>
<td>TRS-80</td>
<td>Keys/alphabet</td>
<td>WM 26</td>
<td>x = 25.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FN 25</td>
<td></td>
</tr>
<tr>
<td>Canon</td>
<td>Keys/alphabet</td>
<td>WM 39</td>
<td>x = 39.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FN 40</td>
<td></td>
</tr>
</tbody>
</table>

*Experimental prototype

### Table 2. Feeding Skills Data.
out mealtime. The arm restraint allowed S.R. to be fed in a shorter time (17 vs 25 minutes).

Educational Achievement—The primary purpose for technical intervention was to assist handicapped children to reach their potential in education and personal care skills. Five of the Project children were in a developmental program, with the remaining in an academic program. The developmental program is designed to develop pre-academic skills such as basic vocabulary and language concepts, arm/hand and head control, and perceptual motor skills utilizing environmental stimuli and normal experiences.

In the academic group, one student, who is hearing impaired as well as non-verbal, participated in a specially designed language-based program coordinated between the multiply handicapped hearing-impaired program and the Shrine School Physically Handicapped program. The remaining four children were in non-graded elementary classes.

In order to evaluate the educational achievement of the Project children, an examination was made of each student’s performance in their classroom from Fall 1979 to Spring 1981, the period after which technology had been prescribed and secured for each child complete with adequate usage training. Student growth was compared to that of a control group that did not have the benefit of the intervention of technology and other support services the Project provided. However, because of the vast differences between the children, it was virtually impossible to make a completely valid evaluation of comparative growth.

For the academic group, progress was measured in terms of the mean growth of children in reading and mathematical skills. For the developmental group, progress was measured by a percentage of correct responses in color recognition (reading readiness) and matching numerals. (See Figure 2.)

Results indicate that the mean reading achievement score for the project children in the academic group was 7 months as compared to 6 months for the control group of four children. In the 1980–1981 school year the mean score was 12 months growth as compared to 8 months for the control group.

In the developmental group, all children progressed during the 1978–1980 school year in pre-academic skills with a mean growth of 77% as compared to the control group of 30%. In matching numerals all students went from zero ability at the beginning of the 1979 school year to recognizing 100% of the numerals at the year’s end; the next year, the same group made 58% progress in matching numerals as compared to 20% for the control group.

As can be noted, the project children made significant gains during the first year when the technology and training were first introduced and then tended to level off in growth, while still performing at higher levels than the control
group. Four students from the academic group were mainstreamed on a part-time basis during the course of the project. Teacher interviews revealed that this was accomplished largely as a result of the technical devices and support provided to the students and teachers by the project staff.

It is not evident from the data which specific aspects (i.e., seating, communication, mobility, or ADL) of the technical support were the most effective in supporting educational objectives. Parent, student and teacher interviews suggest that the achievement of effective student-teacher communication is of the highest priority. Further, it can be deduced that the functional accessing of communication devices is highly dependent on good head and trunk control. This suggests that provision of communication aids should be preceded by the availability of adequate seating support systems. In the academic study group, the final step to mainstreaming was facilitated as a result of powered devices that allowed independent mobility. This permitted transfer between classrooms within an acceptable time frame without any special assistance. Achievements in the area of personal care were particularly important to the morale of the parents as they witnessed the children acquiring skills that were previously considered to be life-long impossibilities. Reduction of staff time required to fulfill the personal care needs of the children during the school day was also a secondary benefit.

**Provision of Technical Services—The Delivery Model**

Figure 3 is the generalized flow model that was developed for the delivery of the technical services within an educational setting. Upon receipt of student referrals the first essential step is a thorough screening and evaluation process by a multidisciplinary team. Our experience suggests that an occupational therapist, a speech pathologist, the parent and an educator should form the nucleus of the team with other specialists being available as required. A vital part of the assessment process is coordination with the child’s ongoing medical and therapy treatment program to insure compatibility of management goals and the receipt of the background information necessary for decision making. Communication with the parents and classroom teachers is most essential, since the ultimate plan must by law be incorporated into the child’s Individual Educational Plan (I.E.P).

In general, four alternatives are avail-
able to the assessment team relative to the provision of a technical aid. These options are (i) provide a commercial device, (ii) provide a modified commercial device, (iii) provide a custom designed device, and (iv) acknowledge that a solution does not exist within the current resources available to the team.

The first option (a commercial device) is usually one that can be purchased directly from a supplier and provided to the child without any significant technical support required. In most cases this is the most practical approach and therefore, as indicated in the flow chart, should be the first route investigated. Risk is diminished if access to trial aids is possible so that an evaluation with the proposed aid can be carried out prior to the commitment of financial resources.

Failure of the "as supplied" commercial aid to meet the needs of the child leads to the two remaining technical options. These options usually require the availability of technical resources in order that modifications to commercial devices can be accomplished, or that custom designed unique solutions can be conceived and produced. If possible, modification of a commercial device is usually the next most practical approach. These modifications are usually concerned with such things as wheelchair mountings, alterations to the input controls, connections without display modes, and interpretations of technical data from the suppliers.

For reasons of cost and time delay, custom designed solutions are the technical approach best reserved for the last resort. Once the modification on prototype design has been validated and the devices fabricated, they should be subjected to usage trials. Failure to meet the needs at this point suggests a complete reassessment of the problem in light of the overall priorities and resources of the program.

In all cases, once a successful device is working under the supervision of the technical resource team, training of others associated with the child's daily environment is the next vital step. The importance of providing detailed instructions and support to educators during the transition phase into the classroom cannot be overstressed. Maintenance and repair of technical aids in a timely manner to minimize "down time" is vitally important in order to maintain student motivation and supportive teacher involvement.

Finally, the technical needs of most children change with time. Therefore, periodic re-evaluation and assessment of the needs is necessary to review the appropriateness of the aid relative to the child's current needs.

In 1980 the National Association of State Directors of Special Education published a delivery model, complete with cost figures and listings of resource facilities (5). This reference is recommended reading to those considering establishing technical resource facilities to serve educational environments.

Cost Distribution

The cost of technical support provided to Project TEACH is summarized in bar graph format (Fig. 4). Cost analysis was related to the five component areas of technical support: seating, mobility, communication, aids to daily living, and evaluation and training aids. The cost within each category has been subdivided into the following three types of aids: commercial, modified commercial, and custom designed.

Technical aids available to children from commercial sources progressed rapidly during the course of the three year project. A number of the children in Project TEACH received custom designed equipment that presently could be provided through commercial channels. To provide cost data more useful for planning and budgeting, the cost distribution data have been adjusted to reflect current (1981) commercial costs of these devices where applicable. Although certain aids are now commercially available, provision is normally through professional consultant channels. In these cases, cost of the aids has been included under the commercial breakdown, while the professional time involved in the prescription and fitting of such aids has been distributed between the modification of commercial equipment and the custom designed solution.

The results in Figure 4 indicate that average seating costs per child were $620, with $330, $40 and $250 distributed between commercial, modified commercial and custom designed solutions, respectively. These costs did not include the wheeled base. Powered mobility costs were the highest with an average of $2,000 per child, with increments of $1,150 for commercial, $200 for modified commercial, $650 for custom design devices. Further analysis of the graph will result in the cost figures for communication aids, ADL devices, and evaluation and training equipment for the 10 Project TEACH children.

The cost distribution does not include the cost of routine maintenance and repair of the aids provided. Over the course of the 3-year project, it was determined that the cost of maintenance, local repair, and repair of aids by commercial suppliers resulted in additional annual expenditures of approximately 10% per year above the cost of the provision of the aids.

Concluding Comments

The provision of appropriate technical aids within an educational setting can have a profound impact on improving the educational achievement experienced by severely handicapped children. In some cases, the support of technical services can lead to the mainstreaming of children that otherwise would not be candidates.

The provision of most aids should be preceded by a multidisciplinary evaluation in which the abilities, the potential, and the comprehensive needs of the child are clearly defined.

A multidisciplinary engineering service team can be a most effective resource for the selecting and providing of specialized technical services, especially those related to the provision of modified commercial aids and/or custom designed devices.

Due to the need for additional head and trunk control, severely handicapped children should be provided specialized seating systems as a prerequisite for the provision of communication, mobility and personal care aids.

The more sophisticated the technology, the more essential the need for liaison personnel to explain the operation and features of each device to teachers and parents. Failure to provide this liaison support will almost invariably lead to rejection of the device.

Breakdowns with lengthy delays can severely interrupt a student's program; therefore, durability of equipment should be a major consideration in the evaluation and equipment selection process. Repairs to equipment must be provided in a timely manner to assure continuing
Technical aids should be provided within an educational setting according to a logical plan. The proposed model (Fig. 3) suggests a generalized operational approach which can be restructured to meet the needs of a specific locality. However, it is recommended that none of the components of the model be sacrificed if results as reported are to be achieved.

Continuing research on technical aids to supplement educational objectives is urgently required to improve the quality and effectiveness of devices available within special education classrooms. These studies should include expanded statistical evaluations with larger populations to better confirm the effects on student progress than has been possible in this preliminary effort.

Federal and state policy makers need to be made aware of the potential of technical resources to supplement the goals mandated by Public Law 94-142—Education of the Handicapped Act, so that these resources can be planned into budgetary allocations for implementation in the future.

Acknowledgement

The Directors of the University of Tennessee—Rehabilitation Engineering Center wish to acknowledge the support and guidance provided by the Memphis City Schools—Special Education staff assigned to Project TEACH under the direction of Mr. Harold Perry. The interest and encouragement of the parents and students were also instrumental to the success of the project.

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Rehabilitation Engineering Center
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Arthur Jampolsky, M.D., Project Director; John Brabyn, Co-Director; and Deborah Gilden, Ph. D., Associate Director

The 6-month period to June 30, 1981, has seen several promising developments in our REC programs. Rather than giving an exhaustive account of developments in all our projects, a brief description of the areas in which major advances have been made is given below.

Orientation and Mobility

Talking Signs. The present reporting period has seen the formation of a private company, Love Lights, Inc., to pursue the manufacturing and marketing of the Talking Signs Orientation System for the Blind. This company has redesigned the Talking Signs receiver to incorporate a wider angle of acceptance and the Talking Signs technology to elevator doorways. In collaboration with Love Lights, Inc., we are investigating the application ofTalking Signs to elevator speech modules. A local manufacturer of elevator controls has constructed a prototype using our designs, and is investigating the feasibility of production.

Collapsible Cane. As a result of the success of our prototype rigid collapsible long cane, we are investigating the possibilities of having 10 evaluation prototypes constructed by a local manufacturing company. These prototypes will be evaluated by selected long-cane users around the country. One result of our initial evaluation of the first prototype was recognition of the need for extra reinforcement of the lower sections of the cane. The 10 evaluation prototypes would incorporate two or more different methods of achieving this reinforcement.

Educational Aids

Our major project in this category has been the continuing development of the Auditory Arcade, described in earlier reports. We have now fabricated a second "Problem Panel" for this device, enabling it to be used to teach different skills.

Our next step will be to fabricate a talking version of this microprocessor-based game.

Vocational Aids

During the current reporting period, we have developed the use of the Smith-Kettlewell Technical File as a tool for the dissemination of vocational aids developed at our Center. Through the publication of circuits and fabrication instructions in this magazine, we have enabled many blind individuals to construct simple electronic aids for themselves.

We have initiated an ongoing followup program to evaluate the vocational aids developed in our laboratories during previous years. Of the first 23 users questioned in this survey, 21 were still using the various aids and devices in their daily vocational tasks. Of the two who were not, one had regained his sight since receiving the equipment.

We are now assembling a complete catalog of vocational devices developed at our Center, to facilitate our research utilization efforts. This catalog will contain complete details of all of the devices, including information as to how the device can be obtained, and will be circulated to prospective users, vocational counselors, purchasers, etc.

Low Vision Research

Our review of flat panel display technology for possible application to a lightweight, affordable, electronic low-vision reading aid is now complete. A summary of this survey will appear in our 1980/1981 Annual Report, of which published copies will soon be available. We are now ready to purchase examples of the most promising types of display for initial experimentation on a small scale, before beginning the design of an aid using a full-sized display.

Training

Our Technical Training Program for blind technicians has thus far proved most successful, in terms of benefit both to the trainees and our researchers. The 4 blind students who have so far participated in this program have received practical experience in electronics which is not available for them elsewhere, while the interaction between the trainees and our staff have produced a number of innovative methods of electronic circuit fabrication applicable to individuals with visual handicaps. These methods are being published through the Smith-Kettlewell Technical File, with a view to encouraging other blind individuals to become involved in electronic technology.

Braille Communications

We have initiated two new projects in the area of braille communications. While the use of synthetic speech is becoming widespread, we are confident that, for many applications, braille will continue to be a primary form of communication for the blind in the future. Consequently, we have turned our attention to developing less expensive methods of braille production and the realization of volatile braille displays.

Braille Communications

Both of the new methods under development utilize different plastic materials as the base upon which the braille is printed. Details of both the approaches will be contained in our 1980/1981 Annual Report. One of our special concerns is the development of low-cost braille output methods for computers. We have conceived a technique whereby the output from a conventional computer printer can be converted into braille without modifying the printer hardware. A prototype system is currently being developed.
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Alojz Kralj, D. Sc., Project Director, Stanislav Plevnik, M. Sc.,
Miroslav Vrabič, Dipl. Ing., and Ruža Ačimović, M.D., Co-directors.

This report (April 1–June 30, 1981) is a followup of the research and development report which appeared in BPR 10-35, Spring 1981. The core area of the Ljubljana REC is functional electrical stimulation (FES) of human extremities and of urogenital mechanisms. Institutions collaborating within the Ljubljana REC are: Rehabilitation Institute, the Faculty of Electrical Engineering and the Jožef Stefan Institute at Edvard Kardelj University, and the Urologic Clinic, all in Ljubljana. This current status report includes only the results and achievements of research tasks which we believe could be of broader interest to other researchers.

Multichannel FES of Lower Extremities for Gait Rehabilitation of Paretic Patients
Resp for task: U. Starlić, D. Sc.,
R. Ačimović, M.D., M. Maležič,
Dipl. Ing., J. Krajnik, Dipl. Ing.,
P. Strojnik

The results of a controlled study performed during the last 2 years, comparing the effectiveness of multichannel electrical stimulation with classical methods of rehabilitation, were analysed. For this purpose two similar groups of hemiplegic patients (9 patients each) were formed. The rehabilitation process of both groups was evaluated by different qualitative and quantitative methods. The former included clinical analysis of gait, evaluation of walking abilities, and test of motor functions; while the latter comprised the measurement of ground reaction by measuring shoes and crutch, measurement of goniograms of the hip, knee, and ankle joints of both legs in sagittal plane, measurement of stride length and gait speed, and recording of EMG activities over six muscle groups of both legs. The measuring techniques and computerized data processing were implemented in our laboratory. Considering the results of different methods of gait evaluation, no positive answer can be given in favour of the existence of the so-called “long-term” therapeutic effects in gait caused by electrical stimulation. Unfortunately, the groups were too small, and too heterogeneous in several important parameters, to prove statistically possible significant differences in the evaluated parameters between the two groups.

However, it is evident that therapy including multichannel electrical stimulation is more intensive and efficient; namely, the rehabilitation period is shorter and higher levels of improvement can be achieved. “Short-term” therapeutic and orthotic effects of stimulation are well established.

A microprocessor-controlled six-channel surface stimulator (Fig. 1) was developed as a result of experiences gained with previous multichannel stimulators. A microprocessor accommodates stimulation sequences to the gait cadence of the patient, and also gives some basic statistical parameters of the gait.

FES of Spinal-Cord-Injured Patients—Fundamental Locomotion Patterns
Resp for task: A. Kralj, D. Sc.,
R. Turk, M.D., T. Bajd, D. Sc.

The wheelchair-attached supporting frame, which enables the patient to balance and partly support himself while standing up and maintaining the erect position by means of FES, was redesigned in Spring 1981 with the goal of improving cosmesis, functionality, and stability. In Figure 2a the frame is shown while collapsed, and in Figure 2b it is shown as used by a T–5 patient during standing by means of FES. Next, this standing frame together with the stimulator will be evaluated and particular efforts made for stimulator improvements in regard to size, electrodes, and user-friendliness.
properties, and fixation means.

In April of this year a four-channel electrical stimulator suitable for the FES of incomplete paraplegic patients was completed. This stimulator provides different triggering possibilities and, according to the patient's voluntary control, can be adapted to the patient's needs. The second important advantage of the stimulator is that different stimulation frequencies can be pre-set and if needed partly controlled by the patient. The parameters of electrical stimulation are selected in such a manner that reflex movement of the entire leg can be evoked during the gait. This provides a one-channel control of the entire swing-phase movement.

Figure 3 shows the hip angle dependence of various stimulation parameters for a T-4-6 paraplegic patient. The described stimulator is used for achieving primitive biped gait patterns in paraplegic patients suffering from complete lesion, too.

One paraplegic patient T-5 uses a roller-walker for support and the four-channel stimulator described. The controls for stimulation are mounted on the handles of the walker. The patient, while walking by means of FES, controls the stimulator via hand switches and this way ensures proper coordination of his upper trunk movements and provides the timing (beginning, duration, and ending of the stimulation). Up to now, this patient has been able to walk more than 100 m on even surfaces.

**Figure 2a.** The collapsible wheelchair-attached supporting frame does not interfere with the normal use of the wheelchair.

**Figure 2b.** Patient (T-5) while standing by means of two-channel FES of M. quadriceps using the W/C attached supporting frame.

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**Functional Electrical Stimulation of Denervated Muscles**


Electrical stimulation of the nervous tissue has found clinical use in a wide variety of orthotic and therapeutic applications in patients with central nervous system injuries. It is generally believed that the denervated muscle may be directly excited by a special range of electrical wave-forms, all of which elicit a non-tetanic physiological response. Typical parameters are: pulse duration of a few tens of milliseconds and frequency from 0.5 to 10 Hz and relatively strong currents (10-40 mA). The reaction of the skin under a surface electrode, however, shows a marked depen-
The major goals of our investigations are:
1. Detailed study of the phenomena which arise from electrostimulation of the denervated muscle;
2. Development of a clinically useful functional electrical stimulation (FES) method for a patient with lower motor neurone lesions;
3. Optimization of electrotherapy for a patient with denervated muscles;
4. New knowledge about electrophysiology of denervated muscle; and
5. Minimization of the various waveform parameters which are related to electrically induced redness such as current and voltage levels, energy, power, injected electrical charge, and timing parameters of electrical stimuli.

The goal of the preliminary experiments on the denervated muscle was to obtain a minimum functional movement by means of electrical excitation on denervated muscle. Surface electrodes were applied and a voltage source of the stimulating pulses was used. The results reported here present a comparative study of the skin response, torque, and angle of the ankle joint to four different waveforms: simple monophasic, simple biphasic, chopped monophasic, and chopped biphasic. Time and current parameters have been fixed. The current was 5 mA, pulse duration $T_1 = 30$ ms, pulse frequency $f = 16.6$ Hz, and chopping frequency 500 Hz (Fig. 4). The measurements were performed on 6 normal subjects and 5 subjects with complete denervation of the muscle tibialis anterior.

The redness of skin was estimated visually in three levels. The investigation of problems of electrical stimulation for patients with lower motor neurone lesions shows some possibilities of optimization of electrotherapy and defining the FES to these patients. The redness and the movements are related to the waveforms of stimulation pulses. The stimulation response was better at simple monophasic and simple biphasic waveforms. The redness was essentially diminished at chopped biphasic stimulation pulses. There is also a possibility that the generator of source stimulation pulses is current. Investigations in that direction are running at present.

**Neurophysiological Investigations of Improvements in the Pathological Motor Activity Due to FES and other Rehabilitation Methods**

Resp. for task: F. Gračanin, D. Sc.

It was shown that by FES of peroneal nerve a motor response (M-wave) is not constant and changes its amplitude depending upon some phases of the gait. Current research is directed to the study of M-wave behaviour using continuous stimulation and an off-on control of FES in normal persons and patients suffering from spastic hemiplegia. Our aim is to analyze the related mechanisms (central and peripheral of the neuromuscular system) of uncontrolled changes in the conditions of FES application together with the influence of the electrodes moving, topographical changes of anatomical structures when the leg is in different positions, etc. Results of this research will be helpful to numerous researchers, clinicians and patients who are using FES. Our measurements
are performed by using the system FEPA
10 for off and on control and simulta-
neously the AM-5 system for continu-
ous stimulation during the patients' walk-
ing. The M-Wave is analyzed with
the help of a HP-2100 minicomputer.

The second topic of this task is the
analysis of paravertebral and abdomi-
nal muscles activity in children attend-
ing elementary school. They are
frequently wearing school bags,
weighted up to 5.5 kg. The goal of this
research is to recognize different pat-
terns of motor activity and statiokine-
siological changes in respect to foreseen
possible development of bad posture
and deformation of the spine. Such re-
ognition is important for prevention of
functional impairment and disability.

FES of Urogenital Mechanisms
(FESUM)—Design of Orthotic Aids
and Special Measuring Systems—
Electronics
Resp. for task: P. Šuhel, D. Sc.,
M. Sc.

The Vagicon-X AMFES stimulator de-
sign and prototype manufacturing is
completed and these stimulators are at
present being evaluated in use. The col-
clected results up to now are promising
for the usefulness of the device for pro-
viding patients home therapy. It is sui-
table in cases of recurrent urge
incontinence.

Up to now the application of clinical
hypersuggestion for the cure of urge in-
continence has proved to be efficient. In
four patients the urodynamical param-
eters have been positively modified after
using hypersuggestion for treatment.

The AMFES stimulator for clinical use,
with complete galvanic stimulation
channel selection and incorporating au-
tomatic programming possibilities is al-
ready developed in a laboratory model.
Following the line of our basic studies
of the urogenital mechanisms by help
of EMG of the urethra and the anal
sphincter, a new measuring system was
developed making use of refined elec-
tronic techniques for obtaining great im-
provement regarding the signal-to-noise
ratio of the measured parameters. Re-
results of these better and more accurate
measuring techniques will be used later
in the development of our microcom-
puter-controlled diagnostic system.

FES of Urogenital Mechanisms:
Physiology, Techniques of
Stimulation, and Methods of
Urodynamic Evaluation
Resp. for task: S. Plevnik, M. Sc.,
J. Janež, M.D., S. Rakovec, M.D.,
D. Sc., P. Vrtačnik, Dipl. Ing.,
L. Ravnik, M.D.

In the first half of the year 1981, the
research in this particular subarea was
directed to treatment of urinary reten-
tion using maximal electrical stimula-
tion and to development and testing of
the new technique of evaluation of uri-
nary incontinence using an electric fluid
bridge test.

Nonimplantable short-term maximal
electrical stimulation (MES) benefited
the patients with upper motor neuron
lesion having urinary retention. In the
preliminary study, treatment with MES
was successful in paraplegics with long-
standing as well as recent lesions who
had not developed reflex bladders, as
well as in paraplegics with longstanding
lesions who had well-developed reflex
bladders and in whom retention oc-
curred afterwards.

An electric fluid bridge test was de-
signed and successfully evaluated. The
new test allows the most simple and re-
liable detection of the opening of the urethra during stress (e.g., a cough) and
thus objective evaluation of inconti-
ience. The introduction of the urine into
the urethra which may occur during
stress is detected as a change in imped-
ance, since the urine has much greater
conductivity (or lower impedance) as
compared with the tissue of the urethral
walls (Fig. 5).

FES of Urogenital Mechanisms—
Studies of Urodynamics and
Evaluation of Orthotic Aids
Resp. for task: L. Ravnik, M.D.,
D. Sc., J. Janež, M.D., S. Plevnik,
M. Sc., P. Vrtačnik, Dipl. Ing.,
S. Rakovec, M.D., D. Sc.

During the first part of the year 1981,
the investigations in this subarea were
devoted to basic research of the effects
of maximal electrical stimulation on the
detrusor muscle in experimental
animals.

The dose response relations for ace-
tylcholine and isoprenaline were deter-
mired on isolated strips of the urinary bladders of six control and seven stimulated rabbits.

Electric pelvic floor stimulation produced increased beta-adrenergic activity in detrusor muscle, while the activity for cholinergic receptors was decreased.

From the method used, it is not possible to draw conclusions about the nature of these changes (increased number of receptors, altered affinity) but it is possible to explain to a certain extent bladder inhibition and long-term effects of electrical stimulation.

Rehabilitation Engineering Center
The Institute for Rehabilitation and Research
1333 Moursund Avenue, Houston, Texas 77030
Thomas A. Krouskop, P.E., Ph. D., Program Director,
Jesse H. Dickson, M.D., Co-Director, and Laura Winfrey

The Texas Rehabilitation Engineering Center in Houston, Texas, continues its efforts to effectively manage and treat the long term effects of pressure on soft tissue which result in pressure sores. It also studies materials for percutaneous implants.

Recognizing that soft tissue breakdown can dramatically disrupt the rehabilitation progress of spinal cord injured individuals, Texas Rehabilitation Engineering Center developed and established the Tissue Pressure Management Clinical Program in 1977 in an effort to alleviate pressure problems for the severely disabled. Located in the Medical Center at The Institute for Rehabilitation and Research (TIRR), the Tissue Pressure Management Clinical Program provides patient-oriented services to the severely disabled through a comprehensive program of clinic, research, and education.

In the clinic, patients are provided with services in which existing or potential problems in tissue breakdown are identified and corrected. Through the cooperative efforts of physicians, therapists, engineers, orthotists, and nurses, patients receive treatment ranging from extremely conservative to the most dynamic. Staff members evaluate patients and their problems to provide immediate solutions such as providing conservative medical treatment to existing sores, positioning recommendations, referral for cushion evaluation, adjustment of body jackets, referral for surgery, etc. If the problem requires more intensive study, staff members confer to determine the best solution e.g., design of a custom pressure-relief device or design and fabrication of special adapted equipment.

The Program allows patients to participate in the evaluation of new diagnostic instrumentation and pressure relief materials. This participation aids the Center in collecting useful data concerning the functional longevity of pressure relief devices and materials, the methods of preventing and treating pressure related tissue breakdown, and the techniques to modify existing materials and devices to render them more capable of relieving pressure.

Rap sessions are offered to patients and their families instructing them in the latest methods of preventing and managing skin problems. Workshops, lectures, and seminars that include information on the prevention and treatment of tissue trauma and breakdown are conducted to train nurses, physicians, therapists, and counselors.

Success of Clinical Program—In a recent Rehabilitation Engineering Center update, data collected during the 5-year period of the Program’s existence were analyzed to determine the success of the Tissue Pressure Management Clinical Program. The statistics indicate that, prior to the Program, patients risked developing a second pressure sore at the recurrence rate of 88 percent. However, since the Program started the recurrence rate of individuals developing a second pressure sore has been reduced to 36 percent. These statistics demonstrate the successful implementation and utilization of a comprehensive, multidisciplinary program that significantly reduces the risk of tissue breakdown.

A Commercial Introduction—Currently the Texas Rehabilitation Engineering Center is working with Palm Beach Medical in Boston, Massachusetts, to introduce commercially and implement the hardware of the Pressure Evaluation Pad (PEP) unit, a cushion life monitor, and the educational/instructional materials to prevent tissue breakdown. Using the Tissue Pressure Management Clinical Program established at the Texas Rehabilitation Engineering Center as a guide, Palm Beach Medical is developing a preventative Tissue Management System which will provide a means for making a comprehensive client evaluation and for prescribing the proper support system and health care regimen to avoid tissue breakdown. This endeavor will make a better comprehensive tissue management program commercially available to hospitals, institutes, and rehabilitation centers concerned with the prevention and treatment of pressure-induced tissue breakdown.

To ensure maximum reliability of patient evaluations using the Pressure Evaluation Pad unit, the Center has completed a second study analyzing the transducer pad made of polyurethane film. Statistics from this study show that the pad introduces a maximum error of less than 10 mm of mercury (usually about 5 mm of mercury) when compared to a single-cell pneumatic-type spot transducer.

The Texas Rehabilitation Engineering Center is also proceeding in the development of materials for improved implant-tissue compatibility. Implant studies using laboratory animals have demonstrated the biocompatibility of such materials as porous vitreous carbon, pyrolytic carbon, and carbon coated titanium buttons with dermal tissue. Preliminary findings on porous vitreous transcutaneous devices show that transcutaneous passage is stable for 4 years. Recent studies suggest that titanium implants induce a more fibrous reaction in subcutaneous tissues. Further studies will determine how large a cannula or tube can be implanted through the skin surface with long term stability.
Rehabilitation Engineering Center  
Northwestern University  
Room 1441  
345 East Superior Street  
Chicago, Illinois 60611  
Clinton L. Compere, M.D., Project Director

ANALYSIS OF RETRIEVED TOTAL JOINT PROSTHESES

Total joint replacement has proved to be a highly successful procedure for the rehabilitation and restoration of persons disabled by severe arthritis. Total joint replacement (TJR) however, is not yet a perfected procedure, particularly for joints other than the hip. Prosthesis design, and surgical procedures used to implant TJRs, continue to evolve to meet perceived current or potential problems. Monitoring and evaluating the usefulness of these changes is difficult because of the lack of data on both frequency and types of TJR failure.

One approach for monitoring TJR performance is the retrieval and examination of removed TJR implants. The study of each retrieval, when coupled with surgical observations at the time of revision surgery, and the clinical history of the patients, can yield detailed information on the in vivo function of the implant and the conditions which led to its ultimate removal.

**Materials**

Over a period of 6 years, 130 prostheses were retrieved, including 75 hips and 52 knees; all were removed for clinical failure. The original participants of the study were six surgeons associated with the Northwestern University Medical School Hospitals. The study was then gradually expanded to encompass eight hospitals in Metropolitan Chicago area with 21 contributing surgeons; no new contributors have been added since 1978. The surgeons agreed to contribute all removed components so that, to the best of our knowledge, all the TJRs removed by these physicians during their participation are included.

Of the 130 prostheses, 61 hips were of the type made up of a metal femoral component and an ultra-high-molecular-weight (UHMW) polyethylene acetabular component. In addition, 44 knees were of the type where 1 or 2 metal femoral components articulate on 1 or 2 UHMW polyethylene tibial components. Results from a close examination of the data on these particular 61 hips and 44 knees are presented (Table 1). The specific prosthesis types are given in Table 2.

Of the 61 hips, 44 (72%) were originally implanted by the participating surgeon, 16 (26%) were referrals, mostly from the Chicago area, and one case was of uncertain origin. Of the 44 knees, 26 (59%) were originally implanted by the participating surgeon and 18 (41%) were referrals.

**Methods**

The study of the removed components included (i) examination of patient medical records, (ii) analytical review of patient roentgenograms, (iii) observations at the time of revision surgery, and (iv) postoperative examination of the removed components. The protocol followed for each patient was that all pertinent medical records and X-rays were reviewed by a member of the project team, usually a biomedical engineer, who, when this was practical, attended removal surgery to record all surgical findings. When possible, the patient was later interviewed to complete the medical history.

Data from all medical records and analyses, summarized on the coding forms, are transferred to magnetic tape for storage and later computer analysis.

**Results and Discussion**

**Cause of Removal**—The most frequent cause of total hip joint revision was idiopathic loosening of one or more of the prosthetic components, Table 3. One third of all the removed hips were so classified. The other major causes of total hip removal were trauma (21%) and sepsis (15%). Iatrogenic factors were re-
sponsible for only 11% of the revisions. By contrast, one third of the total knee revisions were performed for iatrogenically induced reasons. The other major reasons for total knee removal were idiopathic loosening (30%) and trauma (11%).

The knee joint is an anatomically intricate joint, consisting of three separate articulations, multiple constraining ligaments, and complex geometries. The relationships between the multiple knee motions of rotation, antero-posterior sliding and flexion-extension, and knee joint structures are not yet fully understood. Accordingly, knee joint prosthesis design is a somewhat imprecise art with new designs and surgical procedures continually evolving. All these factors are reflected in the high incidence of technical problems leading to total knee revision.

**Time Between Surgery and Revision**

The total time period, grouped by years, for which the prostheses were implanted before removal is plotted in Figure 1 for hips and knees. Both histograms seem to indicate a greater portion of the removals occurred within 3 years after the original arthroplasty. However, if the removal cases which were prejudiced toward early failure at the time of surgery, namely those cases involving early sepsis or technical problems, are eliminated, the rate of total hip removal appears to be approximately constant for at least 8 years. In particular, there is no increasing loosening rate with time.

On the other hand, the incidence of total knee removal remains elevated for the initial 2 or 3 year postoperative time period even after the iatrogenic and early-sepsis cases are removed. Thus, total knee patients may be at increased risk of joint failure during the short-to-intermediate postoperative time period. There were insufficient total knee cases retrieved after long-term use to be able to make any predictions on the long-term survival rates of knees, although no evidence of any upsurge of late loosenings was observed.

Total hip replacement has remained relatively unchanged with regard to overall design concept for the past decade, and substantial numbers of patients have been receiving total hip arthroplasty at least since 1972. Thus, the rate of hip removal is probably not influenced by recent rapid changes in

<table>
<thead>
<tr>
<th>NUMBER OF CASES:</th>
<th>hips</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>knees</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>130</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROSTHESIS TYPE:</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIPS</td>
</tr>
<tr>
<td>Aufranc-Turner</td>
</tr>
<tr>
<td>Charnley</td>
</tr>
<tr>
<td>Charnley-Muller</td>
</tr>
<tr>
<td>T-28</td>
</tr>
<tr>
<td>CAD</td>
</tr>
<tr>
<td>Total Condylar</td>
</tr>
<tr>
<td>UC1</td>
</tr>
<tr>
<td>McKee-Farrar</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KNEES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dup-Patellar</td>
</tr>
<tr>
<td>Geomedic</td>
</tr>
<tr>
<td>Marmor</td>
</tr>
<tr>
<td>Polycentric</td>
</tr>
<tr>
<td>St. Georg Sled</td>
</tr>
<tr>
<td>Total Condylar</td>
</tr>
<tr>
<td>UCI</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

**TABLE 2.**

Types of retrieved prostheses.

<table>
<thead>
<tr>
<th>PRIMARY PREOPERATIVE INDICATION FOR REMOVAL OF TJR:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hips</td>
</tr>
<tr>
<td>Number</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>loosening with pain</td>
</tr>
<tr>
<td>pain only</td>
</tr>
<tr>
<td>sepsis</td>
</tr>
<tr>
<td>dislocation/subluxation</td>
</tr>
<tr>
<td>bone fracture</td>
</tr>
<tr>
<td>prosthesis fracture</td>
</tr>
<tr>
<td>other</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

<p>| KNEES                                         |</p>
<table>
<thead>
<tr>
<th>Number</th>
<th>Percent</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>loosening with pain</td>
<td>20</td>
<td>45%</td>
<td></td>
</tr>
<tr>
<td>pain only</td>
<td>12</td>
<td>27%</td>
<td></td>
</tr>
<tr>
<td>sepsis</td>
<td>4</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>dislocation/subluxation</td>
<td>5</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>bone fracture</td>
<td>1</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>prosthesis fracture</td>
<td>1</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>1</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**REVISION PROCEDURE:**

<p>| Hips                                          |</p>
<table>
<thead>
<tr>
<th>Number</th>
<th>Percent</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>replace component</td>
<td>34</td>
<td>56%</td>
<td>14</td>
</tr>
<tr>
<td>new prosthesis</td>
<td>17</td>
<td>28%</td>
<td>21</td>
</tr>
<tr>
<td>suction-irrigation</td>
<td>6</td>
<td>10%</td>
<td>3</td>
</tr>
<tr>
<td>pseudo-arthritis</td>
<td>3</td>
<td>5%</td>
<td>0</td>
</tr>
<tr>
<td>arthrodes</td>
<td>0</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>other</td>
<td>1</td>
<td>2%</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>61</td>
<td>44</td>
<td></td>
</tr>
</tbody>
</table>

<p>| KNEES                                         |</p>
<table>
<thead>
<tr>
<th>Number</th>
<th>Percent</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>replace component</td>
<td>14</td>
<td>32%</td>
<td></td>
</tr>
<tr>
<td>new prosthesis</td>
<td>21</td>
<td>48%</td>
<td></td>
</tr>
<tr>
<td>suction-irrigation</td>
<td>3</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>pseudo-arthritis</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>arthrodes</td>
<td>5</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>1</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SUMMARY, REASONS FOR TJR REMOVAL:**

<p>| Hips                                          |</p>
<table>
<thead>
<tr>
<th>Number</th>
<th>Percent</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>iatrogenic</td>
<td>7</td>
<td>11%</td>
<td>14</td>
</tr>
<tr>
<td>sepsis-early</td>
<td>4</td>
<td>7%</td>
<td>2</td>
</tr>
<tr>
<td>sepsis-late</td>
<td>5</td>
<td>9%</td>
<td>1</td>
</tr>
<tr>
<td>trauma</td>
<td>13</td>
<td>21%</td>
<td>5</td>
</tr>
<tr>
<td>idiopathic loosening</td>
<td>20</td>
<td>33%</td>
<td>13</td>
</tr>
<tr>
<td>prosthesis fracture</td>
<td>6</td>
<td>10%</td>
<td>1</td>
</tr>
<tr>
<td>pain only</td>
<td>2</td>
<td>3%</td>
<td>3</td>
</tr>
<tr>
<td>other</td>
<td>3</td>
<td>5%</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>61</td>
<td>44</td>
<td></td>
</tr>
</tbody>
</table>

<p>| KNEES                                         |</p>
<table>
<thead>
<tr>
<th>Number</th>
<th>Percent</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>iatrogenic</td>
<td>14</td>
<td>32%</td>
<td></td>
</tr>
<tr>
<td>sepsis-early</td>
<td>2</td>
<td>5%</td>
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<tr>
<td>sepsis-late</td>
<td>1</td>
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</tr>
<tr>
<td>trauma</td>
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<td>11%</td>
<td></td>
</tr>
<tr>
<td>idiopathic loosening</td>
<td>13</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>prosthesis fracture</td>
<td>1</td>
<td>2%</td>
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</tr>
<tr>
<td>pain only</td>
<td>3</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>5</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 2 early sepsis listed as iatrogenic
** 1 prosthesis fracture listed under trauma
*** 3 prosthesis fractures listed under idiopathic loosening

**TABLE 3.**

Summary clinical data for retrieval patients.
the total hip population. However, the number of patients receiving total knee replacement has been rising in recent years. The lack of long-term total knee data is, in part, a reflection of the relatively few patients with total knee arthroplasties of long duration.

**Loosened Interface and Loosening Etiology**—The loosened interface varied with prosthetic component. Since this observation may be important in understanding the etiology of the failure process, the nature of the failed interfaces were recorded. Interface failure was classed as one of three: (i) bone-cement interface only, (ii) cement-component interface only, and (iii) at both interfaces. The results are shown in Table 4.

A significant observation from these data is that all (29/29) loose total hip femoral components were loose at the cement-component interface. This finding is at odds with the data for the other three components which were loose more frequently at the bone-cement interface and less often at the cement-component interface. The most frequently observed failed interface might be expected to be the one which failed first. If failure occurred first at the bone-cement interface, which in turn led to cement-component interface failure, a significant number of failures only at the bone-cement interface should be seen.

The implication of this observation is that the hip stems are failing first at the cement-component interface and that this is the weak element in the system. This implication does not have direct data to support it; other processes are possible. However, it agrees with other studies which show that failure of this interface leads to high PMMA cement stresses, implying subsequent PMMA cement fracture and bone-cement interface failure. This observation also supports the need for more research on this interface regarding failure processes and prosthesis design.

Another observation from this data is that the metal femoral components of the knee rarely loosen, and that when they do (or when a firmly fixed component is removed) the PMMA cement is firmly fixed to the component and there is no PMMA fracture. This observation implies that if the PMMA cement remains fixed to the metal, there will be no cement fracture.
The converse is observed with the UHMW polyethylene components, i.e., the acetabular cups and the knee tibial components. Although there were several cases where only the bone-cement interface failed, the more frequent observation in these cases was failure at both interfaces with pieces of PMMA cement remaining firmly fixed to both bone and component. This situation implies cement fracture without total failure of cement-component interface and perhaps even without total failure of the bone-cement interface. Thus, either failure of the bone-cement interface or cement fracture is more likely to be the initial factor in the loosening process in these cases.

Summary

Our implant retrieval program has the inherent problems of a retrospective study and data collection from multiple institutions. Results of high statistical significance are difficult to obtain. Also, retrieval studies cannot give absolute failure rates, since the patient population from which the sample is drawn is unknown, but TJR failure modes and their relative rate can be determined. Finally, not all implants which may be classified as clinical failures come to removal so that retrieval studies do not monitor all failure modalities.

Nevertheless, retrieval analysis provides an efficient means of obtaining detailed information on the in vivo behavior of implants, particularly the failed implants, which are of greatest interest, and is a good means of monitoring and evaluating the failure modes of TJRs in use.

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P.O. Box 3368, University Station
Charlottesville, Virginia 22903

Warren G. Stamp, M.D., D. Sc., and Colin A. McLaurin, D. Sc., PE.

MOBILITY RESEARCH

Wheelchair Propulsion Studies

Task leaders, Clifford E. Brubaker, Ph. D., Gregory B. Shasby, Ph. D.

The task objective is to determine the conditions for optimum efficiency and effectiveness of wheelchair propulsion for the various populations using wheelchairs. These include type of propulsion system (lever, rim, crank), position of system interface relative to size, and proportion of users. Limitations including the effects on maneuverability posed by the various propulsion systems for different populations are also considered.

A static lever device will be used to study the interplay of lever length and spinal lesion level on isometric lever-pushing at each of a range of positions. The incorporation of the EMG telemetry equipment, recently acquired, will offer evaluation of muscle function and thereby provide useful information with regard to the variation in prime movers as a function of lever length, arc length, and lesion level. Next will be a study of the effects of hand supination and pronation on predicted propulsive power, as well as the effect of lever shape. In the latter case, the current data should give an indication of an optimal lateral distance between lever handgrips. Plainly, the lateral distance between the handles and the lateral distance between the lever mounting points on the drive mechanism need not be the same. The levers could be bent either towards or away from the mid-sagittal plane. Thus, it will be necessary to assess what effect various bent positions might have, first in terms of isometric lever pushing, and then in terms of dynamic activity.

Once the static tests have reached fruition and the results have been incorporated into a lever drive design, dynamic testing will be launched. These studies will center on the evaluation of metabolic efficiency. Incorporated into these studies will be the EMG telemetry system and a motion analysis system. These two devices, operating simultaneously under microcomputer control, should provide biomedical analyses previously unavailable for wheelchair propulsion.

Microcomputer-Based Paper Transport Mechanism

Task leader, James H. Aylor, Ph. D.

The purpose of this project was to design a system capable of aiding the handicapped programmer in handling large amounts of computer printout. Specifically, a low-cost system of hardware and software was developed to provide for moving the printout back and forth between critical locations, while requiring that the only user input be through a mouthstick-operated keyboard. A prototype was built and is being evaluated. No future work is planned on this project, but we feel that the overall scheme applied to the paper handler could very well be extended to book page-turners in the future.

Electric Wheelchair Control System

Task leader, James H. Aylor, Ph. D.

The objective of this project was to develop an electronic controller for an electric wheelchair with the central element of the controller being a commercially available microcomputer. The principal advantages of using a microcomputer were (i) reduction in the number of components required, and (ii) the extensive flexibility that was provided by the resulting system. Also investigated is the application of digital transducers to the design of joysticks for wheelchairs. The advantages of this aspect of the project are (i) that digital transducers are normally wear-free, and (ii) the normally required analog-to-digital conversion process for the microcomputer may now be eliminated.

A very flexible wheelchair controller has been developed and future research will be geared towards utilizing the full
potential of this controller. Automatic battery monitoring is already being investigated, as is the potential of sophisticated automatic guidance and automatic collision-avoidance techniques.

One problem that will need to be investigated in future research is that of fault detection and fault tolerance of the microcomputer systems.

Electric Wheel

Task leader, J.J. Kauzlarich, Ph. D.

The objective is to design an electric motor, transmission, and brake to fit in the hub of a powered wheelchair wheel. One of the goals is higher efficiency through the use of a new type of disk motor.

All of the tests so far show that the electrical wheel of the Mark I design meets the design specifications and demonstrates the advantages for the design. A Mark II design has been considered which will significantly reduce the costs of the motor. Assuming success with the Mark I design, and demonstrated interest by the wheelchair community, we plan to consider implementing the Mark II design.

Due to the cost of the SmCo$_3$ permanent magnet material, which has been severely affected by the rising price of cobalt, it would be most beneficial to pursue a Mark II version of the electric wheel motor that has a smaller volume of magnet material. This will happen if the motor can operate at a higher speed. The proposal is based on using a gyroratory gearbox with a ratio of 22:1 plus a 4:1 epicyclic input stage, at a motor speed of 10,720 rev/min. The epicyclic unit is needed because, although a gyroratory unit alone could provide a ratio of 88:1, it could not tolerate this high an input speed.

The overall weight is considerably reduced, the permanent magnet volume is 28% of the Mark I value, and the armature resistance is reduced to 22% of the Mark I design. A similar reduction in the FR power loss is anticipated.

Wheelchair Dynamics

Task leader, John G. Thacker, Ph. D.

This study involves the collection of information on the forces influencing wheelchair motion and power requirements.

The intent of this work is to predict the power and torque necessary to propel a manual chair over a particular surface at varying velocities. Torque and power are mainly influenced by the type of wheels used on the wheelchair. Once the simple wheel/surface rolling resistance equations are modeled, more generalized situations such as power/torque necessary to negotiate building ramp entrances and to cross streets can be simulated on a computer to optimize patient utilization.

Three different types of drive wheels will be evaluated over four surfaces: (i) Solid tires (spoked wheels), (ii) Pneumatic tires (spoked wheels), and (iii) Solid tires (magnesium wheels).

The surfaces to be investigated will include concrete, tile, pile carpet and shag carpet. The pneumatic tire pressure will be varied at 70, 50, 30 and 20 psig. The speed ranges will vary from 0 to 6 km/min. The patient weight to be added to the chair weight will range from 400 to 1,000 N over 200-N increments. The chair frame and front casters will remain constant throughout the test. The alignment of the wheels will be monitored and corrected if necessary.

A second study will be performed on the front caster wheels. Pneumatic and solid tires will be studied, with the rear wheels remaining constant. An in-depth study and comparison of all data will be made.

Also a study is being made on the dynamics of wheelchairs with soft suspension systems. The two important elements that are being studied during this analysis are ride quality and propulsion efficiency.

Design parameters will be optimized and centered on propulsion efficiency and ride comfort. A computer-based analysis will be performed and critical chair parameters will be indicated.

Wheelchair Design

Task leader, Colin A. McLaurin, Sc. D.

The objective is to develop, construct, and demonstrate design concepts for wheelchairs. Promising designs are pursued through various changes and prototypes until significant advantages can be shown. It is then hoped that they can be made commercially available by working in cooperation with manufacturers. Four specific design problems are under investigation, the center of gravity wheelchair (grasshopper), the airchair, a lever propulsion system, and the beach wheelchair.

Wheelchair design will become an increasingly active part of the University of Virginia program, working closely with industry. Specific activities are planned as follows:

1. NASA Langley cooperation project. A cooperation project with NASA Langley is in the planning stage. The computer analysis methods and the composite materials experience of NASA and Hercules Corp. will be utilized in developing stronger, lighter wheelchairs. As an initial step, the airchair will be used as an example with manufacturing as the realistic goal. If this indicates the effectiveness of a cooperative program, then the process will be applied to a wheelchair design for the major market, possibly using the grasshopper or some other innovative configuration.

2. Sidewinder. Kinetic Concepts, of San Antonio, Texas have acquired the North American rights to the Swedish wheel concept that allows a wheelchair to move in any direction. The design is based on four independently powered wheels each with eight free-turning rollers set at 45 degrees around the rim of the wheel. Discussions are now under way to formalize a plan whereby the University of Virginia Rehabilitation Engineering Center will work with Kinetic Concepts in the design, development, and evaluation of a wheelchair embodying this concept.

3. Grasshopper. This chassis configuration appears to be meeting the major design requirements. The next step is to build a folding model, based on sketches that have already been made. When the model(s) are satisfactorily made, user testing will be initiated. Further concepts have been considered whereby the weight distribution will be automatically changed to optimize curb climbing without sacrificing level ground traction and performance. Working models of this concept will be made for testing.

4. Lever Drive. The present model will be completed and mounted on a wheelchair for testing. Further development will be based on the results.

5. Beach Wheelchair. Development of this item will continue to decrease the cost and enhance performance and durability. When levers are available (see 4 above) these will be tried.

6. Dynamic Brake. Hub brakes, based
on Sturmey Archer bicycle brakes, will be fabricated to test the concept.

SPINAL RESEARCH

Spinal Cord Monitoring
Task leader, Steven I. Reger, Ph. D.

The objective has been to develop the equipment and techniques for monitoring the electrical activity in the spinal cord. Spinal evoked responses will be used in the operating room and in clinics to show changes with spinal cord obstruction and other trauma.

Work has begun to assemble, test and begin to operate the spinal cord monitoring instruments for intraoperative use at the University of Virginia Hospital. Work will continue to quantitatively describe the effect of spinal cord contusion, compression, cooling and nerve root block on the evoked responses in the cat.

Spinal Stabilization
Task leader, Gwo-Jaw Wang, M.D.

This project has presently emphasized static flexion tests of canine cervical spines. Our ultimate objective is to conduct mechanical load tests on reconstructed cadaver cervical spines. Before testing cadaver specimens (of limited availability), this research will focus on other facets of spinal stability in order to converge on the critical aspects of spinal stability. To that end, we propose to:

1. Improve our data collection and recording techniques by developing an online capability of recording and displaying the data from the mechanical load tests.
2. Examine the fatigue capability of the constructs (simulate one year of a patient flexing his neck) to determine if cyclic stress on the various constructs produces a different pattern of relative strengths from those recorded from static tests.
3. Continue static tension tests on the wire loops used in some of the fixation procedures to obtain baseline data concerned with the metal grade and size of wire used as well as the strength of the wire-tying procedures.
4. Possibly examine the feasibility of using other metals (i.e. age-hardening coated aluminum that would be kept in a very pliable state during surgery but which achieves a doubling or tripling of strength after a few hours of "aging") or other non-metallic materials as competitors to the present stainless steel and Vitallium wires used in assembling a construct.

COMMUNITY RESEARCH

Community Engineering Program
Task leader, Ronald C. Gordon

Note: This task is primarily supported by grants from the Commonwealth of Virginia's Governor's Employment and Training Council, Employment Commission (CEA Division), and Developmental Disability Unit.

In the Spring of 1979, the Community Engineering Program (CEP) was established to design, establish and optimize a demonstration rehabilitation engineering system at the community level. It was proposed that the engineering technology services be offered through local organizations. It was envisioned that once the program was established, continuous re-evaluation and research would optimize the model system for increased positive impact, minimum cost, and efficiency of operation.

The identification of the disabled population and the needs assessment study in the target community is expected to be completed in fiscal year 1981. After completion of the study, the registry of the population will be maintained and updated so that it will be available for future research.

Small pilot service projects will continue to be operated in fiscal year 1981-82 contingent on availability of funding sponsors. The purpose of these pilots will be to develop procedures for assessing needs of individuals for engineering technology and acquiring data on potential community and agency support structures for the handicapped.

EDUCATION AND PRACTICE

Rehabilitation Engineering Education
Task leader, John G. Thacker, Ph. D.

Note: This task is funded separately by a grant from NIH to the Department of Mechanical and Aerospace Engineering.

Formal educational programs have been developed in rehabilitation engineering for both engineers and persons from other disciplines involved in rehabilitation engineering activities.

The objectives of the present dual-track 5-year graduate traineeship program at the University of Virginia is to attract and train a minimum of 35 students with engineering and clinical science backgrounds in the general field of rehabilitation engineering. Particular emphasis will be placed on practical training through internship activities at the University of Virginia Rehabilitation Engineering Center. Field experience is available at the Woodrow Wilson Rehabilitation Center and the University of Virginia Children's Rehabilitation Center.

Students participating in the program will complete a 2-year program of study organized to provide sufficient engineering and clinical background necessary to permit graduates to enter employment in the field of rehabilitation engineering. Students will take existing graduate courses offered by the Department of Mechanical and Aerospace Engineering, Electrical Engineering, and Biomedical Engineering in the School of Engineering and Applied Science. Internship and thesis activities will be conducted through the Rehabilitation Engineering Center. Graduates of the program will obtain a Master of Science or Master of Engineering degree in one of the engineering fields, with emphasis on biomechanics and rehabilitation engineering.

Rehabilitation Engineering Practice
Task leader, James R. O'Reagan, M.S.

Rehabilitation Engineering Practice serves as a mechanism by which Rehabilitation Engineering graduate students participate in clinical practice. This endeavor provides customized engineering for rehabilitation needs for the physically disabled and serves as a nucleus for a comprehensive rehabilitation engineering service program on a fee-for-service basis.

During the summer months, the graduate engineering students were involved in approximately 23 client cases. Under the supervision of a staff engineer, the students participated in problem solving whether it was report consultations or device fabrication and subsequent fitting. The approach to this effort took the commonly used ap-
approach that commercially available equipment was recommended whenever possible as the first course of action. The second choice was to modify a commercially available item and, if neither one of these choices were available, design and fabricate a custom device.

Rehabilitation Engineering Practice has established a fee for rehabilitation engineering consultations, and design and fabrications in the areas of seating, mobility, communications, daily living, school and job applications, home modifications, and medical devices. This direct service to clients will continue to keep the REC staff in touch with the disabled and their specific needs.

EVALUATION

Battery Testing
Task leader, J.J. Kauzlarich, Ph. D.

The objective is to clinically evaluate standard demand cycles for electric wheelchairs and to test batteries designed for powered wheelchairs.

An electric wheelchair has been instrumented with a recording wattmeter, inclinometer (grade meter), and tachometer, and has been operated over a number of typical days of use to establish simulated demand cycles. The simulated demand cycles are played back through a pulse-width-modulated wheelchair type controller into a suitable load. The discharge and charge cycle are monitored to establish battery performance.

Foam Block Seating
Task leader, Colin McLaurin, Sc. D.

The objective is to clinically evaluate the foam block seating from Tumble Forms. This design originated with UVa REC; but all fabrication and product development is now undertaken by Tumble Forms who will eventually manufacture and market the product if the evaluation proves to be positive.

Staircat Evaluation
Task leader, Colin McLaurin, Sc. D.

Since July 1979, a multidisciplinary team has been conducting a 1-year evaluation of the Staircat Mark IV Prototype Wheelchair, a stair-climbing wheelchair produced by Staircat Incorporated of Nashua, New Hampshire. The Staircat Wheelchair was designed primarily to be used by paraplegics to overcome their inability to climb stairs both within and without their living environment.

The purpose of the investigation has been to evaluate the wheelchair's suitability both as a stair climber and as a standard wheelchair—from functional, safety, and acceptance point-of-view. The ultimate goal was to collect mechanical and metabolic efficiency data, performance data, and paraplegic user impressions.

The Staircat Mark IV prototype was found to be somewhat mechanically and metabolically inefficient, unreliable in its stair-climbing performance, and questionable as a standard wheelchair. If the Staircat can overcome its deficiencies it will attract a potential market of consumers who desire a second wheelchair that can climb stairs.

Orthoses
Task leader, Steven I. Reger, Ph. D.

A simple adjustable orthosis to prevent (or help correct) contractures at the elbow has been designed and prototypes fabricated in three sizes for use by therapists.

The usefulness of the elbow extension brace is now being evaluated by the Occupational Therapy Departments at Rehabilitation Institute of Chicago, Harmerville Rehabilitation Center (Pittsburgh), and Craig Hospital (Denver).

Powered Chair Performance Testing
Task leader, J.J. Kauzlarich, Ph. D.

The objectives for this task are to establish performance criteria for powered wheelchairs.

A set of standard tests to determine the operating characteristics of powered wheelchairs will be established. These tests will determine electrical efficiency, rolling resistance, turning radius, etc. A wheelchair route will be used to determine subjective performance characteristics such as stability, braking, holding, ease of control, etc. A variety of terrain will be used to determine such things as control on wet grass, sand, etc.

Laboratory measurements of powered wheelchair performance are conducted on a slider bed conveyor (treadmill) specially designed and constructed by Yankee Engineering Co., Inc. of Baltimore, Maryland, under Rehabilitation Engineering Center supervision.

The treadmill was placed in operation during September, 1980, and initial testing of the first powered chair with a 200 lb. load has been highly satisfactory. So far, studies have been carried out on (i) rolling resistance, (ii) castered wheel flutter, and (iii) effect of a bump on ride acceleration and shock with and without a seat cushion. Future studies will include (i) range per battery charge, (ii) overall efficiency, (iii) speed under load, and (iv) stall thrust.

Future plans involve testing the available powered wheelchairs for rolling resistance, efficiency, speed, etc. Also, the test procedures will be modified and refined toward simplicity and reproducibility.

Access to the Skies
Task leader, Colin A. McLaurin, Sc. D.

In response to government regulations concerning accessibility for the disabled, the airlines and the aircraft manufacturers are examining various means for conveying disabled persons into aircraft and, while on board, providing access to lavatories. The “Access to the Skies” program is headed by Rehabilitation International and TARC 218-2, a committee of aircraft manufacturers appointed for this purpose. A technical advisory committee, with Colin McLaurin as chairman and including engineering and rehabilitation experts from several countries, reports to both these groups. The role of the University of Virginia Rehabilitation Engineering Center is to introduce new concepts in wheelchair design and to formulate and to assist in evaluation procedures.

The University of Virginia wheelchair and sliding toilet seat are currently being evaluated at Boeing in a mock-up of their new 767.

Complete details of the aforementioned projects are available from this REC.
A Proportional Speed
Pneumatic (Breath) Control System for Powered Wheelchairs with Automatic (Closed Loop) Speed Control (New Research)

An automatic (closed loop) speed control compatible with the IRM pneumatic (breath) proportional speed control for powered wheelchairs has been developed. The system enables a severely disabled user to vary the speed of the chair over its entire range, and to maintain any speed while travelling up or down sloping terrain. The system is adaptable to all powered wheelchairs utilizing permanent magnet motors. The rotary speed signal to the feedback loop is produced by Hall effect sensors. No mechanical linkage is required between the rotating drive wheel and the sensor. See Figures 1 and 2.

Vocational Rehabilitation of the Severely Disabled: Voice Controlled Computer Programming (New Research)
G. Markowsky, IBM Watson Research Center, M. Youdin, T. Reich, NYU Medical Center

Speech recognition technology has developed to the point where many activities can be controlled by voice. In recent years, this technology has been used to help the disabled achieve better control of their environment. A prototype voice-controlled programming system has been developed to make programming easier for the severely handicapped. The system is now undergoing clinical evaluation. See Figure 3.

Evaluation of Electronic Self-Help Devices for Use by Severely Disabled Persons
Ruth Dickey, M.A., O.T.R.

The purpose of this project, begun in October 1974, is to conduct comprehensive clinical evaluation of selected commercially available electronic assistive devices on a long-term basis, in order to determine their usefulness for diag-
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Charles H. Herndon, M.D., Project Director

The activities of the Rehabilitation Engineering Center at Case Western Reserve University are directed toward restoration of function in patients with mobility disorders. Studies are directed toward development of a program for evaluation of the control of movement and restoration of upper extremity function involving tendon transfer, functional electrical stimulation, sensory augmentation, and command control signal generation. Mobility studies include development of control sources for powered wheelchairs, and evaluation of the therapeutic effects of functional electrical stimulation in gait.

1. Restoration of Upper Extremity Function through Functional Electrical Stimulation

Principal Investigators:
R. Hunter Peckham, Ph. D.
Alvin A. Freehafer, M.D.
Michael W. Keith, M.D.

These studies are the core area of research in the center. The purpose of the project is to develop and evaluate systems employing functional electrical stimulation to provide control of hand movement. Eight quadriplegic subjects with C-5 or C-6 level motor function continue to be involved in outpatient evaluation of these systems. These studies are being performed in conjunction with the VA Rehabilitative Engineering R & D program, and the current status is detailed elsewhere in the Bulletin (See “Development of Upper-Limb Orthoses Employing Electrical Stimulation” under VA RER&D Service Programs).

2. Restoration of Upper Extremity Function through Tendon Transfer

Principal Investigators:
P. Hunter Peckham, Ph. D.
Alvin A. Freehafer, M.D.
Michael W. Keith, M.D.

Tendon transfer provides a viable means of restoring motor control to paralyzed limbs. The purpose of this study is to investigate techniques for improving upper-extremity function in spinal cord injury patients through the use of tendon transfers. We are presently monitoring function of the transferred muscle during surgery to establish proper functioning of the transferred muscle tendon unit, and monitoring changes in the activity patterns of the muscle following the transfer.

Intraoperative monitoring of muscle properties. The intraoperative monitoring of muscle properties is an ongoing project. The purpose of this project is to evaluate the available excursion and length-tension properties of the muscle-tendon during tendon transfer surgery. The methodology was reported in BPR 10-35. These tests were performed on 73 muscles in 46 subjects.

The results of the excursion studies were reported in the previous report.

The length-tension characteristics of a muscle showed differences from subject to subject and from muscle to muscle. The brachioradialis muscle usually was measured after soft tissue dissection. This muscle showed active properties which were generally quite flat over a 15 mm length centered approximately 5 mm longer than the reference marker. (The reference marker is the point of tendon cut, and is described in the methodology).

The pronator teres muscle showed length-tension characteristics similar to the brachioradialis. Six of seven muscles demonstrated flat active properties over at least a 10 mm length.

The flexor carpi radialis muscle showed a more peaked length-tension curve. In three of five muscles studied, there was a peak at the reference point, and in one muscle at 5 mm longer than that point.

The extensor carpi radialis longus muscle was similar to the FCR. Each of four muscles had a peak active force curve, with three muscles peaked at 5 mm longer than the reference length and one peaked at the reference point.

The posterior head of deltoid showed generally quite flat active force characteristics. A slight peak occurred at 15 mm beyond the reference length or longer in four of eight muscles, at 20 mm or longer in three muscles, and 5 mm in one muscle.

The following procedure is used to establish the correct muscle length at surgery. It incorporated the results of the excursion and length-tension measurements as determined intraoperatively.
The required excursion is measured by moving all joints across which the transfer will act through the full range of motion. Secondly, the available amplitude of the motoring muscles is measured. The decision for the pairing of motor and insertion is then based on providing sufficient excursion for the required function(s). Other factors, such as synergistic activity patterns and mechanical linkages, may be important in this decision as well. The appropriate length is determined by the length-tension characteristics. The arm and hand are placed in the posture at which maximal force is required, and the length of the motoring muscle is set at the length of peak active force. If the active characteristics are flat, approximately mid-range of the flat portion is used.

The technique of electrical stimulation of the muscle provides a measure of confidence of the function of the transfer. Following tendon transfer and suture, a low level of stimulation was delivered to the muscle to observe the movement of the joints. If appropriate movement was not obtained, then adjustments were made before final closure. This technique, combined with traditional passive ranging of the joints, provided a simple, effective method for evaluating the function of the transferred unit.

Postoperative changes in activity of transferred muscles. The objective of this project is to assess changes in the myoelectric activity of muscles which have undergone tendon transfer, in order to establish more rigid criteria for specification of muscles to be used in transfer.

Experiments are under way to test the hypothesis that muscles do not change their phasic activity following tendon transfer, but that individual control of the muscle can be achieved by conscious effort provided that antagonistic function is provided.

Three different tendon transfers are being studied in spinal cord injury patients. They are transfer of the posterior head of deltoid to provide elbow extension, and transfer of the brachioradialis and pronator teres to provide finger flexion or thumb opposition. These transfers are those most commonly performed in our center for restoring upper-extremity control in C-6 quadriplegic patients. Under static conditions, measurements are made of joint position, contractile strength (pinch or elbow extension), and myoelectric activity of the principal muscle under study and its synergists and antagonists.

Through these studies, we expect to be able to determine (i) the ability of a muscle to assume a new function and the conditions required, (ii) at what point the new function appears, and (iii) whether or not the transfer functions in an automatic sense.

3. Evaluation of Abnormal Motor Control

Principal Investigators:
Patrick E. Crago, Ph.D.
George H. Thompson, M.D.

This project is a study of the control of movement with the objectives of characterizing normal and abnormal mechanisms of motor control, and to use this characterization to develop improved methods of evaluation and diagnosis of movement disorders. Subjects are mostly cerebral palsy patients, and for comparison purposes, normals.

One of the most productive methods of evaluating motor function is to measure the mechanical and electromyographic (EMG) responses to externally applied loads. If torque loads are applied at a joint, the rotation magnitude and time course are determined by: (i) the mechanical properties of the muscle fibers that are active prior to the load change; (ii) the reflexively induced changes in muscle activation; and (iii) the voluntary changes in activation that the subject produces in reaction to the load. Other fixed parameters such as the initial torque and angle, and the disturbance magnitude and time course also affect the response.

A comprehensive study has begun of these dependencies both in patients with movement disorders and in normal subjects.

In order to obtain reproducible measures of motor function, it is imperative to control these parameters, and to know exactly how they influence the results. A comparative study can only be carried out when these factors are understood and controlled.

Work began this year on establishing a data base for responses to load change in the flexor pollicis longus muscle. This muscle was chosen because it is the only flexor acting across the interphalangeal joint of the thumb. The dependence of responses on the amplitude of a torque disturbance and the initial values of torque and angle are presently being studied. Torque, angle, and EMG are recorded as a function of time—before, during, and after a torque disturbance.

The change in angle elicited by a step torque disturbance was also steplike, with the majority of change taking place before any reflex was detectable in the EMG response. Position and EMG became stable after approximately 250 msec.

For fixed values of initial torque and angle, the magnitude of the steady-state angular change increased more than proportionally with the torque disturbance. Thus, the incremental stiffness (defined as the amplitude of the disturbance divided by the change in angle) decreased as the amplitude of the disturbance increased. The greatest effects were seen with angular changes less than one degree.

Steady-state stiffness was measured as initial torque was varied with a constant amplitude disturbance. For torque less than approximately 15 N-Cm, stiffness was nearly proportional to initial torque. For larger torques, stiffness increased less than proportionally.

Major emphasis in the next year will be placed on expanding the data base for both normal subjects and patients with movement disorders.

4. Command Controller Development and Evaluation

Principal Investigators:
Dennis D. Roscoe, Ph.D.
Michael W. Keith, M.D.

Work is proceeding on a multichannel command system which provides proportional control signals for functional electrical stimulation systems or powered prostheses. The system consists of two subsystems: an implantable electrode array in conjunction with a telemetry device, and a receiver/myoproessor unit. Designs are being reviewed for the telemetry device with consideration being given to a device completely RF powered and to one with a rechargeable battery source. The telemetry will consist of four channels of EMG signals with a bandwidth of 400 Hz per channel.

Electrode array configurations will be evaluated in an animal model (1) within the next several months. Basically, the
array will consist of stainless steel electrodes embedded in a thin Silastic sheet sutured to the control muscle. In quadriplegic patients, arrays will be placed over the upper and lower portions of the trapezius muscle, and in amputees, over the appropriate residual stump musculature.

A single-channel myoprocessor (2) has been implemented with a laboratory digital computer and its performance is presently being evaluated. A multichannel version is concurrently being developed. The real-time bandwidth of the single channel system is 660 Hz and 560 Hz for the projected four-channel system. Once the myoprocessor design is finalized, a microprocessor-based unit will be developed for outpatient usage.

A joint endeavor has been initiated with a leading wheelchair manufacturer to develop commercially our two-axis proportional position transducer described in previous reports (BPR 10-33 and 10-34). A universal controller scheme is being considered which engages the fundamental design of the position transducer into a hand, chin or shoulder controller. This scheme has the obvious advantage of providing patients with a variety of powered wheelchair controlling techniques to best suit their handicap, while simplifying the interface problem between controller and wheelchair electronics. A powered wheelchair will be modified to be used to evaluate the universal control scheme.

References

5. Sensory Substitution Using Electrocortaneous Stimulation

Principal Investigators:
Ronald R. Riso, Ph. D.
John T. Makley, M.D.

Studies are in progress to develop feedback devices which will provide patients having asensory hands (or prosthetic hands) with an awareness of the extent of their hand opening and the amount of prehensile force applied to a grasped object.

Electrical stimulation of the skin has been demonstrated by others to be an effective means for providing a variety of information to sensory-impaired individuals. An initial coding which is being evaluated is as follows: the spatial extent of hand opening is represented by the relative separation of two simultaneously activated electrodes from a linear array of 6 electrodes mounted along the skin of the upper arm on the same body side as the sensory-impaired limb or prosthesis. The amount of prehensile force developed is signaled to the patient by modulating the burst-repetition rate of the electrical stimuli of the activated electrodes.

Concentric surface mounted electrodes, and subdermal fine wire electrodes are being investigated. The former would be utilized when an externally worn hand prosthesis is employed. The latter are being studied to serve patients whose natural hands will be instrumented for sensory augmentation, with the long-range goal of developing totally implantable sensory feedback systems.

In order to evaluate objectively the performance of the sensory feedback coding scheme and electrode displays, computer generated tracking tasks, similar to those suggested by Szeto et al. (1979), are being utilized. Because these studies have only recently begun, no results are reportable at this time.

Reference

6. Control of Abnormal Muscle Contractions

Principal Investigators:
Ronald R. Riso, Ph. D.
John T. Makley, M.D.

The objective of these studies is to assess the effects of functional electrical stimulation (FES) of muscles on neuromuscular control. As a model, the effects of stimulation of the ankle dorsiflexors in hemiplegic or diplegic cerebral palsy children having either dropfoot or spastic ankle extensors are being studied. A few other children having these same motor disorders, but whose brain damage occurred in later childhood, are also being studied.

Clinical gait analysis, including foot-to-floor contact patterns, ankle joint goniometry and dynamic electromyography of the ankle flexor and extensor muscles is being employed to determine; (i) to what extent the dorsiflexion produced during the period of application of the FES continues after the stimulation is turned off and (ii) whether ankle extensor hyperactivity can be diminished by the periodic application of FES to the ankle flexor muscles. Evaluations for "carry-over" effects after short-term use of FES are performed immediately after the FES has been applied to the peroneal nerve for 20 minutes. Effects due to chronic treatment using FES are evaluated after 2 weeks use of the FES, and then at monthly intervals thereafter.

For all of the eight patients who have been tested several times for short-term usage effects, the dorsiflexion and evasion of the foot concomitant to the electrical stimulation was not sustained with the stimulator turned off.

Seven patients have been evaluated after being given daily FES for at least 5 months to more than 1 year with the following results: (i) no consistent changes in the patient's gait performance could be demonstrated for five of these patients; (ii) a very favorable therapeutic effect has been unequivocally demonstrated for one hemiplegic child whose abnormal toe-first stance was converted to a normal heel-strike-first stance; (iii) for one diplegic child who previously walked exclusively on his toes, heel contact during walking could be observed after several months use of the FES.

Additional patients will be evaluated in the future to establish the incidence of therapeutic effects that may be expected to occur in a given population of patients.

The scope of the investigation will also be increased to include a different class of patients who walk with crouched gait due to excessive hamstring activity. For these patients, electrical stimulation will be applied to their quadriceps muscles as they pedal on an exercise (stationary) bicycle. Therapeutic effects which will be sought are increases in quadriceps strength and decreases in dysphasic hamstring hyperactivity. A bicycle is presently being instrumented for use in this new protocol.
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and
Wichita State University, College of Engineering
Co-Directors: Jack F. Jonas, Jr., John H. Leslie,
Ph. D., and Roy H. Norris, Ph. D.

The Rehabilitation Engineering Center, Wichita, Kansas, was established on July 1, 1976, under the joint research auspices of the Cerebral Palsy Research Foundation of Kansas, Inc., and the College of Engineering, Wichita State University. The core area of research is the development of vocational opportunities for severely disabled persons through engineering.

The most frequently occurring functional description of disability is hemiplegia, the incapacity of one side of the body. Therefore, in an occupational setting a pervasive problem in designing modifications for a disabled worker group is the accommodation to hemiplegia. Any engineering solution to the problem of hemiplegia has the potential of applicability to a large number of similarly disabled workers.

Center Industries Corporation has two large numerically controlled lathes. Either may be operated using only one hand except for securing stock in the jaws of the lathe chuck. That operation requires the use of one hand to hold the material while the other hand actuates the control which opens or closes the chuck.

Center Industries had an employee who had use of only one hand. He had performed a variety of tasks competently. It was felt that if the part of the lathe operation which required two hands were modified, the hemiplegic employee might be able to perform the operation. A bracket was suspended above the worker's head. A round padded surface was placed at either side connected to a switching apparatus. The operator could cause the chuck jaws to open by moving his head to the left and cause them to close by moving the head to the right (Fig. 1). The switches on the adaptation were wired in parallel with those on the machine itself so that, with the bracket swung back out of the way, the lathe could be operated in the usual manner. A second lathe was similarly modified; the interface with the chuck controls was carried out somewhat differently as its controls were pneumatic rather than electrical.

The hemiplegic worker performs a variety of operations on the lathe at rates similar to those of his nondisabled fellow employee. It is anticipated that this format of actuation modification can be applied to a variety of machines to accommodate a similarly incapacitated worker.

FIGURE 1.
Adaptation for lathe puts duplicate chuck-jaw switch control within reach of hemiplegic worker's head, allowing the worker to deal successfully with a "two-handed" portion of the job.
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J. Raymond Pearson, M. Sc. M.I., Director

Design and Development of
Vehicle Adaptive Devices
and Systems

Task Leaders:
Robert C. Juvinall,
Mohamed Y. Zarrugh,
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The concept of a prototype wheelchair that uses a General Motors X-body (2-door sedan) was presented in the Bulletin of Prosthetics Research, Fall 1980 (BPR 10-34, p. 182) and the construction of a prototype of that system is nearing completion. The basic criteria for a satisfactory wheelchair-modified car combination were outlined in BPR 10-33 (Spring 1980, p. 138). The feasibility and cost advantage of such a system over the van system have been clearly demonstrated.

The “door-mounted chair” system developed by the University of Michigan Rehabilitation Engineering Center provides access for a specially built wheelchair through the door on the driver’s side of an Oldsmobile Omega. The “door-mounted” entry concept is quite simple; the wheelchair acts as its own transfer device, and additional lifting equipment is unnecessary. The chair is driven onto a special bracket that is mounted on the open door. With the seat supported by the door, the seat height adjustment mechanism raises the undercarriage of the wheelchair. This action reduces the overall height of the wheelchair and its occupant so that they will fit through the door opening.

A compact wheelchair with adjustable seat height (Fig. 1) was specifically designed with an automobile door opening in mind. When the seat is in its lowest position, the bottom of the sling seat is almost at ground level; this allows for maximum head clearance at the door opening. The overall length of the chair is restricted by the width of the door opening.

The chair consists of four major sections: (i) seat, (ii) chassis including a cross member and seat guides, (iii) wheel-suspension assembly and (iv) footrest. A ball screw actuator moves the seat along two 5/8-inch vertical guides via four linear ball bearings. The seat frame is made of 3/4-inch (outside diameter) round tubing over which the sling seat and the backrest are stretched in a manner similar to that of a standard wheelchair. A backing plate (Fig. 2) behind the backrest provides a means of mounting the linear ball bearings and transferring seat loads to the screw.

The two rods for the seat guides are supported at their base by the cross member. Two bars extend from the top of the guide rods and attach to the frame behind the guide rods (Fig. 2). These bars reduce the deflection of the top end of the guide rods (Fig. 2).

The cross members and attachments (i.e., chassis) are connected to two leaf springs. The cross member is shaped in such a way that the seat is lowered almost to ground level between the leaf spring and in front of the cross member. (With the leaf springs, the ride is very soft. An experimental structure that is more rigid will be installed to produce a firmer ride.)

The armrests enclose the springs when the seat is in its lowermost position (Fig. 3). The left armrest also serves as a bracket to attach the chair to the support frame inside the door cavity (Fig. 4).

Two caster wheels are fastened to the front end of the springs. The two 8-inch driving wheels with their drive units (Everest and Jennings 3N motor drive) are mounted at the back ends of the springs (Fig. 2).

The adjustable footrest is supported by an A-shaped 3/4-inch round tubing frame pinned to the front of the seat section. The position of the footrest is adjustable by a cable pulled by a screw placed inside the seat-frame tubing at the armrest. The screw is rotated by a chain drive from a motor mounted on the backing plate.

The nature of the loads the chair applies to the car door during lifting necessitated stiffening the door and strengthening the hinges (Fig. 4). This was accomplished by replacing the hinges and by providing a separate frame within the door cavity to support the chair. That frame is bolted directly to the hinges and bypasses the door shell itself. Deflections occurring in the door frame will have little effect on the door; misalignment between the door and the car (i.e., door opening) is minimal. A ball screw actuator opens and

FIGURE 1. Wheelchair with seat fully raised.
closes the door under the remote control of the driver. One end of the actuator is bolted to the dash; the other is bolted to the door above the chair support frame. The operation of the actuator is augmented by a latching device during the last few degrees of door closing, so that a force large enough to compress the door seals and latch the door is exerted.

FIGURE 2.
Caster wheels are fastened to the front end of the springs and the driving wheels are mounted at the back end of the springs. Thin arrow indicates backing plate. Each broad solid arrow points to one of the support bars. Broken arrow identifies guide rod.

FIGURE 3.
Wheelchair is brought into driving position inside the vehicle. Note how the armrest encloses the leaf spring.

FIGURE 4.
Support frame inside the door transfers chair loads directly to door hinges bypassing the door shell itself.