V. Functional Assessment

Development of a Computer-Automated System for Functional Assessment

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Investigators at the University of Texas at Arlington (UTA) have developed a computer-automated system to quantitatively assess a broad selection of sensory and motor functions. The objectives of this project are to further develop and expand the basic system, and to prepare two complete prototype systems for clinical evaluation and application studies at our clinical settings, the University of Texas Health Science Center at Dallas (UTHSCD), and the Dallas Rehabilitation Institute (DRI). In this battery of tests, each function is assessed by having the test subject carry out very specific, simple, and short-duration tasks that usually involve responding to computer-generated stimuli. Special-purpose transducers have been designed to convert responses into voltages suitable for digitization by computer. For most tests, algorithms compute single-number results that quantitatively indicate the level of a specific function. Software for test administration, and for printing of formatted results, has been developed. New software to graphically indicate composite and specific function results, as well as their change over time, is under development.

Over the past year, the basic system was redesigned to improve performance and to facilitate modular expansion and replication. In 1984 a prototype of the redesigned basic system was completed and placed into clinical evaluation at UTHSCD during January and a second identical prototype was placed at the DRI in June.

Since more than 250 measures can be obtained, a sensory and motor function data base structure was defined and implemented on a mainframe computer. Data recorded for each subject is transferred via modem to be entered into the data base.

New tests are being developed for incorporation into the system. A device that measures pronation and supination strength, speed, and range of motion was added in June 1984. A prototype of a three-dimensional digitizer, called the bio-curve tracer, also was completed. This device was designed for accurate range-of-motion measurements about all body joints, as well as for handling entry of anthropomorphic data directly into the computer. Clinical studies are now in progress to evaluate reproducibility, and to develop a test administration protocol for this device.

Progress was made on another device that is capable of measuring isometric and isokinetic strength, resistance to passive motion (rigidity and spasticity), and proprioception about specific joints. The device is similar to a previous one for resistance to passive motion measurement. A first version completed recently is used to assess these functions about the finger and wrist joints. A second is being fabricated for knee and elbow evaluations. These devices will be incorporated into the clinical systems by December 1984.

Inquiries were received from other institutions about the possibility of replicating the sensory and motor-function system for use in their own research. In accordance with our intention to promote quantitative, objective assessments, arrangements have been made to respond to a limited number of such requests, with our center replicating the system at cost. Data obtained at remote locations would be included in the sensory and motor function data base.

Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment—Part I

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The first prototype of this center's redesigned computer-automated functional assessment system, developed by the University of Texas at Arlington (UTA) investigators, is being evaluated for test-retest repeatability, effects of age, gender, and handedness, and for stability of patient data. The clinical setting at the University of Texas Health Science Center at Dallas (UTHSCD) includes functional assessments of patients with progressive neurologic diseases such as

Parkinson's disease, multiple sclerosis, myasthenia gravis, and Huntington's disease, as well as a major emphasis on those with chronic low back pain. The function of carefully screened normal subjects, aged 20 to 80 years of age, will be determined to form a data base that will be used to indicate a patient's function in terms of percentile of a normal population of appropriate age range and gender. Over the 4-year period of FY84 through FY87, it is expected that over 300 normal subjects and 400 patients will be evaluated during the course of these studies. As of June 1984, 125 subjects have been tested in the clinic. Emphasis has been placed initially on evaluating the system and test administration personnel, as well as on establishing the normal function data base. The data base is essential in order to express results of patient evaluations in a form that will facilitate interpretation and that will provide clinicians with feedback useful in evaluating their progress in restoring or preventing loss of functions.

The data base is currently in a rough format in that it contains a sufficient number of subjects (from past as well as present efforts) to establish young (18 to 40 years) adult and old (41 to 80 years) norms for 150 different measures of sensory and motor function. As the sample total grows, efforts will be directed toward establishing norms for each decade for each of the more than 250 measures in the system. This task is greatly facilitated by the nature of the system's automated data acquisition and result logging design. The majority of these measures can be obtained in a 2-hour test session■

Clinical Evaluation and Application of a Computer-Automated System for Functional Assessment—Part II

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A second prototype of this center's computer-automated functional assessment system is being evaluated clinically at The Dallas Rehabilitation Institute (DRI). Work was recently begun to evaluate the function of patients with head injuries, spinal cord injuries and peripheral neuromuscular damage, adult cerebral palsy, amputated limbs, and spina bifida. Data will be used to develop functional profiles of these conditions, as well as to form a sensory and motor function data base. DRI investigators will work in close collaboration with those at the University of Texas at Arlington (UTA) and the University of Texas Health Science Center at Dallas (UTHSCD) to improve test devices as experience with these patient groups is obtained.

Another sub-project will compare data acquired at the UTHSCD clinical site with data on the same set of subjects evaluated at DRI. Results will be used to assess factors such as instrument calibration and effects of training on test administrator performance. It is expected that over 500 different patients will be assessed (up to five times each) over 4 years during these studies. Results are expected to show that the computer-automated system can detect and quantify small but significant changes in function due to rehabilitation therapies and assistive devices, thereby objectively determining the efficacy of these interventions. Patients with different disabilities will be categorized by functional profiles. Thus, the progress of patients undergoing rehabilitation and monitoring by instrumented quantitative assessments can be judged against appropriate norms■

Quantification of Motor Performance: Muscle Strength and Endurance Testing

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The project has developed three prototype isometric testing stations with stabilization to test 13 different muscle groups. Reliability testing has been completed on handgrip and elbow flexion. A study was completed comparing the effects of different types of pelvic and lower limb stabilization on the extent of pelvic movement during trunk strength testing.

A prototype of a portable myuodynamometer has been used in a clinical setting (Neuromuscular Disease Clinic at the University of Minnesota Hospitals). Sixty-three patients have had initial strength testing of five different muscle groups using this device. Clinicians are currently utilizing this information to map disease progress and to assist in the decision making process regarding therapeutic intervention decision.

Two surveys were completed regarding methodology currently being used for assessing spinal rom and strength.

Computerization of the quantification process has progressed during the past year. A software package

has been developed to sample force signals, display results in real time, direct the subject's actions by sounding tones, and store the results. A linkage with a data base management system (CLINFO) has also been developed.

Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions

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Background—The 1983 Veterans Administration Rehabilitation Research and Development Progress Report outlined this comprehensive project—combining precise and rapid kinematic recording and analysis of abnormal gait with dynamic estimation of joint forces for the human lower extremities into a patient-specific musculoskeletal model of the pelvis, thigh, shank, and foot to establish the time-course and activity level of the individual muscles. Then presenting the relevant anatomical detail of the patient to the surgeon via computer graphics so that the surgeon could simulate a procedure, such as an osteotomy or tendon transplant. The computer system would then automatically alter the preoperative state of the musculoskeletal model to conform to the simulated change and show (again via computer graphics) the effect on the gait pattern of the subject. It is the direct analog of Computer-Aided Design (CAD), now so universally applied in simulating product to system design prior to manufacture.

The 1984 VA RR&D Progress Report updates the 1983 description.

Gait Analysis—Our Selspot I/TRACK system, now in routine use, is being adapted to the Selspot II Camera with four-fold improvement in translational and rotational kinematic resolution and accuracy, and with greater flexibility in the number of light emitting diode arrays versus sample frequency. Automated techniques for calibrating camera optics and electro-optical transducers have been developed. Feasibility studies for large-volume TRACK are underway to employ either moving cameras or multiple cameras to record movement over larger viewing volumes than the intersection of two fixed location cameras. Large-volume TRACK will place fewer restrictions on the movement trajectory of the patient.

Dynamic Joint Force Estimation—The NEWTON computer program automatically calculates joint forces and movements from TRACK kinematic data, force plate input, and body segment mass and inertial properties. We have developed computer programs which automatically calculate the patient-specific data, using as input computer tomographic scan data of human extremities. We are currently planning physical experiments on cadaver limb segments to compare direct measurement of the inertial tensor with our CT-based computer analyses.

The first pressure instrumented femoral head hemiarthrosis has been implanted into a consenting patient and we have accumulated much data—intraoperative, postoperative, through recovery and rehabilitation and most recently in normal gait. Local pressures correlated well with the high readings recorded here in vitro on cadaver specimens. Spatial integration of the pressure during gait, combined with TRACK/NEWTON data and analysis, will permit comparison of external estimation of force with direct internal measurement and illuminate the role of muscle co-contraction, not discernable from gait analysis.

Musculoskeletal Models—Our current hip/knee/ankle model has seven degrees of freedom and incorporates representations of 36 mono- and bi-articular muscles. We know (from prior studies using TRACK, NEWTON and then optimization analyses to predict individual muscle activity) that the model's greatest deficiency is the knee representation which has been thought of as a planar hinge. An explicit knee model is being generated based on experimental measurement, using an ultrasound technique of articular and menisci geometries and incorporating the passive restrains of the ligaments. When inserted into the overall model, including the 15 muscles which span the knee, the joint will have at least four degrees of freedom and will improve the accuracy of prediction of individual muscle activity. Reduction and interpretation of the human volunteer bone pin TRACK array data on knee kinematics has begun.

Computer Graphics Displays—The surgeon must be presented with a realistic, manipulable representation of the subject's anatomy as he undertakes the simulated surgery. The same CT data used for segment inertial property determination serve also as input to the anatomical representation. Progress has been made in automatic feature detection, so that, for

example, the computer automatically differentiates between hard and soft tissue in outlining for a detail such as the geometry of the condytes of the knee joint.

Much work has yet to be done but we expect to be able to automate to a large extent the delineation of the anatomical features from the CT data and thereby present color-graphics displays of patient anatomy.

We also are anticipating the more widespread use of NMR to avoid radiation exposure and we also are analyzing NMR scan data. Ultimately the same anatomical data will be used to scale and alter the musculoskeletal model to faithfully represent the specific patient's anatomy.

The computer vector graphics displays of patient movement preoperatively and subsequent to a simulated operation must be as realistic as feasible. Stick figure representation, for example, is not adequate to capture nuances of pathological and/or idiosyncratic movement. We have begun the development of display programs which represent the limb segments as articulated solid bodies, driven by the TRACK kinematic input■

Quantification of the Functional Capacity of Upper Limb Amputees

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This project is intended to develop a technique for quantification and measurement of the upper-extremity functional capability of able-bodied and disabled persons. The technique being developed will use dynamic optimization theory to produce a single meaningful number derived from accessible measurements (such as myoelectric activity, speed, range of motion, etc.) and is intended to provide an essential link between measured performance and inferred functional capability.

An important aspect of dynamic optimization theory is that it yields a quantitative statement of the best way to perform a movement to accomplish the task modelled by the criterion function—subject to the limitations of the mechanical or biomechanical system performing the task. This ideal performance is then a benchmark for that task—that is, a yardstick against which other executions of that task may be compared. This is the key to the measurement technique: if a criterion function can be found which describes normal movement behavior, it is the natural quantitative measure of functional capability. It permits a disabled person's performance to be compared numerically to the "ideal" performance of an able-bodied person, and it defines the functional meaning of the comparison.

In previous work, dynamic optimization theory successfully predicted patterns of muscle activation of an able-bodied person maintaining one (carefully chosen) posture of the forearm against changing gravitational loads, thereby demonstrating the feasibility of the approach. In the past year, the mathematical technique has been refined, extended and improved. The major outcome has been the separation of the analysis into two separate components, one dealing with the static constraints of the nonlinear geometry of the musculoskeletal system, the other accounting for the dynamics of posture. The benefit of this separation is that realistic representations of the moving limb can be dealt with more simply. The analysis has been extended to provide a description of the maintenance of any posture of the forearm against changing loads. Extending the analysis to provide a description of the maintenance of any unconstrained posture of the upper extremity (arm, forearm, etc.) is presently under consideration.

Automatic Calibration Achieved—Work on the experimental verification and application of the mathematical technique is in progress. The most important requirement is a clean, high-fidelity measurement of myoelectric activity. An improved method of processing myoelectric activity is being developed. The processing technique is based on a mathematical model of surface myoelectric activity, from which the optimal (maximum likelihood) estimator of muscle force was derived. This optimal processor (which was previously implemented and tested using a laboratory-bound computer) has now been implemented using microprocessor technology, and this has yielded approximately an order of magnitude of improvement over conventional processing techniques. A major advantage of this digital microprocessor implementation is that the tedious but essential calibration process is performed automatically without user intervention. This is an important step towards making this new technology accessible on a turn-key basis to a clinical user with no specialized knowledge of computer programming■

Quantitative Evaluation of Nerve Repair

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Hypothesis—The lack of objective methods for assessing the extent of nerve injury or regeneration forces physicians to rely on subjective criteria in making clinical decisions and hampers the search for better methods of peripheral nerve repair. Similarly, better methods of nerve repair need to be developed because present methods, even those employing modern methods of microsurgical techniques, rarely result in full functional recovery.

We believe that regeneration can be quickly and reliably assessed by newly developed electrophysiologic methods which estimate the number and health of the axons crossing a focal lesion or repair site. In order to meaningfully enhance regeneration following injury, modern mechanical methods, including sutureless techniques, must be combined with pharmacological adjuncts that influence the rate and direction of regenerating axons.

Methods—Using computer-generated waveform simulations, we propose to characterize an electrophysiological assessment technique that generates a histogram indicating the distribution of added conduction delays (DAD) over a focus of injured or regenerated nerve. Following computer validation, we propose to test various assumptions regarding the DAD in a sequence of animal studies employing rats and primates in whom varying degrees of nerve injury have been surgically created. A newly developed system that magnetically measures the action currents generated by the passing wave of depolarization and repolarization potentially allows easier, more reliable recording of evoked potentials in these animals. These advances will be incorporated into software systems capable of being run on modern intraoperative assessment hardware. Simultaneously, we propose to study the effects of various adjuncts to nerve repair, including drugs that reduce scar formation at the repair site, agents that influence regeneration rates (nerve growth factors), and agents that suppress adverse effects of the immune response to regeneration.

Preliminary Findings

1. Distribution of added delays (DAD)—computer simulations indicate that by comparing various characteristics of two waveforms recorded from the same site well proximal to a local lesion (the first generated by supramaximal stimulation just proximal to the lesion, and the second stimulus delivered just distal to the lesion) a reasonable assessment of the proportion of axons crossing the site of injury and an estimate of their health can be derived.

2. Magnetic recordings—A number of animal studies demonstrate that the magnetically recorded action current is the magnetic analog of the electrically recorded compound action potential, and that standard assessment parameters such as conduction velocity, peak amplitude, etc., can be calculated from the magnetically recorded signal. The potential advantage of this method over standard electrical recording techniques is that the nerve is allowed to remain safe in its physiologic milieu during recording. Electrical recordings typically require the recording site to be suspended in air and thus endangers the nerve of dessicating under hot operating room lights.

3. Adjuncts to repair—We have partially analyzed the results of a primate model comparing the effects of tension at a nerve repair site. A significant gap (12mm) was created in the median and ulnar nerves. In one group (ES), the cut ends were approximated under tension with 8-0 sutures, in 2 other groups the gap was bridged intrafascicularly with autogenous nerve grafts using either 10-0 intrafascicular sutures (FS) or interfascicular hypoantigenic collagen tubes (FT). At 6 months postoperatively, electrophysiologic measurement of the proportion of proximal axons having regenerated across the site of repair or graft demonstrated the following:

ES (epineurial repair under tension)	—mean = 0.81 (range = 0.64–0.89)
FS (no tension/ graft)	—mean = 0.61 (range = 0.45–0.82)
FT (no tension/ graft/tube)	—mean = 0.56 (range = 0.40–0.71)

The slightly larger fraction of fibers crossing the epineurial suture repair done under tension indicates that some tension is not deleterious to regeneration.

Future Goals—Animal studies of other adjuncts are in progress as are refinements in magnetic recording techniques and further validation and implementation of the DAD analysis software■

Quantitative Measures for Assessing Therapeutic Effectiveness

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This project has developed and built photoelectric modules that are used in a laser scanning system for tracking limb segment positions. A major effort was devoted to developing a calibration technique for the laser scanning system. A portable instrumentation package has been built which includes all the necessary signal processing for six channels of EMG and two footswitches, allowing interfacing with a PDP 11/34 computer. Some data collection on normal subjects has started.

Predictive Assessment in Prescription of Functional Aids for the Motor-Disabled

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The goal of this project is to develop data and theory on which to base prediction of functional gain from technological intervention. It was proposed that this concept be applied to three handicapping conditions:

1. Disabling tremor of the upper extremities;
2. "Equinus" and other spastic gait abnormalities; and
3. Loss of vocal communication due to impaired articulatory motor control.

The motivation derives from the impracticality of exhaustive try-it-and-see assessment. As descriptive and predictive models of disabled human function are developed, they are hypothetically applicable to the clinical problem of streamlined assessment for optimal prescription.

Device Control-Interface Study

With respect to tremor, an initial study aimed at establishing the effect of three characteristics of device control interfaces on the accuracy of displayed movement, has been completed. The protocol required that the subjects perform discrete target acquisition and continuous pursuit tracking tasks in two dimensions on a computer-generated video display. They accomplished this by manipulation of either a conventional displacement-sensing joystick or one that rigidly sensed isometric force. The response signal was displayed directly, with low-pass filtering, or with integration providing control of cursor velocity. Data collected showed a significant improvement in signal-to-noise ratio and other measures of performance (for each of six adult neurology patients disabled by intention tremor) for at least one of the unconventional experimental conductions (force-sensing, filtering, or velocity control). While the combination of force-sensing and unfiltered velocity control was optimal for several subjects, it appears at this point that individual assessment will be clinically necessary. The number of subjects was insufficient to establish a correlation between etiology and optimal interface choice. The results were also consistent with earlier one-degree-of-freedom data showing isometric torque tremor to be invariant with respect to the voluntary tracking torque.

Spasticity-Damping Orthosis

The spastic gait project, active under past REC funding, was reactivated in the Fall of 1983. This work continues use of the wearable computer and interactive ankle orthosis simulator, that allows generation of energy-absorbing torque profiles across the ankle during gait. The objective is to extend the single-subject data already collected that show that the inappropriate ankle extension of equinus can be suppressed by a compliant brace applying a damping-like load during particular portions of the gait cycle. Experiments are now being conducted in the Newman Laboratory for Biomechanics and Human Rehabilitation at M.I.T.; these will use the TRACK system for collecting multi-segment gait data during trials with the orthosis simulator. Experiment-control software adjusts loading parameters as the subject walks, in order to minimize a simple cost function which measures the extent of abnormality. In effect, this lab system is the prototype of an automated prescription scheme. A simplified all-mechanical damping orthosis has been built for preliminary Activities of Daily Living (ADL) trials.

Work in the area of computer-guided assessment and prescription of non-vocal communication devices is presently very active, under the investigator's joint contract support from the National Institute of Neurological and Communicative Diseases and Stroke with Dr. Cheryl Goodenough-Trepagnier at Tufts-New England Medical Center. That scheme is based on predic-

tion of communication rates for candidate devices from motor assessment data as well as estimation of learning time and perceived benefit from evaluation of cognitive status and functional needs, respectively■

Investigation Regarding the Optimal Application of Technology-Based Treatment Modalities Applied to Assessing and Ameliorating Motor Defects

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The purpose of this study is to examine the role of cerebral and spinal contributions to motor control, and how they are influenced by therapeutic intervention. The rationale for the latter stems from the therapeutically relevant finding that specific pathways connecting supraspinal areas and spinal motoneurons can be strengthened by exercise and training.

The specific objectives are as follows:

1. To establish normative data from neurologically intact subjects.
2. To obtain data from hemiplegic patients previously treated in our program who are able to employ their involved extremity to perform the maneuvers necessary for conducting the test.
3. To correlate the presence of cerebral response EMG activity with the degree of motor recovery made by our previously treated patients, for the purpose of validating the degree to which our therapeutic intervention correlates with its presumed effect.
4. To obtain data from hemiplegic patients to determine whether the character of the cerebral response recorded on the intact side changes as a function of the degree of independence attained in performing ADL activities requiring use of the non-involved hand.
5. To correlate the electrophysiological measures obtained to standard measures of progress such as EMG gains, range-of-motion, and functional skills■

The Efficacy of Surgical and Rehabilitative Procedures of the Knee

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This project is nearing the end of the third year. In order to test the efficacy of these procedures, a knee machine originally designed by P. C. McLeod was modified and used for this study. This machine measures in real time (with the aid of a desk top Apple IIe computer) nine functions of a cadaver knee specimen. These are: (1) flexion extension, (2) tibial rotation angle, (3) varus/valgus angulation, (4) anterior/posterior distance, (5) anterior/posterior force, (6) tibial rotational torque, (7) varus/valgus angulation torque, (8) body weight, and (9) quadriceps force.

Any of the above nine data channels may be used as a control channel at the convenience of the operator. The increments at which data are taken are also set by the operator; each time an increment of test input is achieved, all nine data channels are read and stored immediately by the computer and a high speed, 12-bit analog-to-digital converter. Once this information has been stored within the computer's memory, any two channels may be plotted graphically against each other, or the computer monitor, or an EPSON RX80 printer. Also, a complete data listing may be displayed on the printer or the data may be stored on a 5¼ inch floppy disk and examined at the leisure of the orthopaedic surgeon. It is important to note that since the data from the knee test are obtained in essentially real time any of the nine parameters may be plotted against any other to give realistic data of interactive motion and force from a given test set. All of the necessary software is provided for knee testing, graphics, and data storage and listing. The software is menu-driven and is very user-friendly.

In a knee testing apparatus modified for this project, the ankle at the lower end of the tibia will move vertically a total travel of 18 inches. Body weight is applied up through the ankle and is automatically controlled, once preset by the operator. The control near the top of the right-hand panel will cause the hip and ankle to rotate 360 degrees in synchronism about a vertical axis through the hip and ankle so that the specimen may be operated on or X-rayed from any direction. The lower control on the side panel is the input of a remote master-slave hydraulic system to change the quad

length which in turn controls flexion/extension. The other two controls on the ankle provide tibial rotation and varus/valgus angulation. Either or both of these controls may be used as input or may be very quickly (without the need for tools) disconnected so that the knee is free to follow its own natural geometry throughout a test. However, the angular motion of the tibia in both transverse and coronal planes is monitored even though the force mechanism has been disengaged.

A typical tibial rotational versus torque plot may be viewed either on the monitor or the RX80 printer for a permanent record.

To date, six papers have evolved from this study and four are being reviewed at this writing■

Epidemiology of Physical Activity

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Sponsor: National Institutes of Health
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During the next year, we will continue our data collection and analysis of previously collected data designed to evaluate the Large-Scale Integrated (LSI) activity monitor as an objective measure of physical activity for epidemiologic research. The focus of the upcoming year will be to complete the requirements of the grant in addition to expanding into new areas of physical activity research. Specifically, we have completed the first phase of the research; 48 college students have worn various activity devices including the LSI. We will analyze these data during the next 2 months.

Thirty postal carriers have been recruited, and by November 15 they will have completed the first seasonal assessment of activity. We plan to obtain the winter measurements in January. We have modified the LSI monitors for assessing activity in spinal cord injured patients. The population is available, and in November this phase of the project will begin. The industrial group has been identified; however, participants have not yet been identified. This phase will not begin until January 1.

We plan to expand our research efforts by including two new methods of physical activity evaluation as well as an additional population. The two methods of assessment will include a new survey which is being employed in the MONACA study in Europe. We have special permission to test the survey. The second measurement will be a new type of monitor which has been developed in Wisconsin. These instruments will be available within the next 2 months. We also plan to expand the evaluation of activity into our clinical trial of activity in postmenopausal women (RO 1 AM 21190). Dr. LaPorte is co-principal investigator of this project■

[See also **II. Orthotics, B. Upper Limb**, Assessment of Hand Function and the Development of Wrist-Hand Orthoses; **VI. Biomechanics, C. Human Locomotion and Gait Training**, Evaluation of Methods to Measure Locomotion Performance and Activity; **VIII. Properties of Muscle**, Myoelectric Assessment of Human Lumbar Muscle Function, Muscle Fatigue Differences Due to Handedness and Gender, the Muscle Fatigue Monitor, and The Estimation of Muscle Fiber Conduction Velocity]