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《招待講演》

Physical Medicine and Rehabilitation : Past, Present, and Future

Frederic J. Kottke, M.D.,Ph.D.*

Introduction

Physical methods for relieving pain and treating injuries were used in prehistoric times, long before written records, based on the observation that the application of heat, massage, stretching relieved pain and hastened healing after trauma to the musculoskeletal system. Physical methods of treatment of pain and injuries are recorded in cuneiform on the clay tablets of the Sumerians in 5000 B.C. Throughout Greek history from 2500 B.C., and especially at the time of the Hippocratic school of medicine at Cos, the description and prescription of physical treatment of injury and illness were recorded, using thermotherapy, hydrotherapy, massage, stretching, exercise, heliotherapy, and also electrotherapy by the application of torpedofish.

Extensive use of physical therapy continued throughout the known world during the period of the Roman Empire. The Romans recognized the benefits to health of clean water and the washing away of sewage although they did not understand the basis of infectious diseases, but thought the causes to be internal and external toxins. Spa therapy fitted into this concept, and throughout the Roman world, in Europe, Africa, and Asia, wherever there were natural hot springs, spas were established providing physical therapy. Through the Medieval Period up to the Eighteenth Century spa therapy continued in those centers originally established by the Romans. However, the Christians of the Middle East and Europe tended to repress earlier methods of medical practices as the behavior and beliefs of heathens and focused on Christian faith-healing. Because of this rejection of earlier medical knowledge, or failure to record it, these medical practices continued only at spas. Observations of health benefits of spa therapy stimulated the development of the hypothesis that the mineral content of the spas contained miraculous healing powers and that toxins developed in or entering the body were the cause of illness and had to be removed. This concept of healing waters and toxins causing illnesses persisted in some cases even into the 20th century.

Especially after the middle of the Nineteenth Century great scientific advances suddenly changed medicine from a system of beliefs to medicine based on sciences, which led to the development of modern medicine. The most important of the these discoveries were : bacteriology, antisepsis, anesthesiology, pathology, and physiology. About 1850 Louis Pasteur, a

* Professor Emeritus in Physical Medicine and Rehabilitation, University of Minnesota Medical School, Minneapolis, Minnesota, U.S.A.

French chemist, was hired by vintners to find why the wine in barrels was turning to vinegar. His research led to the discovery of bacteria and established that bacteria (microorganisms) were the cause of infectious diseases. This discovery greatly changed the concept of illness and the reliance on non-specific therapies. Joseph Lister, a Scottish surgeon, ten years later, developed the method of preventing infections in surgical wounds by spraying the area with phenol, and established the practice of antiseptic surgery. From antiseptic surgery, by small steps over the next few years, surgeons proceeded to develop the clean fields of aseptic surgery.

In 1846 Morton introduced ethyl ether as a general anesthetic for surgery, which changed surgery from a rapid painful procedure to a careful scientific procedure which could be conducted under the greatest of precision for prolonged periods of time. Likewise effective anesthesia made it possible to conduct surgical experiments on living animals.

At about the same time histological pathology developed under the leadership of Rudolph Virchow, of Berlin, and his colleagues. It was demonstrated that each disease produced specific changes in cells in the body, so pathology became the final verifier of the medical diagnosis. Today histological and chemical pathology are the essential tools of definitive diagnosis. Physiology developed as a science during a parallel period. Physiology is important for understanding how each of the organs of the body function and how all organs work together, but since pathology rather than physiology difines specific medical diagnoses, pathology reins supreme for identifying the causes of death. The techniques of physical therapy are related more to changing or improving physiology than they are to attacking specific pathologies. Until patients survived with chronic disabilities neither physiology nor physical therapy were considered to be of primary importance in the practice of medicine. Long term survivals after disabling illness now bring physical medicine and rehabilitation to the fore to restore patients to their **optimal quality of life**.

In spite of the centuries of observed effectiveness of the various modalities of physical therapy medical scientists were not willing to accept the physical means of therapy on their apparent face value without subjecting them to scientifically controlled tests to determine the effectiveness of each. On the other hand practitioners of physical therapy, who had accepted these various therapies on the basis of long and repeatedly successful use, were often slow to subject these measures to the necessary scientifically controlled testing. For this reason certain modalities and methods of physical therapy, which have been established by prolonged repeated successful application have been rejected by medical scientists outside the practice of physical therapy. So those practices, formerly recognized as useful but now rejected in general medicine and by the various insurance agencies, need to be demonstrated by means of scientifically planned tests to, indeed, be useful for the treatment of defined pathologies.

During the early twentieth century Physical Therapy in the United States developed mainly from two sources. Central European physicians, immigrating to the east coast cities of America brought with them and introduced the various components of spa therapy, as a very important aspect of their medical practices. Spa therapy was used empirically, based on age-old "authority" as the treatment for a wide variety of diseases following the basic concept that "toxins must be removed from the body." The availability of many natural hot springs provided the milieu for hydrotherapy for such treatments. However, by 1950 research had discredited the alleged benefits of the minerals in hot springs, so the use of water as a means of cleanliness and the application of heat remained as the therapeutic benefit. The physiatrist, arising from this background, who was one of the most outstanding leaders in teaching, research and organization of the field of physical therapy as a medical specialty was William Bierman of Mt. Sinal Hospital, New York.

The second source of physiatrists in the early Twentieth Century was World War I. The many wounded soldiers created a demand for doctors in the military hospitals to use physical therapy for treatment and restoration of musculo-skeletal injuries. There was the recognition at this time of the need also to restore the surviving but disabled soldier at least to the level of independent self-care and a sedentary life style. Also, vocational placement consistent with his disability was just beginning to be considered and represented the beginning of vocational rehabilitation. A number of the physicians who became acquainted with the valuable uses of physical therapy carried over this knowledge into their practice in the civilian hospitals. About a dozen physicians who had learned the uses of physical medicine in the war returned to positions as professors in medical schools. The most outstanding of these as a teacher and national leader in the organization of physiatry as a medical specialty was John Coulter, who taught at Northwestern University in Chicago. Several physicians, who had had a background in physical education, were attracted to physiatry while serving in the Army Medical Corps, and returned to civilian practice as teachers in medical schools, among them George Deaver. These educational positions provided, not only for the teaching of medical students, but also for the beginning of organized research on the modalities of physical medicine. The discussion of some of the specific advances through research will be considered after we have completed the discussion of the chronology of the development of PM & R as a medical specialty.

The Organization of Physical Therapy as a Medical Specialty[1)]

In 1920 the First American Congress of Physical Therapy, X-Ray, and Radium was held, to be attended by any physicians interested in the use of any physical means for diagnosis or treatment in medicine or surgery—heat and cold, water, ultraviolet, massage, manipulation, exercise, radiation, radium, X-ray, and electricity including electrosurgery. This was the beginning of the American Congress of Rehabilitation Medicine (which evolved through a number of different names over two decades but continues to have as members individuals from a number of health professions. In 1936 the Congress organized the American Registry of Physical Therapy to test and certify therapists who had acceptable training to be qualified practitioners. By 1938, when the American Society of Physical Therapy Physicians (the predecessor of the American Academy of Physical Medicine and Rehabilitation) was established for physicians specializing in physiatry there were only 40 qualified members in the United States. This organization did not grow to the 100 members required for a recognized specialty board, the American Board of Physical Medicine, until 1947.

Physiatry Specializes in the Treatment of Dysmobility

The concept that physiatry had become a specialty treating DYSMOBILITY in order to increase the QUALITY OF LIFE grew to awareness by 1950 due to the almost simultaneous occurrence of five major developments occurring in the 1940s. The first was World War II which resulted in many seriously wounded soldiers and created a shortage of manpower, both for military and civilian service. This shortage created a demand for more soldiers and more civilian workers and stimulated a major expansion of the teaching of physical medicine in medical schools in order to increase the number of physiatrist for the Army and for civilian hospitals.

Concurrently in 1943 the Baruch Committee on Physical Medicine was funded by Bernard Baruch, a wealthy philanthropist whose father had been a spa therapist, to evaluate the benefits of physical medicine and if validity were established to promote research and education in physical medicine. This committee was composed largely of medical school dears, and research scientists, and Dr. Frank H. Krusen was selected as the Executive Director. The need created by the war plus the focus on education and research provided by the Baruch Committee greatly augmented the rate of formation of new departments and 50 more Departments of Physical Medicine were established in medical schools. The Baruch Committee under the leadership of Dr. Krusen facilitated the recruitment of medical graduates to academic and clinical careers in Physical Medicine. At that time, also, the specialty training program for residents in physiatry was expanded to three years. Dr. Krusen was an ideal physiatrist for this position. He was a vary convincing advocate of the great value of physical medicine and a recruiter of future academic physiatrists. He was highly knowledgeable as a treating physiatrist and greatly admired by his patients and the physiatric residents training under him. He established at the Mayo clinic an outstanding, productive research program so that all of his graduate physicians participated in research during the course of their training. In addition, he was the foremost physiatrist in bringing other physiatrists together, both nationally and internationally, to organize the American Congress of Rehabilitation Medicine, the American Society of Physical Therapy Physicians, later the American Academy of Physical Medicine and Rehabilitation, and the International Congress of Physical Medicine and Rehabilitation. In 1939 he wrote the first general textbook of Physical Medicine. Because of all of these outstanding characteristics of advocacy, leadership, education, and research in physical medicine and rehabilitation he can truly be thought of as the Father of Physical Medicine.

The concept of rehabilitation to optimal function again in society was stimulated from quite another source, initiated by the observations, advocacy and publications of Dr. Howard Rusk, the Father of Rehabilitation in the United States, although there had been slowly developing interest is that direction by doctors of Physical Medicine as they learned to deal with patients with severely disabling conditions who would still live for many years. Dr. Rusk was an internist in St. Louis Missouri, when in 1939 he entered the Medical Corps of the Air Force and was assigned to Jefferson Barracks, which was convalescent station for injured airmen. Under Air Force and Army regulations a sick or injured soldier was not allowed to return to duty until he was totally fit, and until that time was assigned to a convalescent unit. Dr. Rusk observed that convalescing soldiers, sitting around a barracks doing nothing, might become more deconditioned physically and more depressed psychologically rather than regaining fitness and drive to return to action. As Rusk made his rounds many of the soldiers expressed to him the longing for activities and interests of which they were deprived. Rusk conceived that a prescribed program oa progressively more vigorous physical activities would hasten the regaining of strength. He convinced his commanding officer to let him set up a controlled experiment between two barracks of convalescing soldiers. The soldiers in the "control" barracks carried on as they had been doing. But soldiers in the test barracks were ordered to engage in a regime of exercises throughout each day, which progressed from light activities to heavy, and included sports and increasingly prolonged physical exercise until they could again participate in required troop assignment of day long distant marching with full pack and rifle. To modify the boredom of these exercise requirements, competitive games of increasing intensity were also introduced. Under this directed rehabilitation program the period between disability and restoration to full capacity to return to duty was greatly shorten. This experiment flew in the face of the older medical concept which had existed in America and Great Britain for a century that rest was the way to restore health and strength after illness or injury, and the weaker the individual was the longer he should rest in convalescence.

As a result of this controlled experiment showing the value of prescribed "Rehabilitation" the Military made Rehabilitation a requirement for all of their medical programs. Rusk presented his data to the members of the Civilian Medical Manpower Board who were so impressed that they arranged to set up a national conference on early ambulation for all civilian doctors throughout the country. The outcome of this conference was a major change in the concept of post-illness convalescence. Instead of a post-illness or post-surgical convalescence of total bed rest for two to four weeks, the time after illness or surgery for bed rest was reduced to days, or even hours, depending on the cardiovascular tolerance of the patient. The roles of Physical Medicine and of Rehabilitation Medicine as individual medical specialties now overlapped in the post-acute period and after several years of negotiation, with approval from the American Board of Medical Specialties, the two combined into one accredited specialty of Physical Medicine and Rehabilitation in 1949. The combination of the two philosophies broadened the field of specialty application to treat all potentially-surviving patients from the acute phase of their illness until they were restored to their optimal capacities physically, mentally, socially, and vocationally to return to and participate in their homes, communities and recreational activities.

A concurrent problem of the 1940s was a poliomyelitis epidemic which crescendoed throughout that period, badly frightening the civilian population and greatly increasing the public's demand for physical medicine services. In 1941 Sister Elizabeth Kenny, a nurse who had gained experience in the treatment of polio in her native Australia, came to the United States and Minneapolis with the claim that her treatment of polio would prevent or greatly reduce the paralysis and deformities which were the common sequellae of polio. The treatment by (1) extremely hot, but rapidly cooling, damp-dry packs, (2) early mobilization of involved muscles to prevent the development of "stiffness," and (3) precise muscle retraining, did result in prevention of sequellae of the patients who had polio with the resultant tightness of connective tissues and muscles, but not total destruction of motor neurons. These patients, treated by the Kenny method, did not have residual restriction of motion nor deformities. Careful, specific retraining of control of weeakened prime mover muscles resulted in better control and coordination. As a consequence they had more useful function of their upper and lower extremities to perform the usual activities of daily living, and they needed less bracing and less orthopaedic surgery than was so often the case for polio patients treated by the previously-used American method of immobilization while acute, and bracing or surgery later as indicated. The success of physical therapists and physiatrists who used the Kenny method for the treatment of polio created a great demand for an increased amount of training and the introduction of physical medicine and rehabilitation into civilian hospitals. Increased research on neuromuscular problems encountered in the acute stage of polio and in the later stage when paralysis resulted in severe weakness and respiratory problems of polio patients also was stimulated. The development of a highly-effective polio vaccine ended this epidemic but

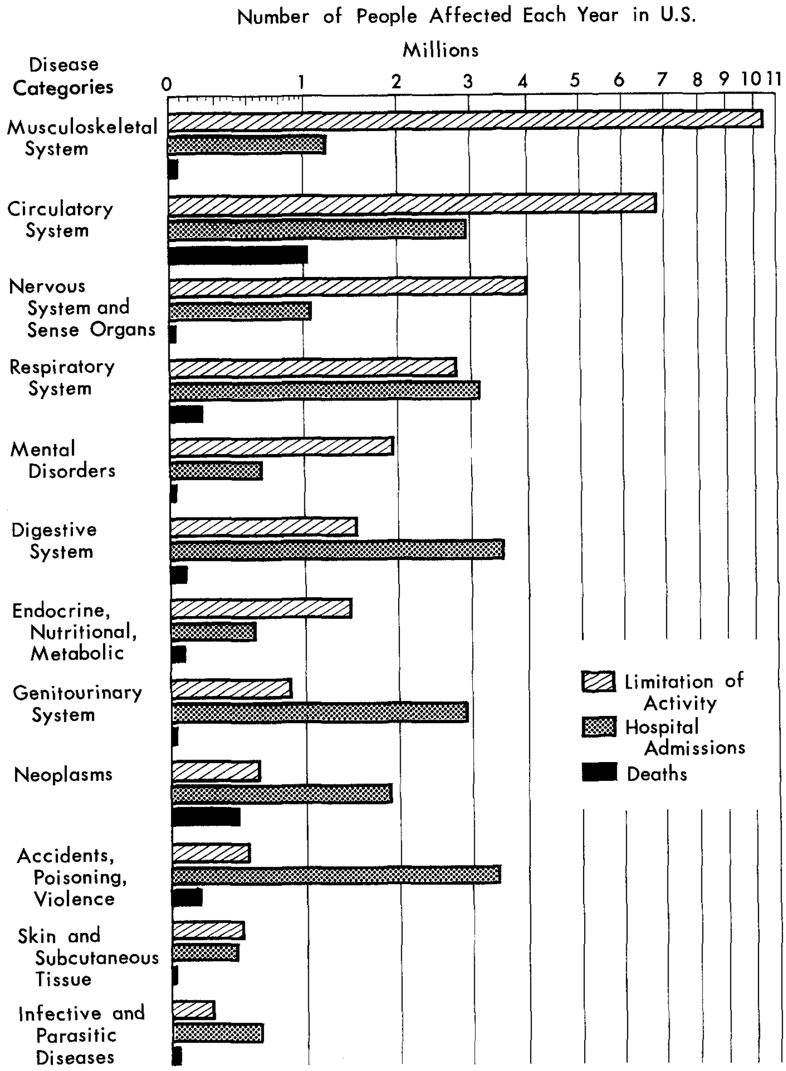

Fig. 1 The 14 major categories of diseases indicating the annual occurrence of disability, hospitalization, and death

the civilian population had learned that even severely disabled persons could return to an active and productive life in normal society.

Finally the advent of antibiotic drugs dramatically changed the survival of patients with infectious diseases and post-surgical patients so that quite suddenly many patients, who previously would have died, were surviving with disabilities which added to the cost of care or interfered with their returning to their homes and communities after acute treatment in the hospital. This, too, rather suddenly increased the demand for PM & R services within the hospital and in extended care facilities established for those patients who no longer needed the very expensive acute nursing care of the acute hospital. The nevelopment of a whole armamentarium of antibiotics against acute infections changed the entire practice and extent of medicine from a fight against acutely fatal infections to physician management of patients with life-long disabling medical problems. (**Fig. 1**)

Techniques were developing to train patients to assume more of their self-care as they regained ability. At the same time hospitals and extended care facilities developed rehabilitation services directed to helping the patient become progressively more self-sufficient to resume the normal activities to be found in his

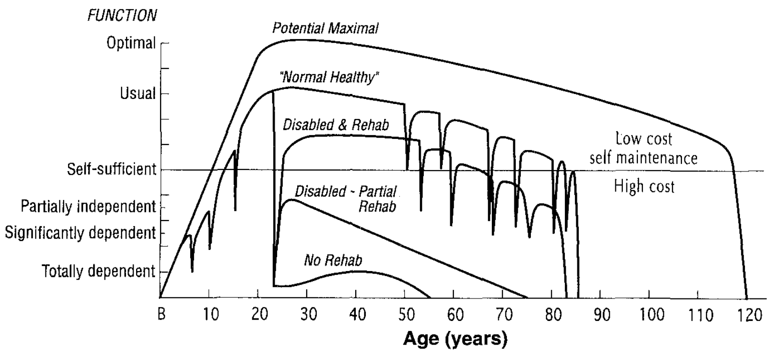

Fig. 2 Development and maintenance of performance level throughout life plotted against age. The potential maximal performance is shown, compared to the current normal individual, and the disabled patient, with and without adequate rehabilitation. Restoration to the level of self-sufficiency or above greatly reduces the cost of maintenance. Note how each episodic illness temporary decrease performance and self-sufficiency

community. These factors combined to focus on the achievement of an optimal level of performance, or as HIGH a QUALITY OF LIFE as possible within the limitation of the permanent disabilities of each individual. A HIGH QUALITY OF LIFE requires high MOBILITY, so although dysmobility is not necessarily fatal, rehabilitation from DYSMOBILITY is necessary to restore that HIGH QUALITY OF LIFE to which we all aspire. The designation of those qualities which each of us considers to be most important for our Quality of Life may vary, but they include: freedom from pain, ability for personal self-care, ambulation, self-feeding, dressing, living in a home of the patient's choice, socialization and interaction with others, a productive vocation, avocational activities, community participation, and recreation. All of these require mobility in a variety of ways, and impairment of mobility prevents the participation which we desire to obtain our high quality of life. *Optimal restoration of mobility, therefore, is essential to regain the highest quality of life possible within the limits of the disability.*

Figure 2 is a graph of human performance showing development from birth, when an infant is essentially immobile and helpless, progressively through childhood and youth to reach peak performance early in the third decade of life. The rate of increase in performance can be speeded significantly by proper training so that by age 18 years the person has achieved peak level. Then with continuing use of his/her abilities that person retains that peak level until about 35 years of age, at which time there begins to be a gradual, slow decline until 50 to 60 years, at which time the rate of decline increases. At 70 years of age muscular performance of an elderly man is about equivalent to that of a 12-14 year old youth. We know today that with proper care of health the time of survival can be greatly lengthened from 75 years to more than 90 years, and there are indications that when throughout life there is successful maintenance of health without serious illness, and exercise is performed regularly, maintenance of a high quality of life has been projected to extend up to the final preterminal decline at 120 years.

The great developmental need of PM &R, as a specialty, in the 1950s and 1960s was to obtain adequate financial support to conduct research on the many problems which were observed to accentuate the dependence of handicapped persons. There were two obstacles to be overcome. The public had greater interest in support of voluntary agencies and philanthropies which devoted their money to solve the problems of diseases which were quickly lethal and much less interest in chronic disabilities, for which the research did not appear to be so urgent. The second obstacle was the direct opposition from those research interests already in the National Institutes of Health, who were concerned with finding answers for the acute deadly problems of health. Because PM &R focused its knowledge and application on methods of therapy to reduce disability and dysmobility, while the acute medical specialties were focused on problems of diagnosis and pathology of diseases, there was a lack of common interest and a common approach in the research programs. This difference in approach had led to the conviction by participants in the National Institutes of Health that any added centers should maintain the focus on the pathologies of organ systems, and should not be focused on the problems of therapies which seemed to them to have an entirely different orientation. Therefore, there was opposition from the acute medical specialties, which had already gained the support in the National Institute of Health (NIH), to an Institute of Medical Rehabilitation which was devoted to research to develop and improve therapies, especially for chronic rather than acute deadly diseases. So, failing to get entry to the National Institutes of Health, which would appear to be the natural research institute for all aspects of medicine, attention was turned to another agency, the Vocational Rehabilitation Administration. In 1962, with the combined advocacy of Dr. Krusen and Dr. Rusk, Research and Training Centers in Rehabilitation were set up under long term grants from the Vocational Rehabilitation Administration. These and project grants provided for research on a small scale with much less support for medical research programs than the research endeavors of the NIH, but also included support for rehabilitation counseling and social issues related to rehabilitation. It was not until two decades later that a Center for Research an Medical Rehabilitation was finally established in the NIH.

Now let us look at some of the advances in knowledge and practice which have occurred for reducing dysmobility and increasing the quality of life for disabled persons because of research. There is not sufficient time to cover all of the advances of PM & R over the last 50 years because there are many. Perhaps the outstanding addition to physiatry was the development of electromyography. In 1931 Adrian received the Nobel prize for his studies on the electrical currents produced by muscles during their quiet and active states. This diagnostic technique, electromyography, was taken up almost immediately and soon physiatrists were using it for the diagnosis of normal and abnormal conditions of muscles and nerves. It has become an extremely important part of physiatric practice and continues to be of major interest for research and practice.

The use of electricity as therapy or diagnosis in medicine goes back many centuries. Because electricity is poorly understood by the average person there is an imputed metaphysical or magical aspect about it. These magical aspects of electricity have been used by charlatans, alleging curative effects, from ancient times right up to modern times. These implied magical properties have caused physicians of orthodox medicine to be suspicious about all claims for the effects of electrotherapy, and unfortunately, often the claims of the values of electrotherapy have been rejected out of hand rather than tested scientifically to determine whether or not that claim is valid. Throughout the twentieth century there have been claims made for electrotherapy being useful for localized reduction of fat for obesity, for healing of decubital ulcers, for extraordinary strengthening of muscle, and a vast variety of other claims. Until methods were developed for producing electrical currents by other means than direct currents by the battery or interrupted alternating currents by the induction coil it was difficult to test and challenge claims made of the amazing effects of electrotherapy. In recent years it has been found that there are many effects which can be produced by electrical stimulation of different types of cells. Stimulation of nerves, both transcutaneously or by implanted electrodes, makes it possible to activate muscles which are isolated from normal innervation by upper motor neuron lesions. Prolonged transcutaneous stimulation has been used to correct or reduce idiopathic scoliosis. It has been established and is now in active medical use that appropriate transcutaneous electrical stimulation (TENS) of sensory nerves can produce effective analgesia for relief of pain. Electric currents of only milliampere intensity, either by implanted electrodes of by external induction have been used to promote the formation of callus in the healing of fractures. Functional electrical stimulation (FES) has been developed to activate paretic muscles for patients with upper motor neuron lesions. Peroneal nerve stimulation, suitably triggered by a switch under the heel can relieve foot-drop for hemiplegic or cerebral palsy patients. FES for tetraparetic patients after spinal cord injury may enable them to control wrist extension or knee flexion-extension for walking. For very high tetraplegic patients who have lost their control of breathing, electrical stimulation of the phrenic nerve has proved to be successful. Use of potentials of the forearm muscles to trigger the action of the forearm prosthesis has also been developed. The practical questions of application of functional electrotherapy for continuing use in community practice have not been worked out completely and more development needs to be done.

Significant progress has been made in research on neuromuscular physiology and exercise. This is of prime importance because it is central to the problem of reducing dysmobility. For the century prior to 1940 in the practice of medicine in America and England it had been a standard postulate that when a body was sick it needed rest to heal and the sicker the body was, the longer should be the period of rest. Oddly, the rest applied not only to the organs in which the pathology occurred but also to all of the remainder of the body. Thus, when a person was sick, muscular work should not be done. During convalescence from any illness exercise should be kept very light until the patient was fully recovered. In 1942 DeLorme, who had been a weight lifter, challenged this assumption when he found that very light exercise for injured soldiers did not improve their performance. Using the system of progressive resistive exercise from 10% to 100% of strength DeLorme[2] found that disabled and weak patients increased their strength by about 5% per week. His publication of this research initiated a new insight and the beginning of systematic effective exercises in medicine.

The combined information from recent studies of muscle histology, chemistry of muscular contraction, and the physiology of muscular exercise have added greatly to our understanding of exercise.[3-5] Exercises can be divided into those which increase momentary maximal strength or force, using the energy already stored in the actin-myosin apparatus of the sarcomere; maximal power, or the ability to do work at a maximal rate, using the anaerobic metabolism of the enzymes in the mitochondria; or endurance, depending on the capability to supply oxygen and nutrients to restore the anaerobic metabolism of the sarcomeres. Training to increase capacity of each of these components of muscle metabolism has been shown to have special requirements. Studies reported by Keul, Doll and Keppler[3] analyzed the instantaneous proportion of these various substrates throughout a 130 second period during a sustained maximal muscular contraction of human subjects. When the intensity of

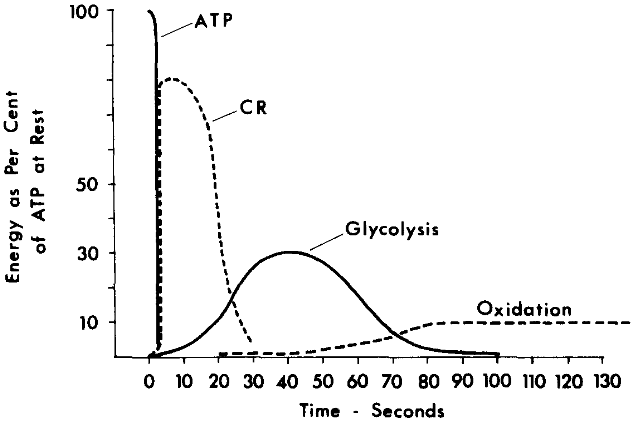

Fig. 3 Instantaneous sources of energy for anaerobic and aerobic metabolism over 120 seconds of a sustained maximal contraction of human muscle. Available energy from each source is plotted as percentage of maximal energy available at the instant of beginning contraction of rested muscle

metabolic activity is adjusted to the isometric tension produced by muscle during sustained voluntary maximal contractions during the first two minutes[4,5] the energy available from each substrate is derived as shown in **Fig. 3**. This data showed that the concentration of ATP in the sarcomere falls from maximum to near zero in less than 5 seconds, and with it the strength of the contraction.

Initiation of a maximal isometric tension from rest can be maintained for only 1-2 seconds before beginning to fall.[5] When the ATP and the isometric tension has fallen to 80 percent the breakdown of creatine phosphate begins to restore ATP at that level. The build up of creatine stimulates the glycolysis of carbohydrate due to enzyme activity in the mitochondria. The rate of production of anaerobic energy from enzyme activity in the mitochondria peaks at 30-45 seconds at only 30 per cent of the maximal energy from ATP, and then declines rapidly. This anaerobic metabolism provides the energy producing maximal power to do work over that period of only about 45 seconds and then becomes totally dependent on the slower aerobic metabolism. For prolonged activity we are dependent on oxygen consumption or aerobic metabolism which is limited by the ability of the circulation to supply oxygen to the muscle.

In 1952 Muller[6] and his associates, in Germany, began to publish their studies on very short term, isometric, maximal exercise. They reported that a six second isometric maximal exercise (and later a one second isometric maximal contraction[4]) was as good for increasing maximal tension, or strength as exercise of any greater duration. This study was repeated and confirmed by Rose.[7] Multiple daily six second exercises interspersed with rest periods of some hours' duration was slightly more effective for increasing strength to the physiological maximal that single daily exercise. They also showed that isometric exercise of muscles which had become extremely weak could bring those muscles up to maximal physiological strength again, at essentially the same rate as for normal muscles. The physiological effect of one isometric maximal contraction lasted for 14 days, so that one maximal contraction of a muscle every two weeks would maintain existing strength. The muscles of most "normal" persons were found to be at less than 70% of potential physiological maximal strength rather than at maximal, and the multiple daily activities requiring more than 30% of maximal strength were sufficient to maintain the muscles at the usual level. This study was repeated and confirmed by Rose. These studies showed that brief maximal isometric exercise was the most effective and efficient and the least fatiguing way to increase the strength of muscles of patients. Athletes and directors of sports programs immediately adopted this method of exercising which resulted in a remarkable increase in performance for those sports requiring instantaneous exertion of maximal strength such as jumping.

Studies on power producing exercise revealed that maximal power could be produced for only about 45 seconds after which it declined to the level of endurance exercise using aerobic metabolism.[4,5] Exercises which increase the ability to produce power must cause exertion which fatigues the muscle and stimulates the increase of glycolytic enzymes in the mitochondria[8]. Repetitive exertion of force greater than 30% of maximal strength until the muscle was fatigued was found to be necessary to increase power and bulk of muscle. The maximal metabolic rate of mitochondrial metabolism is only about 30% of the rate if instantaneous ATP metabolism.[5] (**Fig. 3**)

Endurance exercise, exercise which can be maintained for more than 10 minutes, is dependent on the circulation of the blood for the supply of exygen and nutrients to the muscle and removal of carbon dioxide and other metabolites. Although endurance exercises are usually repetitive contractions continued for many minutes or hours, it has been found that interval exercises in which the muscles were contracted repeatedly at a force which caused profound fatigue after 2-4 minutes, and which produced metabolites at higher rates than could be produced during a prolonged exercise, interspersed with short rest periods, were superior to prolonged steady exercise to increase endurance. After 2 minutes of maximally exerted effort the metabolism is reduced to the rate at which aerobic metabolism can restore, in reverse order the cascade of anaerobic metabolism. Any muscular activity continuing for more than two minutes becomes dependent on, and occurs at the rate that oxygen is available to support the oxidation of lactic acid. This means that after the exhaustion of anaerobic metabolism, the ATP is being restored to the sarcomere only 10-15% as fast as it is consumed by the sarcomere during a maximal muscular contraction. It has been found that the best way to increase the capacity for endurance running is interval training, which means two to four minutes of highest intensity exercise alternating with two to four minutes of rest, and repeated for many bouts. Bannister, the Englishman who was the first to run a mile in four minutes in 1954, trained by repeatedly running up the steep slope of a sand pit. Alternate training of this type entails a high level of anaerobic metabolism of the mitochondria, and the breakdown products of this anaerobic metabolism prove to be the maximal stimulus for stimulating an increase of aerobic metabolism. In the same way the very short term maximal isometric contraction produces metabolites which stimulate the maximal activation of anaerobic mitochondrial metabolism. In this way we have a cascade of decreasingly intense metabolism within the muscle. We know that we increase maximal tension of the muscle only by initiating maximal force of contraction, which metabolizes ATP. We know now that the breakdown of ATP will stimulate the anaerobic breakdown of creatine phosphate and of carbohydrates to lactic acid. We know that this anaerobic reaction stimulates the increase of the circulation through the muscle to maximize the oxygenation of lactic acid. This cascade of metabolic reactions does not appear to work in the reverse direction, so that prolonged performance of endurance exercises does not increase either power or strength. And performance of power exercise, appears to increase maximal strength only as extreme fatigue forces the maximal use of whatever ATP is available. Even repeated exertion of maximal isometric exercises, which does increase the peak of power production, does not increase the ability to prolong that exertion of power. We have, therefore three kinds of exercise from which we must select and use judiciously the specific exercise which will most efficaciously produce the end result we wish to obtain. We see the exertion of instantaneous maximal strength in the jumpers in basketball. We see the 40 second use of maximal power in the hockey players. And we see the use of endurance metabolism in the long distance runners.

Finally, we must be concerned with exercise

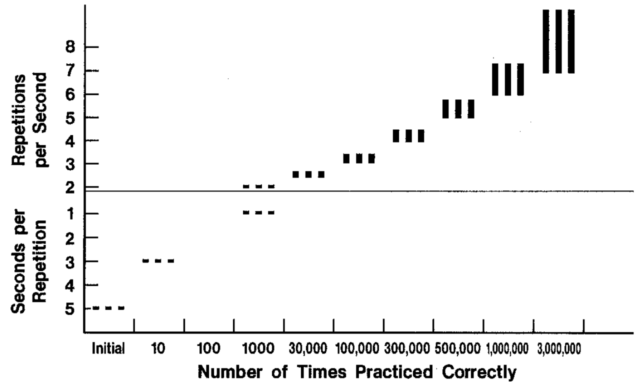

Fig. 4 Concept of time and repetitions required to train engrams of coordination involving multiple muscles to maximal speed. Note that lower one-half of graph represents time of response of conscious control of a single muscle in seconds per repetition, and upper one-half of graph represents the number of responses of engram patterns in repetitions per second, both plotted against the number of repetitions necessary to learn

which increases the coordinated use of multiple muscles with the correct sequences of contraction of agonists and inhibition of antagonists, appropriate timing of reversals, and correct sequencing of the cocontraction of supporting muscles near or distant in the body. This illustrates that coordinated motion is far more complex and has far more elements than can be managed by cognition, which can attend to only one activity at a time. For efficiency of movement, muscles which do not contribute to a pattern of motion must not be active. There has not been agreement regarding the neurophysiological mechanisms of the central nervous system which organize and produce coordination. Although it has been found that the precise control of the individual muscles is initiated by the discharge of corticospinal neurons, located in the motor cortex, with axons running uninterruptedly to the anterior horn cells, cognition cannot keep track of changes of more than two motions per second.[9] For that reason no similar mechanism for coordination can exist through conscious control from the cerebral cortex. Moreover, even for control, only 1-5% of motor units of muscles have such innervation, so that strong contractions cannot be produced solely by this mechanism. Since the discovery of the motor cortex and the pyramidal corticospinal tracts it has been postulated by numerous neurophysiologists that there must be a similar organization of neurons somewhere in the cortex which produces coordinated movement. However, after nearly 100 years of experiments such a "coordination cortex" has not been found. Following the research and arguments of Jackson,[10] Sherrington,[11] and others, a number of current investigators now think that coordination results from a hierarchic organization of the nervous system so that the well demonstrated actions of the spinal reflexes are organized to coordinate over a broader range by a higher center in the hind brain and that this again is modulated by a computer-like organization of the cerebral forebrain to produce the exquisite degree of coordination which the body can achieve. Again, like a computer, this mechanism of the forebrain must be programed to develop engrams in order to carry out precise, rapid, strong, multimuscular activities. (**Fig. 4**) Whether this programing is a matter of repetition of that pattern millions of times or whether engrams develop by some other means is fiercely argued. At the least it is clear that engrams do not develop in the absence of prior performance of those patterns with prolonged, precise practice.

Research has been carried on in all other aspects of rehabilitation medicine as well, devoted to relieving disabilities, restoring remaining abilities by rehabilitation, substituting environmental aids when restoration is not possible, and developing community support to return disabled persons to as nearly normal as possible a full life of optimal quality.

Research Needs for the Future

When we look into the future of Rehabilitation Medicine there is extensive research which needs to be carried out to maximize **mobility** and a **high quality of life** for the disabled patients, making use of the advances of science in every area. In all of these areas research needs to be continued to achieve further gains in rehabilitation medicine. As long as it is found that the handicapped individuals do not have an optimal quality of life it is possible that further gains can be achieved. For children with disabilities, cerebral palsy for example, there is lack of understanding of the time and the sequence of physical training and development and intellectual training and development. Both seem to require more time than is available in the day. Conjoint programs for training throughout the period of childhood always seem to result in neglect of one or the other need. Carefully designed studies need to be carried out to develop more effective programs for intellectual-physical development. For adults with congenital or acquired disabilities, **Quality of Life** is the goal to keep in mind. Removal of dysmobility so that the individual can provide self-care and independent ambulation and other home and community activities is a basic requirement. Better methods need to be developed to improve this self-sufficiency.

Improvement in mobility requires further research on connective tissues as well as on muscular performance. Both ends of the connective tissue spectrum of improving extensibility of connective tissues and increasing the strength and resistance to stress are needed depending on the condition of disability of the patient. We know that under normal conditions an individual is the most flexible in childhood and loses flexibility as he/she grows older. Superior skill in the performance of physical activities which require both flexibility and high coordination occur when the individual is 13 or 14 years old, and at his/her highest degree of flexibility and has had prolonged (constant) coordination training for at least 6–8 years. Finding ways to preserve that flexibility would be of great advantage both to athletes and to disabled individuals who must continually battle progressive development of stiffening connective tissue which results in progressively decreased performance with age. On the other hand, if we learn how to develop stronger formation of connective tissues for healing and maintenance of ligaments, tendons, and adventitia of blood vessels, we can hasten recovery from injuries or even decrease the likelihood of injury.

Research on neuromuscular physiology needs to be continued, especially research on effective methods of developing coordination engrams in patients with CNS damage. The more severely these patients suffer damage, the greater is the need. Does precise, prolonged training, using the simple control of individual muscles which the patient is able to perform, and then combining and practicing those individual precise motions as they are brought under control, lead to simple engrams of coordination, which can, in turn, be linked into larger and larger engrams by precise practice. This method had not yet been tested in a way which gives us definitive answers. For children the development of educational play activities which will use this paradigm is necessary to make use of the day's activities for the millions of repetitions necessary under this hypothesis. For adults activities can be defined more specifically as exercises, which, again, must be performed millions of times to develop good engrams of coordination. Even for adults, exercises which contain an inherent reward encourage prolonged practice. The varieties of activities which need patterns or sequences of training to develop the needed engrams are legion. The steps necessary to achieve each of the self-care activities, ambulation activities, vocational activities, and recreational activities, each need a sequence of progression from control to simple coordination, to linking of units to make up complex coordination.

For geriatric patients research is needed on methods to delay or prevent loss of both mobility and intellect. Is prescription of daily activities of mobility and of intellect a means of protection against the progressive loses of aging? If so, which activities are most important because they are the most effective.

Summary

As we follow the history of the development of physical medicine from earliest times, when physical measures were used for symptomatic relieve of pain, through the development of spa therapy to the development of systematic physical therapy and the recognition that rehabilitation to optimal performance with the highest possible quality of life was the goal, we find that the important advances depended on research. The more advanced systematic physical medicine and rehabilitation became, the more necessary has been carefully thought out and executed the research. This continues to be the case. All areas of rehabilitation medicine have remaining problems which will be resolved only by research. Clinically effective research requires not only the discovery of and answer to a problem but, also, the development of a system of application so that the benefits are applied to those patients in need.

Maintenance of abilities as persons age is important, both for enjoyment of a high quality of life and to decrease the costs of living by maintenance of the maximal ability for self-care. If we do this the period of preterminal rapid decline of performance should be no longer when a person lives to 110 years than when he/she lives to 75 years.

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