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VIII. Properties of Muscle

A. General

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Automatic Decomposition of the Clinical Electromyogram

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Sponsor: VA Rehabilitation Research and Development Service

Purpose—The electromyographic (EMG) examination plays an important role in the diagnostic evaluation of many neuromuscular disorders. It involves recording an electrical signal from a contracting muscle by using a needle electrode and assessing the motor-unit action potentials (MUAPs) of which the signal is constituted. This assessment is still widely performed in a qualitative fashion by watching the EMG signal as it flashes across an oscilloscope screen and by listening to its sound.

There is a widely felt need for ways to quantitate EMG analysis in order to make it more objective, more reproducible, and more diagnostically sensitive.

Progress—A number of methods have been proposed for quantitating EMG analysis. The ones which extract MUAPs from the EMG signal have proven to be the most diagnostically sensitive. To date, however, the difficulty of decomposing signals containing more than four or five MUAPs has hampered quantitative analysis of EMGs recorded during any but the weakest contractions.

We hypothesized that advanced signal-processing and pattern-recognition techniques could be used to efficiently and accurately decompose moderately complex EMG signals into their component MUAPs.

We have developed a software package called ADEMG for Automatic Decomposition Electromyography for extracting MUAPs from EMG signals recorded during conventional EMG examinations. The program can extract as many as 16 simultaneously active MUAPs from EMGs recorded at strengths up to 30 percent maximum voluntary contraction. It is designed to analyze EMGs recorded during 10-second constant isometric contractions using a standard concentric needle electrode and thus conveniently supplement the conventional qualitative EMG examination. The analysis time is 90 seconds on a PDP-11/34 computer.

Preliminary Results—We are in the process of collecting a database of MUAP properties from healthy subjects and patients with known neuromuscular disorders. Preliminary normative data have been collected for the biceps muscle from 10 normal subjects. Two papers are in press—a technical description of ADEMG and a presentation of the preliminary results. In order to make the ADEMG software more widely available, it is currently being translated to run on an electromyograph manufactured by Nicolet Biomedical Instruments of Madison, Wisconsin.

A Smart Trigger for Real-time Neuroelectric Spike Classification

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Purpose — Neuroelectric signals recorded from muscle and brain often contain action potentials or "spikes" arising from more than one cell. In order to study the behavior of the individual cells, it is necessary to sort out the spikes. In some applications it is necessary to perform this sorting in real time.

An automatic real-time spike classifier would benefit physiologists engaged in extracellular recordings in muscle and brain. It would also find application in "single-fiber electromyography," a technique for diagnosing neuromuscular disorders. This technique is currently hampered by the poor performance of available spike classifiers. Another possible application would be the decoding of myoelectric signals to control prostheses or functional electrical stimulation.

Progress — Simple electronic devices called triggers have been available for real-time spike sorting for some time, but they tend to be unwieldy to use and to give poor discrimination performance. Computer programs employing sophisticated signal-processing and pattern-recognition algorithms are also available for spike sorting. They are capable of automatic operation and excellent discrimination, but they are too slow to operate in real time. Algorithms used in spike-sorting computer programs can be transferred into an inexpensive, microprocessor-based device which will be fast enough to operate in real time.

Preliminary Results — We are building a device that we call the "Smart Trigger" which will be able to classify as many as eight simultaneously active spike trains. It will identify spike signatures automatically, adaptively track slow changes in spike shape, and make use of fast detection and template-matching algorithms that grew out of our previous work on analyzing clinical electromyograms. The Smart Trigger will employ three M68000 microprocessors in addition to specially designed digital filtering and peak-detection hardware. Funding for this project began in April, 1985.

Ethanol-Induced Cytoskeletal Dysgenesis in Muscle

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Purpose — The purpose of this project is to develop an animal model in which ethanol-induced myofibrillar dysgenesis occurs and to characterize the ultrastructural abnormality with associated hypotonicity and weakness.

The project plan entails examining *in utero* morphologically damaged muscle when exposed to ethanol. First, female rats will be acclimated to a diet in which ethanol constitutes 36% of their caloric intake. This diet is administered throughout gestation. Muscles from rat pups born of these females will be examined histochemically and ultrastructurally to document alteration in the contractile proteins (myofibrillar dysgenesis). Appropriate control animals will be studied. Blood ethanol and acetaldehyde levels will be drawn periodically on mothers and newborn pups in an attempt to correlate those levels with the degree of damage and manifestation of hypotonicity. Additionally, growth parameters of myocytes will be studied employing *in vitro* cultures of cardiac and skeletal muscle from newborn pups gleaned from the above experimental and control groups. Morphometric data analysis will be generated from both *in vivo* and *in vitro* materials to record the dysmorphogenesis associated with *in utero* ethanol exposure.

Muscle biopsies from the rat pups will be studied using frozen section histochemistry and ultrastructural preparations standard in our pathology morphology laboratory. Ultrastructural examination of cell cultures will be performed using a monolayer recovery technique. Morphometric analysis will be performed on a Zeiss MOP III quanitmat. Blood ethanol and acetaldehyde levels will be performed on a H-P gas chromatograph in consultation with Dr. Dean Tuma.

Evaluation of Spasticity

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Sponsor: Osaka Rosai Hospital

Purpose — Our goal is to develop a system of quantitative evaluation of spasticity where hemiplegic and paraplegic patients are involved. This system keeps records of EMG, covering a full day or more for evaluating spasticity, by using a system of handheld computers which enables us to record all kinds of biological phenomenon during daily activities. We can eliminate many difficulties by measuring spasticity quantitatively.

Measurement and Reduction of Spasticity

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Sponsor: The Multiple Sclerosis Society (UK)

Purpose — The pendulum test was used to assess spasticity in the knee extensors in a group of SCI patients and to evaluate the beneficial effects of dermatome stimulation.

A microcomputer-based instrument was developed to automate the pendulum test data acquisition, analysis, display, and storage of patient data. This system is presently being evaluated as a clinical tool.

The present aim is to optimize the stimulus parameters and to investigate the effects of articular stimulation by knee joint effusion.

Muscle Structure and the Contractile Mechanism (Rabbits, Protozoa)

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Sponsor: National Institutes of Health

Purpose — The objective is to determine the precise molecular architecture of a diverse class of Alpha-fibrous proteins whose role is both structural and dynamic. The chief methods are coordinated X-ray crystallography, electron microscopy, and image analysis. Muscle proteins are a central focus and provide the background for studying related systems. A major aim is to determine the structure and motions in two calcium-dependent protein switches that control contraction. Thus, crystals of the regulatory complex tropomyosin/troponin are being analyzed, and the topology of the myosin molecule with its associated light chains will be determined to establish models for regulation. The molecular basis of blood clotting is being studied by a similar approach. The structure of fibrinogen will be determined by X-ray crystallography and its packing established in the fibrin clot. These structural methods also will be applied to certain cytoskeletal and cell surface proteins (including those on human parasites) that play important roles in cell form, movement, and interactions. The broad study of these systems is directed towards identifying distinctive features of structure that are essential to their function.

Progress — Knowledge of the molecular mechanisms of contraction and its regulation in normal muscle is needed to account for failure in various heart and muscle diseases. Similarly, a full understanding of blood clotting, and its malfunction in certain cardiovascular diseases, requires detailed information about the structure and interactions of the fibrinogen molecule. We recognize now the vital role of the cytoskeleton and various arrays of internal and external cell surface proteins in normal cell function and in development, and the responsiveness of these structures to cell transformation. The occurrence of fibrous proteins that may be related to muscle proteins at the surface of pathogenic organisms has important medical implications. Our broad study of the structure and interactions of these fibrous proteins will lead to a deeper understanding of both normal and abnormal cellular function.

Quantification of Dynamic Muscle Strength (Human)

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Sponsor: National Institutes of Health

Purpose — Manual materials handling (MMH) activities can cause high stresses on the musculoskeletal system. The dynamic nature of these tasks, such as lifting, preclude the use of the traditional concepts of human strength: isometric and isotonic contractions. Instead, the novel development of isokinetic muscle contraction has expanded the study of dynamic muscle strength. Isokinetic contractions occur against a lever arm which controls the velocity of movement and offers resistance proportional to the muscle dynamic tension developing capacity at every point in the range of motion. Thus, the maximum demand can be placed on the muscle at any time, and, by selecting appropriate velocities, muscle power can be maximized. The proposal is to quantify the dynamic strength of those muscle groups that relate to MMH activities in a four-phase research plan: 1) investigate in detail the dynamic properties of muscle strength for those muscle groups used most often in manual materials handling activities; 2) compare the measurement of these properties on the stationary Cybex isokinetic dynamometer with those measured on the portable Mini-Gym isokinetic dynamometer through correlation analysis; 3) devise dynamic strength tests that would be representative of the actions and muscle groups for manual materials handling activities and that could be easily implemented for pre-employment strength testing; and 4) compare the dynamic strength tests with existing static and psychophysical tests and with predictions from dynamic models.

Alterations in Skeletal Muscle with Use and Disuse (Rats)

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Sponsor: National Institutes of Health

Purpose—Our primary objective is to continue experiments designed to elucidate the effects of use (exercise-training) and disuse on fast and slow skeletal muscle, and to determine to what extent and by what mechanism exercise-training protects against the development of fatigue. Our long-term objective is to understand the molecular mechanisms controlling muscle function such that this knowledge can be utilized in the prevention of fatigue and disease, and in rehabilitative medicine.

The effect of exercise-training and long-term disuse on muscle function, and the etiology of muscle fatigue, will be studied in the rat. The physiological studies will include an *in situ* and *in vitro* evaluation of the contractile properties of the slow-twitch soleus, and fast-twitch extensor digitorum longus (EDL) at rest and during acute contractile activity. The intracellular $H+$ ion concentration will be directly measured using pH-sensitive glass microelectrodes, and pH changes during work determined. The pH changes will be correlated to alterations in substrate levels and contractile properties to assess the role of the $H+$ in muscle fatigue. The skinned fiber preparation will be utilized to determine how exercise-training, fatigue, and disuse affect sarcoplasmic reticulum (SR) and myofibrillar function. The contribution of myofibrillar and SR ATPase to the total activity will be determined and these activities correlated to maximal shortening velocity and force transients, respectively.

The sarcoplasmic reticulum (SR) will be studied to determine how exercise-training, muscle fatigue, and disuse affect the kinetic properties, phosphorylation, and gel electrophoretic patterns of this membrane system. These experiments are designed to test our hypothesis that the SR controls the intensity and duration of the active state, while the maximal speed of unloaded shortening is dependent on the myosin ATPase activity.

Elasticity, Force, and Fiber Length Changes in Aging Muscle (Rats)

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Purpose—A multidisciplinary program is aimed at elucidating the cellular mechanisms involved in the accumulation and remodeling of muscle connective tissue and the reduced range of movement that occur in aging and/or inactive individuals. The amount and properties of the connective tissue in the muscle belly are influenced by the type of activity that the muscle is subjected to. Connective tissue remodeling is linked with adjustments in sarcomere number so that there is a reduced range of movement as well as an increase in stiffness.

The questions asked include: can regular exercise delay the onset of muscle stiffness by altering the distribution and nature of the connective tissue, and which type of stretch (active, passive, dynamic) is the main factor in preventing muscle connective tissue accumulation and sarcomere loss?

The form and amount of muscle connective tissue will be studied by quantitative transmission, EM, and light microscopic techniques. Changes in endomysial and perimysial connective tissue will be evaluated and the rates of synthesis of collagen and contractile proteins will be measured to shed light on the remodeling process. Changes in the functional length of muscle fibers will be determined by measuring sarcomere number and sarcomere length. The cellular mechanisms involved in the addition and removal of sarcomeres will be studied concurrently with those involved in connective tissue remodeling. These will be related to the physical and physiologic characteristics of the muscles studied and will include measurements of muscle force, rate of force development, compliance, and elasticity. Both the morphologic and physiologic changes will then be related to the functioning (force production, compliance, and elasticity) of the aging musculoskeletal system.

The data will be of considerable value to those involved in physical therapy, the management of elderly respiratory, orthopaedic and neurologic patients, as well as elderly patients in general.

B. Muscle Contraction

Motor Unit Firing Rates and Recruitment

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Sponsor: Liberty Mutual Insurance Company

Purpose — Muscle contractions are modulated by the number of motor units recruited and their respective firing rates. Our research has documented an interplay between recruitment and firing rates of motor units. The recruitment of a new motor unit appears to have a disfacilitatory influence on the firing rates of previously activated motor units. Theoretically, this influence may operate, at least partially, through the stretch-reflex loop, and possibly by the recurrent inhibition of a specialized neural feedback pathway known as the Renshaw circuit. (The stretch-reflex loop and the Renshaw circuit consist of neural pathways that exert a regulatory influence on the excitation received by the motor unit.) Such a mechanism would be functionally useful since it would provide for the smooth control of muscle output through peripheral neural circuitry, thus lessening the amount of detailed supervision over the alpha-motoneuron pool required from the central nervous system.

Progress — During the past year, we have observed this phenomenon in four muscles of the upper limb (first dorsal interosseous, flexor pollicis longus, extensor pollicis longus, and deltoid), as well as a muscle in the lower limb (tibialis anterior). We studied the occurrence of the phenomenon extensively in 32 motor units of the first dorsal interosseous and in 39 motor units of the tibialis anterior.

A paper describing this work has been accepted for publication by *Brain Research*. Details on the findings of this project were presented at three conferences.

The Myoelectric Signal Decomposition Technique

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Sponsor: Liberty Mutual Insurance Company

Purpose — During the past several years, we have been developing and refining a system for studying the behavior of motor units. The system analyzes in detail the myoelectric signal that can be detected by a needle electrode in a contracting muscle. With this system, we can extract information from the muscle which helps us to understand the nature of the control schemes that the nervous system uses to govern muscle contractions. Our system works in three phases: 1) the data signal acquisition phase; 2) the data preprocessing and decomposition phase; and 3) the analysis phase.

Progress — During 1984, we documented and streamlined the various computer programs that constitute the data signal acquisition phase. These programs were also organized into a unit so they would be readily accessible to the new investigators in our NeuroMuscular Research Center.

We also expanded our collection of computer programs for the analysis phase by adding programs for analyzing the amount of synchronization in motor unit contractions. Synchronization is the tendency for two or more motor units to contract in a fixed time relationship with respect to each other. Our approach to quantifying synchronization begins with comparing the number of occurrences per unit time of time-locked contractions with the number of randomly occurring contractions of two motor units. The synchronization values thus obtained are plotted in several formats, each specially designed to reveal different features of the synchronization behavior.

Improvements in the decomposition technique are detailed in a paper published this year in *EEG and Clinical Neurophysiology*. They were also discussed at two international symposia.

Synchronization of Motor Unit Discharges

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Purpose — Several other researchers have investigated synchronous behavior within a motor-unit group. Due to limitations in detection and analysis techniques, synchronization has never been studied in detail and remains controversial. Our decomposition technique has removed many of these limitations. Incorporating a statistical analysis technique called the conditional intensity, we now can objectively observe and also accurately measure synchronization.

Preliminary Results — During 1984, we devised an algorithm for producing a numerical measure called the synchronization ratio. A synchronized ratio of 1.0 would be expected if two motor units were contracting independently. Preliminary results have shown that: 1) the ratio is greater than 1.0 in all of seven muscles examined; 2) it is more apparent in smaller muscles than in larger muscles; 3) it tends to increase upon recruitment of a new motor unit; 4) it tends to increase when there is a significant sharp deflection in the force output of a muscle; and 5) it tends to increase as a muscle fatigues.

Future Plans—Our studies lead us to believe that synchronization is associated with the involvement of the stretch reflex that may or may not be activated when a muscle fiber contracts. In future investigations, we plan to study the conditions which tend to increase the incidence of synchronization. We also plan to study the phenomenon in normal subjects and in patients with well-specified neural lesions. Through this study, we hope to devise a clinical test for use in the evaluation of neuromuscular dysfunction.

This material was presented in October at the 14th Annual Meeting of the Society for Neuroscience.

Motor Control in Movement Disorders

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Sponsor: Liberty Mutual Insurance Company and VA Medical Center

Purpose—Since it appeared natural that we apply our ability to decompose the myoelectric signal and to analyze the behavior of individual muscle-fiber discharges to other than normal subjects, we have begun to study in detail the myoelectric signal in patients with movement disorders. We plan to compare the motor-unit contraction properties of such patients with our previously documented findings on normal subjects. We especially want to ascertain differences and similarities in phenomena such as the common drive and the interplay between firing rate and recruitment. Both of these phenomena were discussed in last year's activities report, and the latter phenomenon is addressed above.

Progress—For these studies, we are selecting patients who have well-defined lesions, strategically located in the areas of the brain and spinal cord, that play a crucial role in regulating the output of movement. We hope that the study of such patients will help us to identify and quantify the amount of motor disturbance. To date, we have studied two patients with Parkinson's Disease and one patient with Cerebellar Atrophy, and we have just begun to analyze the data.

Control of Antagonist Muscles

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Sponsor: Liberty Mutual Insurance Company

Purpose—We are attempting to clarify the control mechanism of antagonist (opposing) muscles during the initiation and continued production of force associated with voluntary contractions. Our study focuses on the flexor pollicis longus and extensor pollicis, the two sole activators of the distal thumb joint.

Progress—During the past year, we accumulated additional data and integrated these data with our previous observations. We have also described more accurately the details of the behavior of the motor units in antagonist muscles. Our understanding of this behavior is the same as in last year's description.

Preliminary Results—During pure joint stiffening, the motor units in the two contracting antagonist muscles are controlled by the nervous system as if they constitute a single muscle. Conversely, during alternating flexion and extension contractions, the two antagonist muscles are reciprocally activated. These observations are consistent with the concept that the central nervous system has two separate control schemes for coactivation and for reciprocal inhibition and that these two schemes may be used in different ways to control the torque or stiffness of a joint. The results also support the notion that the central nervous system does not control motor units individually during a muscle contraction and imply that muscles acting on a joint are not necessarily controlled individually. This information is useful in designing exercise programs for impaired muscles.

Future Plans — Two articles are being prepared for publication.

Control of Synergist Muscles

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Sponsor: Liberty Mutual Insurance Company

Purpose — Synergist muscles act in concert and contribute additive force during a specific function. Since the body's musculature is composed of both antagonist and synergist muscles, it is important for us to complement our work on antagonist muscles with studies of synergist muscle control. We are studying the motor-unit interactions of the extensor carpi radialis longus (ECRL) and extensor carpi ulnaris (ECU). These muscles act to control wrist movement and can function synergistically or antagonistically depending on the task.

Progress — A previously developed technique was used this year to decompose the myoelectric signal detected with a needle electrode from the muscles that were associated with each contraction of each active motor unit. In experiments with normal subjects, we made needle-electrode recordings from the muscles during the generation of isometric forces at the wrist. A computerized data-acquisition-and-control system was used to present trajectories for subjects to track and also was used to control the recording of high-quality myoelectric signals. Extensive signal processing and analysis were performed to examine the motor-unit interactions.

Preliminary Results — The results indicated the following:

1) Small 1-2 Hz common fluctuations with no phase shift in the mean firing rates of motor units were noticed within the muscles studied; this was consistent with earlier work on other muscles. Common fluctuations also exist between the firing rates of ECU and ECRL motor units but with a variable phase shift. The variable phase shift suggests that the muscles are not considered as a functional unit by the CNS during synergistic function.

2) Cross-correlation analysis of the motor unit contraction times of either the ECU or the ECRL indicated that synchronization exists among the motor units within each muscle. No other significant interaction between the trains within a muscle were detected. Cross-intensity analysis performed across the muscles showed no significant interaction between the motor units of the two synergist muscles. The absence of interactions between the muscles further supports the notion of the independent functioning of the muscles.

3) Analysis of the firing rate of motor units active during functionally related

changes from wrist extension to adduction or abduction demonstrated a motor unit discharge behavior which is consistent with a notion indicating a multichannel input to sets of motor units in the two muscles.

Future Plans — All the new data are currently undergoing scrutiny. During the next year, we plan to sift through the data and to prepare some clearer descriptions of the phenomena we have observed.

C. Muscle Fatigue

Muscle Fatigue and the Myoelectric Signal

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Purpose — The frequency spectrum of the myoelectric signal detected with surface electrodes changes during sustained muscle contractions. High-frequency components decrease while low-frequency components increase in amplitude. Various studies during the past two decades have searched for the cause of this frequency change and specifically have attempted to determine whether the change originates from the physical properties of muscle fibers, such as their conduction velocity, or originates from control properties, such as firing statistics.

Our investigations of this phenomenon have a twofold purpose: to gain knowledge concerning the process of fatigue within a muscle subjected to continuous usage, and to develop techniques for objectively assessing the fatigue rate of contracting muscles. The latter purpose is particularly interesting because it could ultimately result in a methodology for noninvasively and quantitatively measuring localized fatigue in human subjects. Our continuing hypothesis relates the change in the frequency spectrum of the externally detected myoelectric signal to intramuscular biochemical events that occur as the muscle generates force.

A review article documenting these associations was published by *CRC Critical Reviews in Bioengineering* in January 1985. Two presentations on this topic were made at national symposia in October.

Muscle Fiber Conduction Velocity

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Sponsor: Liberty Mutual Insurance Company

Purpose — In 1983, we developed a new cross-correlation technique for measuring the conduction velocity of the myoelectric signal along the length of the muscle fibers. The technique employs a four-bar electrode and double-differentiated signal output to suppress common-mode signals. In 1984, the technique was incorporated into a plug-in module in the MFM data acquisition system. Now we can more easily analyze and compare measurements of median frequency and conduction velocity.

Progress — Also in 1984, we devised a data-sampling program for the Digital PDP-11 microcomputer so that the myoelectric signal and its conduction velocity and median frequency are presented in a digital display. This will facilitate the storage and graphic presentation of data. In addition, a cross-correlation program to compute the conduction velocity from the sampled data has been developed. With this program, we can measure and compare conduction velocity and median frequency for different electrode locations. Plots of conduction velocity and correlation coefficient as a function of time and electrode position can be produced with this technique. These comparisons enable us to relate anatomical features, such as the location of innervation zones and tendonous portions of muscle, to measurements of the electrical signal. We are now a step closer to interpreting changes in the myoelectric signal that affect measurements of conduction velocity and median frequency.

Future Plans — During the next year, we plan to evaluate the MFM's capability for measuring the conduction velocity of the myoelectric signals in several muscles that are of different size and that have different arrangements of muscle fiber.

Two papers describing our work to date have been accepted for publication, one in the *Journal of Applied Physiology* and the other in the *IEEE Transactions on Biomedical Engineering*.

The Muscle Fatigue Monitor

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Sponsor: Liberty Mutual Insurance Company

Purpose — The portable Muscle Fatigue Monitor (MFM), which we upgraded in 1983, allows us to objectively measure muscle fatigue of subjects in both laboratory and field environments. The computer-assisted MFM automatically measures the median frequency of the myoelectric signal that occurs during a sustained contraction; the signal is detected with surface electrodes placed on a subject's muscle. Changes in the median frequency during a sustained muscle contraction are associated with the muscle-fatigue process. (A detailed description appears in our paper, "Muscle Fatigue Monitor (MFM): Second Generation," which was published in *IEEE Transactions on Biomedical Engineering* in January, 1985.)

Progress — In 1984, to further enhance the MFM, we fabricated a plug-in circuit module to measure the conduction velocity of the detected myoelectric signal. Similar to changes in the median frequency, changes in conduction velocity are strongly associated with a muscle's fatigue process. The additional measurement of conduction velocity therefore can be used for verifying an assessment of muscle fatigue.

We also developed some new and easy-to-use software to coordinate the operation of the median frequency and the conduction-velocity circuit modules. The new software package has been compiled on the VAX 750 computer. Interactive programs have been written to control the MFM, to sample data, and to process eight channels of fatigue-related information. Altogether, this software enables investigators to perform and evaluate a variety of complex muscle-fatigue experiments. With its hardware modules for measuring median frequency and conduction velocity and its new software package, the MFM is becoming a powerful tool for augmenting our understanding of the underlying processes of muscle fatigue.

Effects of Surface Electrode Location on the Myoelectric Signal Parameters

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Sponsor: Liberty Mutual Insurance Company

Purpose—Our muscle fatigue studies depend upon measurements detected with surface electrodes located above a contracting muscle. Measurements of median frequency and conduction velocity are sensitive to the location of the detecting electrode with respect to distance from the signal source, direction of the signal, and conduction properties of the underlying tissue. Consequently, we must establish criteria for locating the surface electrodes with respect to innervation zones and the tendonous portions of a muscle.

Progress—In order to determine the effect of electrode location on measurements of conduction velocity and median frequency of the myoelectric signal, we studied surface-electrode placement in relation to one muscle's innervation zone and tendonous portions. A series of tests were completed on the tibialis anterior muscle of the leg in 17 normal subjects. For each subject tested, we located the tendonous portions of the muscle and the motor points (the surface projections of the innervation zones). Surface myoelectric signals were recorded during short-term and fatiguing isometric contractions sustained at a constant force of 20 percent and 80 percent of the maximal contraction level. Numerous sites along the length of the muscle were tested and then analyzed by the MFM. In addition, measurements of the conduction velocity of the myoelectric signal along the length of the muscle fibers were computed on the PDP-11 microcomputer. (See above for more on the details of measuring conduction velocity.)

Preliminary Results—The tests indicated that, despite considerable variability in the location and number of innervation zones, the value of the median frequency changes in a consistent and repeatable manner. The force level of the contraction did not affect the changes observed except to uniformly increase the value of the median frequency. The rate of decrease of median frequency was not sensitive to electrode placement. These results were consistent with mathematical calculations formulated in this and other laboratories.

Results for conduction velocity demonstrated a typical pattern with respect to location. The distal, or lowest portion of the muscle provided the most reliable measurements. Although the changes in conduction velocity and median frequency at different locations were generally uncorrelated, the median frequency did increase with conduction velocity when the myoelectric signal was obtained from areas other than near the innervation zone and the tendonous regions. Similar studies are planned for other muscle groups.

This material was presented in October at the 14th Annual Meeting of the Society for Neuroscience.

Myobeeper

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Sponsor: Liberty Mutual Insurance Company

Progress—In the past few years, we have been describing the design and evaluation of the myobeeper, a portable biofeedback device that detects myoelectric signals from the surface of the skin above the muscles. In 1984, we documented our extensive testing of the unit in the busy clinical environments of six major hospitals in the Boston area. The results were favorable, indicating that the Myobeeper is well suited for use in clinical environments.

Our evaluation results appear in a paper published this year by the *Journal of Rehabilitation Research.*

Topical Anesthesia and Muscular Hypertonicity

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Sponsor: Liberty Mutual Insurance Company

Purpose—Some form of muscle rigidity (spasticity) affects at least 6 million people in the United States. The estimated annual cost to our society for health care and the reduction of manpower in the work environment exceeds $20 billion.

Progress—For the past 6 years, we have been experimenting with a noninvasive technique for rehabilitating patients who have suffered from strokes or head injuries. This technique entails applying a topical anesthetic to selected skin areas on the affected limbs. We have observed that these applications are associated with notable decreases in muscle rigidity and often with increased limb mobility. The short-term effects (within 1 hour after application of the topical anesthetic) have been studied in 80 patients; the long-term effects are currently under investigation. To date, we have collected various data concerning kinematic parameters, reflexes, and expressions of functional capabilities on 12 patients. During the past year, we continued to analyze these data.

The physiological mechanisms underlying the observed increase in movement capability are still not well understood. Our previous neurophysiological studies suggested an interaction between mechanoreceptors, or sensory receptors, in the skin and the motoneurons—nerve fibers that control muscle force and stiffness. In order to test the mechanical basis for this neural interaction, we used conventional goniometry to measure the active and passive range of limb movements.

Preliminary Results—The mechanical interaction between opposing muscle groups around a joint was measured by comparing the change in the active and passive range of limb movements. The passive range of movement served as an index for the reduction of muscle hypertonicity, or stiffness, and the active range of movement was used to measure the motor output to the muscle. In a few instances, the active range of movement increased with no change in the passive range, indicating an increased output of the motor system with no measurable reduction in muscular hypertonicity. Also, in a few cases, a decreased reduction of muscular hypertonicity with no measurable change in the motor output to the muscle was recorded. In most of our studies, however, where the upper and lower limb joints were tested for different movements (flexion, abduction, and so forth), a simultaneous increase in the active and passive range of movement was recorded. These results indicated a concurrent increase in the output of the motor system with a reduction in muscular stiffness. This association of neural influences provides a noninvasive approach for modifying the performance of the motor output in some patients with muscle rigidity.

Our neurophysiological and clinical observations in this area have continued to attract investigators in other institutions. At the 14th Meeting of the Society for Neuroscience, Pozos and colleagues from the University of Minnesota reported that application of topical anesthesia to the lower limb had reduced the amplitude of physiological tremors in normal subjects and had reduced pathological clonus, or involuntary muscle contraction and relaxation, in patients with spinal cord injuries.

A presentation was made in October at the 14th Annual Meeting of the Society for Neuroscience, and two manuscripts are being prepared to further describe these observations.

Muscle Fatigue and Back Pain

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Sponsor: Liberty Mutual Insurance Company

Purpose — During the past decade, new noninvasive techniques for extracting information from surface myoelectric signals have become available, and proven techniques have become more reliable and quantitative. These developments enable us to assess the performance capability of individual muscles as well as groups of muscles.

As many as 75 million Americans now suffer from back problems, and each year seven million more people develop problems. Back problems are estimated to cost a staggering $11 billion each year due to diminished work productivity, and many billions more are spent for medical treatment. Improved methods for assessing back disorders could help to diminish the problems and the financial burden of this disabling condition.

Progress — During 1984, we began to explore the possibility of using our median-frequency technique, along with measurements of conduction velocity, to assess the performance and interaction of the muscles in the trunk. We hope to develop a reliable screening method for distinguishing between the performance of trunk muscles in individuals with and without back disorders.

Future Plans — We will continue this effort by studying the myoelectric signal of several trunk muscles in healthy individuals and in individuals who have experienced episodes of back pain. The signal will be detected through surface electrodes, and accurate measurements will require a special restraining device to reliably stabilize the trunk. The considerable effort anticipated for constructing such a device will assure that the muscle activity observed is actually associated with the flexion or extension torque being monitored.