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EXECUTIVE SUMMARY

The mission of the National Center for Medical Rehabilitation Research (NCMRR) is to foster the development of the scientific knowledge needed to enhance the health, productivity, independence, and quality of life of people with physical disabilities. This mission is accomplished by supporting research with implications for enhancing the daily functioning of people with disabilities.

The Center was established by legislation (P.L. 101-613) in 1990. This legislation also established two other entities integral to the Center's operations: the National Advisory Board on Medical Rehabilitation Research, and the Medical Rehabilitation Coordinating Committee. The principal function of the Advisory Board is to recommend research initiatives to the Center and to other federal agencies with representatives on the Board; the Board also developed the Research Plan for NCMRR that was mandated in the founding legislation. The Coordinating Committee is charged with making recommendations to the directors of the National Institute of Child Health and Human Development (NICHD) and the NCMRR regarding the Center's Research Plan and its activities that are carried out in conjunction with other organizational entities within the National Institutes of Health (NIH) and throughout the federal government.

The Center's annual expenditures for research and research training grew from $22.1 million in fiscal year 1997, to $37.7 million in fiscal year 2000, an average annual growth of 24 percent (Figure 1). Consistent with Advisory Board recommendations, disproportionately greater support has been provided for research training at the NCMRR as compared, for example, to other NICHD centers. The number of NCMRR projects funded for these fiscal years increased from 137 to 190 (Figure 1). The Center also issued various Requests for Applications (RFAs) and supported a number of conferences consistent with seven emphasis areas described in the Research Plan. Those emphasis areas include:

- Improving functional mobility;
- Promoting behavioral adaptation to functional losses;
- Assessing the efficacy and outcomes of medical rehabilitation therapies and practices;
- Developing improved assistive technology;
- Understanding whole body system responses to physical impairments and functional changes;
- Developing more precise methods to measure impairments, disabilities, and societal and functional limitations; and
- Training research scientists in the field of rehabilitation.

The Advisory Board is presently reviewing the Research Plan and will issue a revised Plan to reflect scientific advances and societal changes.

NCMRR MISSION, BACKGROUND, AND PROGRAM DEVELOPMENT

The mission of the NCMRR, to foster development of the scientific knowledge needed to enhance the health, productivity, independence, and quality of life of people with physical disabilities, is accomplished by the Center's support of research that has implications for enhancing the daily functioning of people with disabilities. One primary goal of the Center is to bring the health-related problems of people with disabilities to the attention of America's best scientists to capitalize upon the myriad advances occurring in the biological, behavioral, and engineering sciences.

The Institute of Medicine's report, *Enabling America*: *Assessing the Role of Rehabilitation Science and Engineering* (National Academy Press, 1997), highlights the national need for research advances to improve the effectiveness of rehabilitation services and practices for promoting the health of people with disabilities. The incidence and prevalence of people with disabilities continue to mount in parallel with dramatic increases in our medicine's ability to prevent deaths due to injury, disease, and conditions associated with aging. An estimated 49 million Americans, about one of every seven citizens, have disabling conditions so severe that they are unable to carry out the major activities of their age group, such as attending school, working, or providing self-care.

As a health care discipline, medical rehabilitation provides the means for combating disability. Medical rehabilitation services are made more effective by putting them on sounder scientific footing. The improved outcomes are reflected by more people with disabilities returning to work and home, rather than being placed in long-term care facilities. The result is both improved quality of life for service recipients, and long-term cost savings for society.

Remarkably, no focus for facilitating medical rehabilitation research existed within the NIH until 1990, when legislation was passed establishing the NCMRR (P.L. 101-613). This legislation also established two other entities that are integral to the Center's operations:

- **The National Advisory Board on Medical Rehab Research** consists of 12 scientists and clinicians in medical rehabilitation, six people with disabilities who have been recipients of medical rehabilitation services, and 17 ad hoc members from government agencies that fund research or service programs of relevance to medical rehabilitation (see Appendix C for a list of current Board members). Its principal function is to recommend research initiatives that it believes the Center and other federal agencies that are represented on the Board should undertake. The Advisory Board developed the Research Plan for the NCMRR that was mandated in the founding legislation. The resulting *Research Plan for the National Center for Medical Rehabilitation Research* (DHHS, NIH Publication 93-3509, 1993) continues to guide priority setting for the Center's programs.

- **The Medical Rehabilitation Coordinating Committee** makes recommendations to the NICHD and NCMRR directors regarding the Center's Research Plan and activities that are carried out in conjunction with other organizational entities, both within the NIH and throughout the federal government. Included on the committee are representatives from

the National Institute on Aging (NIA), National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS), National Cancer Institute, National Institute on Deafness and Other Communication Disorders, National Heart, Lung and Blood Institute (NHLBI), National Institute of Neurological Disorders and Stroke (NINDS), National Institute of Nursing Research, National Eye Institute, National Center for Complementary and Alternative Medicine, and National Center for Research Resources.

NCMRR RESEARCH PRIORITIES

The NCMRR research portfolio must be viewed in the context of two boundary conditions. First, although the NCMRR has primary responsibility for medical rehabilitation research at the NIH, many other NIH Institutes support research that is relevant to this mission, particularly in the context of neuroplasticity, behavioral and social sciences, and bioengineering. For example: the NINDS supports research on neuropathology, particularly with respect to stroke, spinal cord and brain injury, and neuromuscular disorders; the NIAMS supports research on muscle and joint physiology, bone, and skin; the NIA supports research on geriatric issues; and the NHLBI supports research on exercise and cardiovascular function. Outside the NIH, the National Institute on Disability and Rehabilitation Research supports a significant amount of work on participation and sociobehavioral issues; the Center for Disease Control and Prevention (CDC) supports work on demographics, prevention, and secondary complications; and the Veterans Administration (VA) supports research on certain treatment strategies. The second boundary to the NCMRR research portfolio is that NCMRR-funded research is largely a reflection of unsolicited, investigator-initiated applications that hold up in the rigorous arena of NIH peer review. Successful applicants include rehabilitation scientists, as well as researchers from allied fields who have become interested in medical rehabilitation issues. Only a small percentage of NCMRR resources are set aside for RFAs that target research in specific underserved areas.

In its first decade, the NCMRR responded to many of the goals set out in the *Research Plan for the National Center for Medical Rehabilitation Research*. Prepared at the request of Congress, this Plan describes a framework for defining and developing the field of rehabilitation sciences. The document set forth seven research area priorities for the NCMRR. These priorities (in italics) and the Center's research responses are described below:

- Approximately 10 percent of NCMRR research during the first 10 years of its existence fell into the area of *improving function and mobility*. This area includes research on wheelchair usage, coordination and control of arm movements, gait analysis, therapeutic footwear, surgical and drug interventions for spasticity, body strength and exertion, constrained-use therapy, and improving respiratory control.

- Approximately 9 percent of NCMRR research can be classified under *promoting behavioral adaptation to functional losses.* This area includes research on: psychosocial adjustments; health promotion, wellness, and exercise; impact on caretakers and family members; special issues for women with disabilities; geriatric issues; participation of children with disabilities the community; cognitive deficits associated with Multiple

Sclerosis (MS); sexuality; compensatory strategies for memory and cognitive deficits; improving access to certain environments; and virtual reality and other computer-based tools.

- Approximately 6 percent of NCMRR research can be classified under *assessing the efficacy and outcomes of medical rehabilitation therapies and practices.* This area includes research on treatment for pain and depression, interventions for urinary tract infections (UTI) and bladder dysfunction, neuroimaging in stroke and traumatic brain injury (TBI), decision-making and access to health care, economic constraints, tendon surgery for Cerebral Palsy (CP), pharmacological treatments to improve function after injury (e.g., respiratory function), and recovery from hip fracture.

- Approximately 15 percent of NCMRR research can be classified under *developing improved assistive technology.* This research area benefits from the fact that a small percentage of the NIH budget is set aside each year to support small business innovation research; small businesses conduct a great deal of research in assistive technology. Research in this area includes: wheelchair design; prosthetic hands, feet, and knees; improved fitting and monitoring of orthotics and prosthetics; design of specialized recreational equipment; neuroprostheses/microsensors for brain, nerves, muscles, or joints; functional electric stimulation of muscles or nerves; external control of bowel and bladder function; communication aids and computer interfaces; and improved environmental control.

- *Understanding whole body system responses to physical impairments and functional changes* is a broad area that accounts for about 28 percent of NCMRR funding. This area includes motor cortex changes associated with stroke and brain injury, spinal cord plasticity and regeneration, muscle atrophy and decreased bone density, causes of pain and potential treatments strategies, cognitive and behavioral changes (e.g., attention, memory), reproductive function and sexual response, co-morbidities and mortality, spasticity and muscle coordination, skin ulceration, tissue/biomaterial interface, sympathetic and parasympathetic function, and training strategies involving robotics and computers.

- Research in *developing more precise methods to measure impairments, disabilities, and societal and functional limitations* accounts for about 9 percent of the NCMRR budget. This research includes: demographics; archives of disabilities; brain imaging for diagnostics and prognosis; improved measures of well-being, satisfaction, and quality of life; special assessments for children with disabilities; measurement of bone, muscle, and limb function; risk factors; and ethnographic and socioeconomic analyses.

- About 16 percent of NCMRR funds support *training research scientists in the field of medical rehabilitation*. This area includes individual fellowships for postdoctoral fellows, institutional training grants for graduate students and postdoctoral fellows, mentored awards specifically targeted to those in rehabilitation fields, mentored awards

that introduce clinicians to research opportunities, and national development and training programs for physical medicine and rehabilitation departments.

About 7 percent of the NCMRR budget includes more basic research approaches and support of research infrastructure; such topics do not fit into any of the seven areas outlined in the NCMRR Research Plan. Figure 2 illustrates the distribution of funding across disorders, with 70 percent going toward a specific disorder and 30 percent going toward research on cross-cutting issues. Figure 3 illustrates the distribution of research funds that go toward studying specific disorders.

ONGOING NCMRR RESEARCH IN THE BIOLOGICAL SCIENCES PROGRAM

SCIENTIFIC MISSION AND OVERVIEW

The Biological Sciences Program promotes basic research to provide the scientific underpinnings of clinical rehabilitation. Research supported by this program strives to understand the mechanisms of recovery from and adaptation to injury and disease.

As research understanding of these mechanisms expands, the bases for innovative therapeutic interventions develop. Thus, many of the research topics highlighted in this section as part of the Biological Science Program are continued and expanded upon in the Behavioral Sciences and Rehabilitation Engineering Program and the Clinical Practices Program, as investigators seek to bring their insights into clinical practice and commercial developments.

NEUROMUSCULAR CONTROL: MUSCLE AND JOINT FUNCTION

Stroke, trauma, and other neurological conditions often damage key regions of the brain (e.g., motor cortex or cerebellum) or spinal cord that directly affect neuromuscular function. These conditions result in movement deficits, such as hemiparesis, spasticity, or tremors; altered coordination, including gait and posture abnormalities; autonomic dysreflexia; sensory function; or specific organ problems, such as respiratory insufficiency or bowel and bladder dysfunction. Chronic alterations in neuromuscular activity can also have secondary physiological consequences, which may include muscle atrophy, contractures, bone fragility, pain, reduced cardiovascular function, and obesity. NCMRR-funded research explores a wide range of approaches to promote recovery and enhance function, including cellular/molecular approaches to stimulate nervous system recovery and plasticity, targeted therapeutic exercise, functional electrical stimulation of muscle, and the use of neuroprosthetics and assistive devices.

Researchers are exploring how the nervous system controls muscle and joint movements, and how this coordination breaks down in stroke-induced brain injury or other neuromuscular disorders. For example, to direct upper limb movements, the nervous system must coordinate activity among muscle groups and across joints. This movement requires integrating sensory and

motor information to plan and modify movements, despite multiple degrees of freedom at the shoulder, elbow, and wrist joints and potential redundancies in overall trajectory. Initial studies suggest that the nervous system deals with these complexities by co-regulating specific muscle and joint activities to effectively constrain movements and reduce potential degrees of freedom. Furthermore, it may be this level of control that is altered in stroke-induced brain injury, which results in discoordination of limb movement. During stroke recovery, awkward movement patterns emerge in the impaired arm, which could reflect a loss of constraints between muscle activity and joint torque. Understanding the relative contributions of spinal cord circuitry and higher order cerebellar and cortical function is essential for diagnosing movement disorders and planning rehabilitative strategies.

SHOULDER FUNCTION AND IMPROVED USE OF ASSISTIVE DEVICES

The use of assistive devices to enhance ambulation in spinal cord injury, stroke, or other conditions puts special demands on the joints and muscles of the upper arm. Certain orthotics require the shoulders to bear weight or to provide additional thrusting activity. These requirements can cause excessive fatigue and often result in chronic pain and potential musculoskeletal problems. One series of NCMRR-funded studies examines the demands placed on the shoulder joint by forearm crutches and wheeled walkers in persons with incomplete spinal cord injury. To analyze these interactions, the activities of specific muscle groups are monitored by electromyographic recording electrodes, while the motion of the shoulder, elbow, wrist, hip, knee, and ankle are monitored with a kinematic motion analysis system. The actual forces exerted on the assistive devices and on the ground are also recorded. These studies have helped improve the design and use of assistive devices to improve safety, optimize ambulatory efficiency, and minimize secondary complications.

ANALYSIS OF GAIT AND LOWER LIMB FUNCTION

Several NCMRR-funded studies examine lower limb function in individuals with spinal cord injury, stroke, and other neuromuscular conditions, to enhance recovery and explore potential therapeutic strategies. Current approaches focus on motor learning, functional electrical stimulation (FES), and assistive devices. In addition to enhancing neuromuscular function, such rehabilitative strategies may prevent secondary complications such as muscle atrophy, bone fragility, and cardiovascular deconditioning.

One approach to studying lower limb function is the use of a pedaling apparatus. Rhythmic locomotor activity can be analyzed and manipulated in a controlled setting. Further, the apparatus can be adapted to support individuals with partial spinal cord injury of post-stroke hemiparesis. Moreover, the neuromuscular regulation of the reciprocal movements in pedaling has similarities to the patterning of movements involved in walking. In persons with post-stroke hemiparesis, it appears that muscle activity is initiated at inappropriate points in the pedaling cycle, which results in less-forceful and slower movements and overall impaired activity. One potential cause for altered muscle activation is the hyperexcitability of the motoneurons that control these muscles. Post-stroke hemiparesis deprives the motoneurons of their normal level of

activity, causing them to become hyperexcitable, which may cause them to fire too early in the rhythmic cycle leading to inappropriately timed muscle activity. Another potential cause for altered muscle activation stems from changes in the feedback that these motoneurons receive from synergistic and antagonistic muscles in the lower limb, including those of the unimpaired leg. The significance of these post-stroke changes can be studied using the pedaling apparatus by systematically varying the movements and applied forces at specific parts of the cycle. Understanding the coordination of rhythmic activity in lower limbs and how it is altered by stroke, spinal cord injury, or other neurological disorders is key to developing therapeutic strategies and integrating assistive devices that enhance gait and improve mobility.

FUNCTIONAL ELECTRICAL STIMULATION (FES)

Specific nerve fibers or muscle groups can be activated by direct electrical stimulation. FES has shown tremendous promise for directing volitional movements in paralyzed limbs and therapeutically stimulating muscles at risk for atrophy. Already, there have been dramatic examples of chronically implanted FES devices that help paralyzed individuals with coordinated reaching and grasping, standing, and assisted gait. Ongoing work is directed toward developing more sophisticated controllers that can coordinate multi-joint movements and toward developing of sensors that allow patients to direct movements more easily. For example, the NCMRR supports investigation into the use of electroencephalogram (EEG) signals so that patients may control external devices by thought.

REHABILITATION AND CEREBRAL PALSY (CP)

CP is the most prevalent physical disability that occurs during childhood, affecting some 500,000 Americans. Current treatments, such a surgery (e.g., muscle-tendon lengthening and selective dorsal rhizotomy) and physical therapy, often meet with only limited and/or temporary success. NCMRR-funded studies are exploring the use of muscle strengthening to improve outcomes in CP. Strength training is routinely used in athletes and orthopedic populations to increase force production or alter muscle imbalance, but this type of intervention is underutilized in pediatric rehabilitation. Although the neurophysiological and biomechanical basis of CP remains poorly understood, research findings suggest that individuals with CP are indeed weak, which means strengthening programs can produce positive functional outcomes. A particularly exciting new approach supported by the NCMRR is the application of quantitative biomechanical modeling to understand the effects of therapeutic interventions on these children with CP, who have altered neuromuscular control, as well as limb geometries. Preliminary results suggest that this approach may be very valuable in predicting which children may benefit from surgical interventions, such as tendon transfers and lengthening.

IMPROVING MUSCLE PHYSIOLOGY

Following paralysis, skeletal muscle becomes highly fatigable and begins to atrophy significantly. This condition may lead to secondary complications, such as decreased cardiovascular function, contractures (fibrotic alterations in the muscle tissue), and loss of bone density. NCMRR-funded research seeks to develop strategies to maintain muscle mass in paralyzed limbs. Such research includes therapeutic exercise and electrical stimulation. One study examines the molecular and cellular effects of passive stretch on muscle physiology and the prevention of fibrotic invasion. Another study examines the specific patterns and frequencies of electrical stimulation that are most appropriate for maximizing force and minimizing fatigue.

Other studies use non-invasive, dynamic imaging techniques, such as magnetic resonance and sonoelastography, to analyze muscle contraction under various load conditions. In animal studies, molecular probes are used to examine the interplay of activity, metabolism, gene expression, and overall physiology. Endogenous growth factors, such as insulin-like growth factor (IGF-1), show tremendous therapeutic potential for preventing atrophy in inactive muscles.

CONTROL OF RESPIRATORY FUNCTION IN SPINAL CORD INJURY

One of the major life-threatening consequences of high cervical spinal cord injury is the interruption of respiratory pathways, which leads to paresis of the diaphragm muscle and respiratory distress. There are about 200,000 cases of spinal cord injury in the U.S., with 11,000 cases added annually. Mechanical ventilators are the mainstay of current therapy for respiratory compromise, but this treatment leads to a tremendous sense of isolation and loss of independence, while preventing participation in other aspects of rehabilitative therapy.

NCMRR-funded studies have demonstrated the existence of alternative motor pathways for controlling the diaphragm muscle that can be activated upon spinal cord injury. The “crossed phrenic phenomenon” was initially described in a rodent model of spinal cord injury, but has particular relevance to humans who suffer from high cervical injury. Damage to the spinal column that affects the phrenic nerve creates asphyxia; this situation enhances respiratory drive centrally, eventually activating latent respiratory axons in a parallel pathway. Initial studies in animal models suggested that certain interventions could enhance the activation of this crucial backup respiratory pathway. Pharmacological manipulation with theophylline (and other methylxanthines) hastens the re-establishment of communication from the brainstem to the diaphragm after spinal cord injury. Experiments are currently underway to explore the feasibility of theophylline treatment in humans to enhance respiratory function in high cervical spinal cord injury.

DEFINING AND TREATING SENSORY MODULATION DISORDERS (SMD) IN CHILDREN

Because of abnormalities in the processing of sensory information, children with sensory modulation disorders (SMD) either over- or under-react to stimuli in their environment. Their

reactions can cause significant problems with such daily activities as dressing, eating, learning, and social interactions, which can lead to anxiety, poor attention, low self-esteem, and further complications in motor, cognitive, social, and emotional development. Although SMD has only recently been described, initial prevalence estimates suggest that as many as 10 percent of children have sensory symptoms in the clinical range. SMD is often associated with autism, Fragile X syndrome, and other developmental disorders.

Occupational therapists have taken the lead in recognizing SMD, perhaps because it affects so many aspects of a child's life and requires an integrated, broad-based treatment approach. The NCMRR supports studies to operationally define SMD and to determine which treatment strategies are most effective. Currently, diagnosis is based on a range of clinical approaches, including physiological responses to specific stimuli, measures of behavioral/social/emotional symptoms, and studies of resulting functional limitation and disability measures. Treatment strategies involve direct biomedical and behavioral intervention to improve sensory processing, as well as environmental adjustments in the home, school, and community environments. Outcome measures tend not to focus just on the individual, but also on family interactions and functioning within the environment.

URINARY TRACT INFECTION (UTI) ASSOCIATED WITH SPINAL CORD INJURY

Despite improvements in bladder care, the urinary tracts of people with spinal cord injury are often colonized with bacteria. Symptomatic UTI is a recurrent problem, which is compounded by the presence of indwelling catheters. For cases of asymptomatic bacteriuria, treatment may not be warranted. In fact, benign bacteria in the bladder may even be beneficial in preventing infection by more harmful organisms. Bacterial strains are self-selecting and the physician has little knowledge for judging potential urovirulence in this population. Recent NCMRR-funded studies suggest that intentional bladder colonization with certain benign bacteria may help prevent symptomatic UTI. In the pilot study, bladders of subjects with spinal cord injury were exposed to a specially engineered *Escherichia Coli (E. coli)* strain, which resulted in long-term colonization. The participants showed no symptoms of UTI, either from *E. coli* strain or from any invading organisms. Current studies focus on bacterial surface proteins in order to optimize treatment and persistence of this protection. This knowledge could lead to simple, low-cost prevention of a significant health problem for people with spinal cord injury.

REGENERATION OF DIGIT TIPS

There are few documented instances in which human organs are able to respond to injury by complete and perfect replacement the damaged parts. One such case is the tip of the finger, which can regenerate under appropriate conditions, even in adults. Fingertip regeneration is a relatively understudied phenomenon, despite the fact that the most frequent body part injured is the hand, and that approximately 19,000 people in the U.S. experience loss of a digit in any one year. The human digit is composed of diverse tissues, such as epidermis, nail, nailbed, dermis, adipose, and bone. Upon amputation, the digit can recreate a perfect replica of its tip, including the nail and fingerprint, without the deposition of scar tissue. This regeneration response is level

specific: it only occurs following amputations at or distal to the level of the nailbed. Amputations just proximal to the nailbed result in scar tissue formation and incomplete regeneration. Using molecular and histological techniques, NCMRR-funded researchers are using digit amputation in mammals as a model system to study both organ regeneration and scar-free wound healing. Molecular studies have focused on two developmental genes, Msx1 and Msx2, that are re-expressed in the damaged nailbed tissue at the site of the wound and may have a key role in the regeneration process. Another approach is to study digit regeneration in mice that have these particular homeobox-containing genes knocked out. Other studies examine the interactions among particular cells and the extracellular matrix to determine whether digit regeneration recapitulates the initial limb development process, or whether it represents a special form of hyperplasia of differentiated tissues. Taken together, these studies will provide the motivation for more systematic studies of digit regeneration. This work also shows promise for regulating growth both at amputation sites, and in internal organs.

WOUND HEALING

Other NCMRR studies are examining the role of the neurological system in cutaneous wound healing. In skin, it appears that the sensory nerve plays a key role in the maintenance and recovery of skin function. The neurological system can release a number of neuropeptides that are capable of modulating tissue function. NCMRR-funded researchers are examining the effect of neuropeptides, such as substance P and calcitonin gene related peptide (CGRP), on inflammation, wound healing, and angiogenesis. Such basic molecular and cellular studies could lead to novel therapies for a wide range of cutaneous disorders including inflammation, wound healing, ulcers, and neoplasia.

INTEGRATION OF FIBEROUS BIOMATERIALS

Artificial biomateials are increasingly being used to treat soft tissue defects, but their effectiveness is limited by inappropriate host tissue responses. Fibrous encapsulation, a common characteristic of lost tissue response tends to wall off the material, produces scar tissue, and isolates it from mechanical or chemical integration. However, preliminary data suggest that if the biomaterial is composed of sufficiently small-diameter fibers, on the order of 0.5-3.0 mm (similar to that of collagen fibers), then fibrous encapsulation is minimized or eliminated. Current NCMRR-funded studies are systematically examining the biophysical properties of fibro-porous biomaterials to create more effective integration. To generate artificial, small-diameter fibers with specific properties, these studies have adapted technologies, such as electrospinning, from the field of material engineering. The focus of these studies is on the geometry and surface chemistry of the fibers. This work could have relevance to the treatment of burns, skin ulcers, abdominal and intestinal wall defects, and herniation of internal organs.

ONGOING NCMRR RESEARCH IN THE CLINICAL PRACTICES PROGRAM

SCIENTIFIC MISSION AND OVERVIEW

The Clinical Practice Program applies scientific findings to improve clinical practices in rehabilitation. Work supported in this area includes development of new therapeutic interventions, clinical trials of new interventions, and clinical studies to improve and validate existing rehabilitation practices. In addition to investigator-initiated research and targeted research initiatives, the program builds upon recent NCMR- sponsored workshops, including the *Workshop on Clinical Trials in Rehabilitation* (1998*), Workshop on Adaptive Learning: Interventions for Verbal and Motor Deficits* (1999), *Workshop on Stroke and Hip Fracture Rehabilitation* (2000), and the *Workshop on Home Mechanical Ventilation (*2000).

A large proportion of disabilities result from injury or diseases of the nervous system, such as stroke, Parkinson's disease, MS, spinal cord injury, and TBI. Much of the rehabilitation team's efforts during inpatient and outpatient therapy for such neurologic disorders focus on restoring the ability to maintain independence in daily activities. The companion role of medical rehabilitation research is to develop interventions that will lead to functional recovery; this recovery occurs post acutely and is maintained throughout the individual's life. The NCMRR recognizes consequences of disease or injury within the domains of pathophysiology, impairment, functional limitation, disability, and societal limitation. One broad goal of the research supported by the Center is focused on relating neurologic changes to reductions in functional limitations and disabilities.

There are few reports that document rehabilitation techniques' influence on the neuroplasticity of a healing brain. Advances in neuroscience, biology, technology, engineering, and pharmacology combine to offer new information about the plasticity and capacity of the nervous system to repair and regenerate/compensate. These advances also suggest the opportunity for recovery of function, prevention of secondary conditions, and maintenance of life. In addition, there is increased awareness of the need for evidence-based outcome measures that can document changes in function, focus, and target interventions, correlate physiological properties with functional measures, and guide financial reimbursement.

CONSTRAINT-INDUCED MOVEMENT THERAPY

Profoundly impaired motor dysfunction is a major consequence of neurologic disorders, such as stroke, TBI, and degenerative neurological disorders. As a result, a large number of the more than 700,000 people in America who sustain a stroke each year have limitations in motor ability and a compromised quality of life. Therapeutic interventions designed to enhance motor function and promote independent use of impaired upper extremities following stroke are quite limited. There is a need to translate unique behavioral techniques that have been shown to have impact on plasticity in the nervous system into practical, evidence-based, therapeutic

interventions. This need is especially true at a time when the duration and number of treatments for many disorders have been reduced. Hemiplegia contributes significantly to the physical disability and impaired quality of life of individuals affected by neurological disorders. Present rehabilitation strategies emphasize compensatory training of the unimpaired extremities to maximize function and prevention of complications of immobility. NCMRR-funded investigators are developing innovative strategies to facilitate the motor recovery of stroke patients, thereby maximizing their function and quality of life.

One such technique derived from basic research findings has produced results that can substantially reduce the motor deficit of patients with mild-to-moderate chronic strokes and increase their independence. This technique, termed Constraint-Induced Movement Therapy or Forced Use, involves motor restriction of the less affected upper extremity for two weeks. Over this time, repetitive use of the more affected upper extremity is promoted for many hours a day. This technique gives rise to massed or repetitive use of the more affected extremity and to a large increase in use-dependent cortical reorganization, which involves the recruitment of substantial new regions of the brain in the innervations of more affected extremity movement.

NCMRR-funded research is evaluating whether Constraint-Induced treatment is effective for increasing the amount of real-world extremity use among patients with chronic stroke who have a greater level of motor impairment, and if the locus and size of lesion are factors that influence the extent to which motor function can be recovered. Studies to date suggest that this treatment produces long-lasting improvements among patients who are more than one year post-stroke, and that it may be as effective for sub-acute patients, three-to-six months post-stroke, as it is for more chronic patients.

MOTOR LEARNING/MOTOR RECOVERY

The NCMRR also has several studies underway that are exploring how movements are learned and how these fundamental processes are affected by neurologic insult. In some cases, physical therapy and exercise may be prescribed to improve mobility of patients with neurologic damage, along with pharmacological and surgical interventions. If physical medicine and rehabilitation are to be most effective, it is therefore important to understand how the disease itself my affect the patients' ability to learn new movement repertoires.

To learn about more about this topic, one study is evaluating the temporal sequence of changes in limb kinematics and electromyographic (EMG) activity that occurs when individuals learn a new motor task. This study addresses several hypotheses about motor learning and the temporal sequence of changes that occur when subjects learn a new motor task, including the notion that motor learning is invariant.

This research has implications for the treatment and rehabilitation strategies used across many disorders. For example, findings from one study suggest that EMG-controlled neuromuscular stimulation may substantially reduce upper limb paralysis and weakness in individuals following neurologic insult or injury. EMG-controlled neuromuscular electric stimulation appears to invoke neuroplastic changes in the central and peripheral nervous system that facilitate motor

recovery activities of daily living and societal participation. Such intervention may be effective for stroke patients, as well as for persons with other forms of cerebral motor dysfunction, such as TBI, CP, and MS.

In another area of this research, studies into recovery from brain injury posit that activity-dependent plasticity underlies neuro-recovery. This idea motivated NCMRR-researchers to evaluate whether sensory-motor activity facilitates significant recovery of motor function in patients recovering from stroke, and whether the recovered motor performance of stroke patients exhibits characteristics associated with normal motor learning. If true, this idea would provide a basis to adapt mathematical learning theories into a quantitative theory of motor recovery.

For the first time, using robotics and information technology for neuro-rehabilitation will provide objective control and quantification of the motor activity delivered to a patient, as well as precise and reliable measurement of patients' motor behavior, thus enabling a rigorous test of these hypotheses. Researchers expect that results from this study will provide an objective basis for maximizing the benefits of robot-administered therapy, as well as a foundation for a quantitative theory of motor recovery and possible further refinements of neurologic rehabilitation.

ROBOTICS IN REHABILITATION

Recognizing that much of the economic burden of neurologic damage results from the cost of the highly labor-intensive nature of present rehabilitation practice, NCMRR investigators have proposed novel approaches to rehabilitation. Studies are underway to confirm the effectiveness of robot-aided procedures and validate new robotic tools that will improve the productivity of rehabilitation experts, thereby reducing costs of treatment without compromising quality. The long-term goal of one such project is to understand the biological and behavioral consequences of brain injury, and to develop innovative treatments using robotics and information technology to enhance recovery. This research seeks to understand and distinguish between the effects of rehabilitation to enhance recovery of sensori-motor coordination, and rehabilitation to restore muscle tone, strength, and the ability to move against gravity. Researchers intend to use this knowledge to optimize neuro-rehabilitation treatments.

Investigators hypothesize that there are at least two major aspects of neuro-recovery: 1) a process analogous to motor (re-) learning that compensates for damage to brain centers for coordination and control; and 2) a process analogous to recovery of strength and/or muscle tone. Results to date are consistent with the hypothesis that recovery is a process akin to motor learning. Further study will provide an objective basis for maximizing the benefits of at least these two kinds of (robot-administered) therapy, allowing experts to customize this therapy to meet patients' specific needs. These studies may also allow for further refinements of robot neurologic rehabilitation.

REHABILITATION OF GAIT

Independence and access to the surrounding environment are among the most important goals for patients during rehabilitation. The NCMRR currently supports research to determine if a novel method of gait training is more effective than conventional rehabilitation therapy in improving functional gait in people with neurologically incomplete spinal cord injury. This intervention, called body weight supported treadmill training, partially supports the weight of patients via an overhead lift that is attached to a harness worn by the patient. Therapists can then systematically train patients to walk on a treadmill at increasingly more functional speeds with less weight support. This process allows the therapists to correct gait deviations and manipulate sensory inputs that enhance control of the stance and swing phases of walking.

This body weight support strategy has been combined with treadmill-based gait training in several rehabilitation centers, with seemingly dramatic results. The NCMRR currently supports the first multi-center, randomized clinical trial of this task-oriented locomotor intervention for acute spinal cord injury. This strategy applies basic neuroscience research and pilot clinical studies about use-dependent locomotor learning in the lumbosacral neural circuits and supraspinal neurons that coordinate leg movements. These studies will allow scientists to determine whether the functional improvements associated with body weight support-based training are due to neurologic adaptation within the spinal cord, or if they reflect an increased work capacity secondary to fitness training. Both possibilities have important implications with respect to optimizing therapy for persons with spinal cord injury. The results will also be relevant to people with chronic or complete spinal cord injury who, in the future, may receive biologic interventions combined with locomotor training.

Results to date suggest that behavioral gains might follow a strategy that optimizes residual sensori-motor integration for walking after stroke, spinal cord injury, and other neurologic diseases that impair lower limb and truncal function. In addition, recent evidence points to the ability of most patients with stroke and spinal cord injury to accomplish this basic motor learning with task-specific practice. If results continue to show efficacy for locomotor impairment and disabilities, the intervention can be combined with other inputs, FES to elicit reflexive movements and muscle contractions, mechanical or robotic trainers to lessen the physical and timing burdens of locomotor training on therapists, pharmacological interventions to enhance spinal and supraspinal motor learning, and plasticity and biologic manipulation.

ONGOING NCMRR RESEARCH IN THE BEHAVIORAL SCIENCE AND REHABILITATION ENGINEERING PROGRAM

SCIENTIFIC MISSION AND OVERVIEW: BEHAVIORAL SCIENCES

The Behavioral Science portion of this Program conceptualizes, initiates, and supports scientific efforts designed to advance knowledge relevant to the role of behavior of individuals with physical disabilities. A major focus of this Program is supporting research that informs the development or redevelopment of emotional, cognitive, and physical attributes. The Program supports clinical studies of interventions that promote development, as well as basic behavioral studies that underpin redevelopment aspects, such as plasticity. Other work within the Program focuses on identifying individuals with disabilities and measuring their disability to investigate its effects on the family. The Program continues to build on research recommendations from the 1994 meeting: *An Agenda for Medical Rehabilitation Outcomes Research*, and from the 1997 meeting on *Learning Theory and Research in Facilitating Patient Learning During Medical Rehabilitation*.

One example of research in this Program is a longitudinal study of 1,391 individuals with spinal cord injury. The purpose of the study is to identify the types of stable psychological traits or specific behaviors that either protect the individual from early mortality, or are associated with greater risk for mortality. Results from this study will increase the understanding of rehabilitation professionals for factors that place individuals at risk for early mortality after spinal cord injury and could lead to a more integrated effort of preventing mortality among people with spinal cord injury.

Health Services Research Advances

The Center also supports a limited amount of health services research through this Program. In spite of the smaller focus, results from one NCMRR-funded researcher's outcome-based project are influencing medical rehabilitation reimbursement on a national level. This innovative project combined a patient classification system with a prospective payment system to provide incentives for both lower cost and higher quality care for individuals with disabilities.

The types of medical rehabilitation services that clinicians can provide to U.S. citizens with disabling illness and injuries depends on how patient need is measured and how services are to be reimbursed. Also, if appropriate in-hospital rehabilitation is provided following the onset of catastrophic disabilities (i.e., stroke, spinal cord injury, brain injury, etc.), it is possible to diminish the risk of long-term institutionalization following discharge from the hospital. To these ends, an NCMRR researcher created a modular patient classification system to group patients by: expected rehabilitation length of stay, functional outcomes (gains or level of independence achieved), and likelihood of home discharge as opposed to institutionalization. Thus, patients can be classified by expected rehabilitation needs or outcomes of each Function Related Group (FRG) module assigns patients to one of 20 distinct impairments based on the diagnosis for which they are to receive rehabilitation, with the intention of encouraging appropriate aid equitable resource distribution. The systems then classify people by the severity of their physical and cognitive disabilities. The modular structure of the FRGs was designed as a

means to simultaneously assure cost containment, through use of the resource predicting module to case-mix-adjust payment, while encouraging high quality care through use of the outcome-predicting modules in a quality monitoring system.

In a proposed rule published in the November 3, 2000, Federal Register, the Centers for Medicare and Medicaid Services (CMS), formerly the Health Care Financing Administration, plans to implement a Medicare prospective payment system for rehabilitation hospitals and rehabilitation units in large hospitals, based on Case Mix Groups (CMGs). The CMGs, re-derived by CMS to forecast costs, are closely patterned after the FRG modules designed for Length of Stay. As a rehabilitation-specific method of classification, FRGs distinguish restorative rehabilitation as a distinct phase, separate from acute care and long-term care. This classification can have profound implications for the types and quality of rehabilitation services that can be made available to millions of Americans.

FRG research, through its Medicare applications, will directly affect the lives of individuals with disabilities and their families in a number of ways. First, admission to inpatient rehabilitation will be more equitable and will be based on clinical need. Because the current payment system accounts for neither diagnoses, nor severity of disability, there are strong economic incentives against admitting patients with complex diagnoses or severe disabilities; the costs of these treatments will likely be greater than the reimbursed amount per discharge. By adjusting for patients' medical complexity and functional severity, payment based on CMGs will enhance access for people in the greatest need of rehabilitation. Moreover, it will more fairly allocate greater resources to these with the greatest need, thus encouraging the use of more ample resources for their care. At the same time, this research and practice can divert resources away from those patients with less severe disabilities, thus discouraging less appropriate service use. As a result, patients with the most severe disabilities will be able to reach higher functional levels before leaving the hospital. More severely disabled patients and their families will have longer periods to prepare for the challenge of discharge from the hospital. With more opportunity to work with doctors, nurses, and therapists, patients and their families may gain better understanding of their conditions and more fully appreciate their needs. This practice will also help families learn the care-giving skills that will spare their own health and reduce the overall burden on the family unit.

FRGs are also changing clinical practice, particularly in approaches to continuous quality improvement (CQI) and monitoring. FRG case-mix-adjusted benchmarks have been distributed to inpatient rehabilitation facilities across the U.S. through the Uniform Data System For Medical Rehabilitation reporting system, and through the Department of Veterans Affairs rehabilitation services. These benchmarks are used by some facilities in outcomes monitoring for Commission on Accreditation of Rehabilitation Facilities and Joint Commission on Accreditation of Health Care Organizations accreditation, for disability management, and in evaluating patients retrospectively based on the degree to which they achieved expected gains. Such evaluations allow facilities to identify treatment approaches and interventions that appear more effective than others.

The development of FRGs has stimulated significant new directions in health services research for rehabilitation medicine, both nationally and internationally. The system provides the means

to compare alternative settings or levels of care, after adjusting for the disabling conditions of the patients being treated. For example, this system was used in comparing resource use and patient outcomes in VA rehabilitation units to non-VA units. The FRGs were built into clinical algorithms for stroke and amputation rehabilitation within the VA; those algorithms included case-mix-adjusted benchmarks across the full continuum of inpatient rehabilitation and skilled nursing facility services. The techniques, referred to as Outcome Pattern Analysis (OPA) and Efficiency Pattern Analysis (EPA), were developed for CQI, while task performance bench marking was used for clinical practice. OPA and EPA can identify groups of patients who have had higher or lower outcomes or costs than expected. Once identified, treatments or protocols applied to those groups can be compared for study effectiveness. The work has inspired inquiries from Canada, Australia, Japan, Italy, and Sweden for additional information in this area. Some of these countries are now doing their own research on this topic.

In addition, work with FRGs provides new technologies, through the provision of a modular set of case-mix adjustment tools appropriate to medical rehabilitation. By creating quantitative measures of expected resource use and outcomes, the FRG system is expected to stimulate new and more accountable models of rehabilitation care, in terms of both cost and patient outcome. Because patient outcomes and resource use are measurable, and the patterns shown are clinically plausible, the FRGs support a model of disability science that is quantifiable and empirically understandable. Through this paradigm, it is now possible for improvements in health care for people with disabilities, reduction for their families in the burden of care, changes in clinical practice, and new directions in health services research for rehabilitation medicine to take place.

Health Care Reimbursement Research

Program researchers are also analyzing the health care reimbursement system and its implications for individuals with disabilities. Because the elderly often have chronic disabilities the amount they can improve their quality of life with health programs is dependent on their cost effectiveness. In general, the cost effectiveness of programs targeted toward the elderly and persons with disabilities appears relatively unfavorable. These problems might be overcome if health care systems could distinguish between the health-related utility brought by overall health, and the societal value of those programs. One NCMRR researcher proposes to introduce value measurement in cost-effectiveness analysis, using a refinement of the person trade-off method that measures the societal value of health care programs. The goal of this research is to evaluate whether person trade-off determinations can be an effective solution to the problems that arise when conventional utility assessments are applied to the evaluation of health care programs for the elderly and disabled.

The Center continues to be interested in the health care and health care benefits available to individuals with disabilities across the life span. Its research interests range from examination of traditional treatments, to care access and reimbursement.

SCIENTIFIC MISSION AND OVERVIEW: REHABILITATION ENGINEERING

This part of the Program develops and supports the application of engineering and bioengineering principles to study the habilitation of individuals with disabilities. Rehabilitation Engineering continues to build on research recommendations from the following meetings: *Behavioral Adaptation to the Use of Assistive Technologies: Enhancing Human Movement in the 21st Century for People with Disabilities* (1995); *Gait Analysis in Rehabilitation Medicine* (1996); and *Medical Rehabilitation on the Move: Spotlight on Bioengineering* (2001).

An important objective for the NCMRR is to support research for developing assistive technology aimed at helping individuals with disabilities perform daily activities; the Rehabilitation Engineering Program is one aspect of the NCMRR that focuses on this objective. Researchers frequently obtain funding for their ideas by responding to the Small Business Innovation Research and the Small Business Technology Transfer Program solicitations. The NCMRR has been instrumental in helping investigators significantly expedite the movement of their ideas from proof of concept to prototype.

Improving mobility through assistive technologies is one of the NCMRR's highest priorities. During the last three years, the NCMRR has successfully supported many investigator-initiated research proposals that have resulted in increased accessibility for disabled persons through improvements in mobility devices. Selected examples of technological innovations supported by the NCMRR are discussed in this section.

Wheeled Mobility

One NCMRR project will introduce a revolutionary new steering concept that produces a more agile powered wheelchair with superior maneuverability and stability. The parallel all-wheel steering (PAWS) wheelchair allows the operator to easily maneuver without casters even on rough terrain. Additional unique features of this design include simplified electronics and superior stability. PAWS is suitable for use in narrow hallways, such as in mobile homes, and provides high maneuverability in and around elevators and office equipment. The device is also able to easily traverse uneven, hilly areas in warm weather months, and snowy pathways during the winter.

Another NCMRR project is developing a low-cost, lightweight, yet durable manual wheelchair. The chair weights only 26 pounds and consists of eight uniquely molded pieces that are identical for either the left or right side, and interlock without requiring welds or screws. This chair is composed of engineering resins, such as glass filled nylon, and can be assembled in less than 15 minutes. Other unique features include: 1) easy folding; 2) adjustable seating; 3) durable structure; 4) transportability; and 5) affordable cost. If successful, this project, still in its first year, will provide wheeled mobility for the nation's 1.5 million wheelchair users.

Improved wheels are the focus of another Program manual wheelchair project. The investigator is developing a unique, hypocycloidal, two-speed wheel that incorporates a new concept enabling greater mobility and comfort for wheelchair users. The user will be able to engage a lower gear when ascending hilly terrain or steep ramps, thus reducing the effort necessary to progress up the incline. More importantly, the user may remove his/her hands from the push rim

without fear of the wheels rolling back. When pressure is reapplied to the push rim, the user can continue up the incline. This mechanism can be added with the standard quick-release axle to any standard wheelchair, which will improve mobility for individuals who lack the strength needed for a traditional manual chair. As this project enters its second year, the investigator's modifications have enhanced the design of the wheel and reduced the number of working parts in the hub.

Prostheses

In addition to supporting improvements in wheeled mobility, the NCMRR continues to seek ways to improve the lives of individuals with limb loss. Projects supported by the Center involve the development of improved prostheses, with an emphasis on improving the quality of life for individuals with limb loss and their families.

The socket, which provides the interface between the amputee and the artificial limb, is one of the most important elements of prosthesis for the approximately 60,000 new individuals who lose a lower limb each year. The precise fitting of the socket and the maintenance of its fit are extremely important to the amputee's comfort, skin integrity, sense of ambulatory security, stability, and locomotion. If uncomfortable, the fit could lead to disuse of the prosthesis, and/or damage to the residual limb from ischemia or tissue lesions. Swelling and shrinking of the residuum as the amputee participates in daily activities is often a cause for poor fit.

Currently, the socket is a rigid structure and the increase or decrease in limb volume is accommodated by a liner. Although many different types of variable volume sockets have been proposed, none of the available sockets adequately addresses the fundamental problem of volumetric change in the residuum. Air-fill is too compliant; socks and padding cannot maintain a continuously secure fit; and effective use of liquid filling has not yet been accomplished.

The NCMRR supports an engineering project that seeks to design a prosthesis socket system that resolves the problem of poor fit. The project utilizes liquid-filled bladders that automatically regulate their volume to provide a continuously secure and comfortable fit. This system, currently in the final stages of clinical testing, will vary socket volume diurnally and periodically to accommodate natural variation in the amputee's residuum. By maintaining a continuous, secure socket fit, the device should increase the amputee's sense of confidence and willingness to use the prosthesis to perform activities of daily living. This Small Business Innovation Research project, in its second year, will offer this advancement as a kit that may be used during the initial fitting, or to retrofit existing prostheses, beginning in 2002.

For the approximately 10,000 new individuals who lose an upper limb each year, another NCMRR project is attempting to improve the function of upper-limb prosthesis by adding new features. The investigator on this research hopes to improve an electric hand-wrist prosthesis, with a smaller size and weight of hand mechanism than those currently in use. The goal of this project is to integrate a practical wrist flexion/extension device that will allow an additional degree of freedom within the normal adult shape, without sacrificing speed, strength, or cosmetic appearance. This wrist flexion will not be motor-driven, but may be repositioned by the wearer for a specific task. Users can lock into a position of 30 degrees of flexion or extension, in addition to the neutral position. The locking button, which can easily be reached by the

prosthesis wearer, will enable the user to unlock the wrist and snap it into place when the desired position is attained. This improved hand/wrist system will offer the amputee additional functions, such as the ability to hold a tray or pen horizontally, without awkward out-of-the-ordinary positioning of the elbow and shoulder.

Consumer Information

In addition to developing improved devices, the NCMRR supports research to improve information that is available to patients and their families. This resource can help ease the pain of an unknown and scary circumstance for family members of individuals with limb loss, for individuals who may have surgery resulting in the loss of a limb, or for caregivers of individuals with limb loss, as well as for individuals who have suffered other life-shattering events, such as TBI. With the click of a mouse, anyone with a personal computer and a CD-ROM drive will be able to communicate with other patients and their families. As a part of this project, patients and those who care for them will have the chance to meet and interview others who have had similar experiences using simulated-interview technology. For example, more than 20 amputee and caregiver virtual dialogue programs will be available over the Internet for clinicians, caregivers, and individuals with limb loss, thereby providing comfort and possible sources of help for their particular situations.

Cognitive Aids

Approximately two million Americans have experienced head trauma that has resulted in cognitive impairment. Developing engineering solutions to help this group participate more fully in life activities is another area of scientific interest for the NCMRR. One such study, underway in New England, will attempt to develop a local area network that uses fluorescent lights to transmit data. During the pilot study, which was held at a rehabilitation facility, researchers used lights to broadcast information to a personal locator worn by the patient. Lights placed in given areas were set up to broadcast information about a scheduled event, such as therapy, to the personal locator. Using location information derived from the lights, a personal locator would judge whether the patient was proceeding toward the event and provide more detailed directions, if needed. Preliminary results indicate that such a system helps individuals to get to their destinations earlier and with less human prompting. Other potential uses for this technology are to enhance social participation by directing a person with a visual impairment to the correct gate in an airport, or to provide enhanced audio in an auditorium for an individual with a hearing loss.

RECENT NCMRR RESEARCH INITIATIVES

NCMRR REGIONAL RESEARCH NETWORKS

The Research Networks are an important new initiative for the NCMRR, resulting from discussions with the National Advisory Board on Medical Rehabilitation Research. The NICHD has committed almost $4 million per year to support the Research Networks, located in the West, Midwest, South, and Northeast, respectively. As defined in the initial RFA, Networks were to be established through major collaborations among three institutions, with the potential to connect with researchers from other facilities within the U.S. region. Each Network must support multidisciplinary research cores, information transfer, and pilot projects, with the goal of facilitating ongoing projects and stimulating the development of future research activities in medical rehabilitation. Ultimately, the Network must demonstrate the potential for increasing the quality and quantity of research applications. The NCMRR was very pleased with the quality of responses to this special initiative, and with the broader effect that this project has had on the medical rehabilitation community. The four regional networks are described below:

RehabNet—West

RehabNet-West is based in the Department of Rehabilitation Medicine at the University of Washington, but also has connections to the University of California in Los Angeles (UCLA) and Baylor College of Medicine. With its two Scientific Resource Cores and an Information Technology Core, this Network serves the 15-state Western Region. The Experimental Design/Biostatistics Scientific Resource Core provides consultation and training to address the special problems of experimental design and statistics for rehabilitation research; the Neural Imaging/Recovery Scientific Resource Core provides access to UCLA facilities for functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), and Transcranial Magnetic Stimulation (TMS). The Information Technology Core has established a Web-based information system to publicize RehabNet-West and its resources, and to facilitate networking and information exchange in the Western Region. RehabNet-West will also support up to three pilot projects, typically of two years or less, at any given time. Initial projects focus on fMRI-based studies of constraint-induced movement therapy in subacute stroke; motion and force plate analysis of the development of seated posture and balance in infants; and fMRI-based studies of brain plasticity and disability in persons with MS.

Midwestern Network

The Midwestern Network is centered at the Rehabilitation Institute of Chicago, with affiliated laboratories and faculty drawn from Northwestern University Medical School and Northwestern University's McCormick School of Engineering and Applied Science. This Network is focused on the development of a strong quantitative pathophysiological framework for the study of disabling neurologic disorders, based on a range of neuroscience and engineering methods. The Network has three specific objectives:

1) To facilitate the implementation of development and feasibility research projects by junior investigators in the Mid-Western Region. These projects are designed to help junior faculty members become competitive in the field of rehabilitation research, by equipping them with

the necessary skills, training, and preliminary data to allow them to compete effectively for major grants.

2) To attract regional scientists from allied fields and help them acquire pilot data, preparatory to the development of larger-scale applications in medical rehabilitation.

3) To maximize communication among investigators with in the region by establishing Web-based videoconferences, an e-mail communication network, and an annual meeting at which participants will review scientific rehabilitation themes and evaluate the performance of the Network.

In support of these objectives, the Network established an administrative base and three Research Cores. The Information Technology, Computer Science, and Signal Processing Core implements network communications and provides data acquisition technology, signal processing, and computer modeling and simulation. The Fundamental and Clinical Neuroscience Core offers advanced electrophysiological techniques including single-unit EMG, advanced EMG analysis, high-resolution EEG techniques, TMS, and access to basic science laboratories that deal with animal models of spinal cord injury. The third unit, the Biomechanics/Robotics Research Core provides several types of mechanical instrumentation for measuring multiaxial joint forces and torques, and for perturbing joints in one or two degrees of freedom. Resources in this Core also include several robots, among them a reaching guide suitable for training movement trajectories in paretic arms and two smaller robots capable of imposing novel loads on upper extremities. The initial development and feasibility projects selected by the Midwest Network involve 30 months of support to three junior scientists, who will be paired with senior collaborators. Current projects focus on robotics applications in stroke rehabilitation, lower limb force-vector control in hemiplegic humans, and motor unit control in multifunctional muscles.

Enhancing Rehabilitation Research in the South (ERRIS)

The ERRIS Network is based in the University of Virginia, with connections to the University of North Carolina and Duke University. ERRIS is designed to provide an infrastructure to increase the quality and quantity of rehabilitation research in the Southern Region of the U.S. The Scientific Resource Core of ERRIS supports research projects and related activities in the region under the unifying theme of "Quantification of Disablement," which incorporates multiple areas of nationally recognized quantification expertise, including gait analysis, Dual Energy X-ray Absorptiometry, neuropsychology, and anthropometry. The Southern Network uses state-of-the-art information technology to promote new research collaboration, disseminate research results, stimulate participation in educational activities, and encourage the use of Scientific Resource Core facilities and expertise. This Network also provides assistance to new investigators, who are developing projects, in identifying funding sources and writing proposals. ERRIS also supports pilot studies that extend into new areas of rehabilitation research, and are expected to develop into larger, independently funded research activities. The Network especially encourages interdisciplinary, interdepartmental, and inter-institutional collaborations. Initial pilot projects focus on quantifying spasticity and its biomechanical influence on function, as well as growth and sexual maturation in children with CP.

Northeast Cognitive Rehabilitation Research Network

The Northeast Cognitive Rehabilitation Research Network is based in the Moss Rehabilitation Research Institute in Philadelphia, with connections to Magee Rehabilitation Hospital, Bryn Mawr Rehab, and the University of Pennsylvania. Cognitive impairment is common after brain damage and is a major source of long-term disability. Cognitive rehabilitation, even when delivered long after injury, may improve functional independence; however, much of the evidence for this finding comes from methodologically compromised studies. This Network will conduct clinical trials of cognitive rehabilitation interventions. Initial studies focus on interventions derived from promising laboratory research, based on theoretical models of cognitive function and dysfunction. Initial controlled clinical trials will be conducted at a central Research Clinic. Those models that appear to have value will be explored through more naturalistic effectiveness trials in clinical settings throughout the Northeast. Studies that begin by focusing on impairment and functional limitation level outcomes will be followed by those that emphasize societal participation and quality of life. A Clinical Trials Core centralizes subject recruitment and screening across three large rehabilitation hospitals and operates the central Research Clinic with staff trained to conduct the clinical trials. The Core also functions as a methodological think tank and training site for rehabilitation researchers. The Neuroimaging Core conducts research on the methodological problems that limit the application of fMRI in cognitive rehabilitation research, and supports the use of fMRI in current and future research projects. An Information Technology Core oversees main information dissemination and collaborator recruitment activities of the Network. The Network also supports pilot studies: two focus on impairment-based treatments for TBI-related attention deficits (drug treatment) and stroke-related hemispatial neglect (drug treatment and behavioral treatment), and the third focuses on a functional limitation-based treatment for aphasia (Internet-based assistive technology) and relies on the Clinical Trials Core.

PILOT CLINICAL TRIALS GRANTS FOR PHARMACOLOGICAL INTERVENTIONS IN PEDIATRIC TRAUMATIC BRAIN INJURY (TBI)

Over the past decade, many neuroprotective agents have been developed to improve outcomes in patients with acute cerebral disorders such as stroke, subarachnoid hemorrhage, and head injury. A number of different classes of drugs (e.g., calcium-channel blockers, glutamate antagonists, and cholinesterase inhibitors) have been tested in head-injured adults across the stages of recovery; these drugs offer promise in facilitating behavioral management and functional outcome. While small case studies in adults suggest that some of these agents may be useful for improving attention and memory, and possibly, for enhancing plasticity, there is a little data on appropriate dosages and effects of these agents in pediatric TBI patients.

This initiative was developed to provide a research base that will evaluate the efficacy of pharmacological interventions for the physiological and behavioral sequelae of TBI in pediatric patients. The NCMRR recognizes that before proceeding to a large clinical trial, pilot clinical studies are often required. The RFA for this project provides funding for pilot studies to allow investigators to obtain preliminary data and establish a clinical basis to support the rationale for a subsequent, full-scale clinical trial of pharmacological interventions. Using the R21 mechanism, applicants were encouraged to obtain preliminary dates, refine their research designs,

intervention strategies, outcome measures, and target populations, and incorporate creative and realistic solutions for difficult problems in clinical neurological research for the particular intervention being evaluated.

CLINICAL TRIAL PLANNING GRANTS FOR PEDIATRIC REHABILITATION

Traumatic injury is the leading cause of death for children and adolescents in the U.S. With technical advances in medicine and emergency services, the number of children who survive their injuries has increased, but consequently so has the number of disabilities and long-term effects on quality of life. Children who survive traumatic injuries may require rehabilitative intervention to allow them to continue in school, maximize their participation in social and family activities, and develop into productive, healthy adults. Their conditions are managed by a variety of rehabilitation interventions including physical therapy, medication, and the provision of adaptive equipment such as prostheses, orthoses, and wheelchairs. Although these interventions are widely used, very little systematic information exists regarding the effectiveness of many of them.

Although disorders in adults and children may be similar in causality, diagnosis, and treatment, the wide range of developmental phenomena distinguishes the rehabilitation of infants, children, and adolescents from that of adults. The developmental process forms the template for establishing appropriate interventions and rehabilitation goals. However, the identification of objective and effective rehabilitation interventions is complicated not only by the adaptation and recovery processes taking place at different stages following the injury, but also by the additional uncertainties of the process of biological maturation.

The purpose of the Clinical Trial Planning Grant is to facilitate clinical trial projects in pediatric rehabilitation. Current constraints on clinical researchers make the complex and time-consuming process of planning Phase III clinical trials problematic, especially in the field of medical rehabilitation, where there is not a well-established clinical research infrastructure. These Planning Grants will provide a mechanism for early peer review of the rationale and design of a potential clinical trial and will provide support for the development of detailed clinical trial study plans and research collaborations.

COOPERATIVE MULTI-CENTER TBI CLINICAL TRIALS NETWORK

TBI is a leading cause of death and disability in both children and adults. An estimated two million head injuries occur in the U.S. each year. Over the last 25 years, the number of TBI cases treated has increased, particularly as earlier and more specialized emergency treatment, especially at the accident scene, has saved individuals who might otherwise have died before reaching the hospital. This increase in the survival rate from severe brain injury means that there will be an increasing number of patients in need of effective treatment to help them attain satisfactory long-term life adjustment and quality of life following their injury. Approximately 50,000 of these survivors will have persistent physical, cognitive, behavioral, and social deficits as a result of their injury that may compromise their quality of life. The size of this population

argues for the importance of determining the most effective treatment and rehabilitation practices.

During the past two decades, understanding of the pathophysiology of TBI has increased dramatically. It is now recognized that not all neurologic damage occurs at the moment of injury, but rather evolves over the ensuing minutes, hours, and days. It is also well established that a combination of early imaging, removal of extra-axial masses, support of blood pressure, and ventilation in the emergency room, as well as monitoring of intracranial pressure, produces improved survival rates. Equally well established is the role of aggressive follow-up intensive care treatment. In addition, a growing literature suggests that adjunctive pharmacological treatment facilitates behavioral management during the rehabilitation process and may result in a better functional outcome. Despite these advances, much remains to be learned about the underlying damage and pathophysiology of the deficits associated with TBI, and to link acute care, rehabilitation, and long-term patient outcomes.

To address this need, the NCMRR is establishing a multi-center Network of clinical sites that will work together to design clinical intervention protocols and measures of outcome. This interdisciplinary research Network is designed to evaluate the relationship between acute care practice and rehabilitation strategies and the long-term functional outcome of TBI patients. The primary objective of the TBI Clinical Trails Network is to identify which intervention variables result in improvements in long-term outcome. Through rigorous patient evaluation, using common protocols and interventions designed for multiple points of care including the accident scene, emergency room, intensive care unit, rehabilitation and long-term follow-up, this Network will be able to complete their studies more quickly and provide answers more rapidly than individual centers acting alone. This interdisciplinary research Network is designed to evaluate the relationship between acute care practice and rehabilitation strategies, and the long-term functional outcome of TBI patients. The primary objective of the TBI Clinical Trials Network is to identify which intervention variables result in improvements in long-term outcome.

CLINICAL TRIALS PLANNING GRANTS FOR STROKE AND HIP FRACTURE REHABILITATION

The relationship between the timing, intensity, and duration of treatment is an issue that pervades all rehabilitation interventions. The importance and timeliness of this topic was highlighted at the NICHD *Patient Learning during Medical Rehabilitation Conference* (1998), as well as at the NICHD *Hip Fracture and Stroke Conference* (2000).

Individuals diagnosed with either hip fracture and/or stroke comprise the majority of patients admitted to rehabilitation units and, therefore, provide an appropriate model for study. Across the medical disciplines involved in the care of individuals with hip fracture or stroke, there is little empirical evidence that demonstrates how best to maximize a patient's ability to function in a given time frame, the sequence by which different areas of function recover, and how this information may be used to design interventions. Questions regarding the optimum time and role for aggressive intervention have yet to be demonstrated empirically; most obviously missing is information regarding the timing, intensity, and duration of treatment interventions.

The NCMRR will establish Clinical Trial Planning Grants to provide support for the initial development and organization of an effective research team and the elements essential for conducting successful clinical trials. The purpose of this initiative is to encourage clinical trials that focus on evaluating the timing, intensity, and duration of rehabilitation interventions for stroke and hip fracture. The initiative builds on the recommendations of the NICHD/NCMRR Workshops to promote and support clinical research studies that will establish optimal delivery schedules and amount of rehabilitation services for patients in different diagnosis groups or categories.

INNOVATIVE REHABILITATION INTERVENTIONS

With approximately one out of every seven citizens having some type of disabling condition, restoration of function remains a challenge for rehabilitation health professionals. Many of the skills taken for granted, such as running, listening, or recognizing a friend's face, are problematic for a large proportion of individuals with disabilities. Even with current advances in the biological sciences and bioengineering techniques, functional limitations due to development, injury, or disease are difficult to overcome.

Sometimes advances in medical rehabilitation clinical practice take place when advances in other fields are transferred, due to the fact that much more research is directed to curing diseases or to other more viable commercial ventures. Isaac Asimov wrote about robots almost a half century ago; although science fiction at the time, he portrayed robots in the role of taking care of people. Today, robots are present in many commercial applications, but are not available to take care of people, for a number of reasons including the complexity of the task. For example, Honda's multi-million dollar robot walks stiffly without hips that tilt, sway, or twist; such a model would be ill-suited to providing comprehensive care to a person.

In an effort to equip the rehabilitation health professional with the latest scientific advances in related fields, the NCMRR issued an RFA, using an exploratory/development grant mechanism, encouraging investigators to submit applications on non-pharmaceutical and non-surgical rehabilitation interventions for persons with disabilities. The applications received ranged from implementing cutting-edge technology in rehabilitation practice, to improving clinical medical rehabilitation practices, to understanding an intervention at the basic science level. Examples of the science addressed in some of the applications submitted include: using virtual reality for preventing pain in children undergoing painful procedures; examining the use of deep-brain stimulation in coma patients; and studying the cellular response of continuous passive motion.

NCMRR TRAINING AND CAREER DEVELOPMENT

Research training has always been a priority for the NCMRR. Medical rehabilitation does not have a long research tradition, nor is there a clear focus on a particular organ or disease. Moreover, current clinical trainees can get academic positions in physical medicine and rehabilitation departments without a significant amount of research training. Yet, rehabilitative professionals have unprecedented opportunities to explore the biomedical, behavioral, and social basis for rehabilitative strategies. With an increasing population of individuals coping with disabilities at various levels, the field of medical rehabilitation must respond with adequate research to validate approaches, optimize treatments, and incorporate new technologies and opportunities.

The NCMRR supports research training through a variety of mechanisms, including individual fellowships, career development awards, institutional training grants, and research supplements to support qualified individuals who are from an underrepresented group or have a disability. In addition, a significant number of graduate and postdoctoral students are supported as research associates on NCMRR research grants.

From 1998, to 2001, the NCMRR supported 11 postdoctoral fellowships (nine PhD and two MD) through the F32 mechanism. Fellowship studies were mostly at the level of pathophysiology, although studies of impairment, function, disability, and societal limitations were also included. Within the NICHD, the predoctoral F31 mechanism is used only to support individuals who are from an underrepresented group or have a disability; the NCMRR supported four F31s over this same period. The majority of these trainees have remained in research tracks as they develop independent careers. Most continue to publish in peer-reviewed journals, and a few have even submitted research grant applications to the NIH.

Career development is supported through a variety of mechanisms in the K series, which support a period of intense mentored research for postgraduate students, either clinical or basic, at a stage in their careers just prior to appointment as independent faculty. NCMRR applicants included physical, occupational, and speech therapists; physical medicine and rehabilitation physicians (PM&R); neurologists; bioengineers; and more basic researchers. As with the fellowships described above, proposed studies were concentrated at the level of pathophysiology, but also included studies of impairment, function, disability, and societal limitations.

From 1998, to 2001, the NCMRR supported 14 PhD students through the K01 mechanism, which is used by the NICHD to support career development in targeted areas of research, including the field of medical rehabilitation. Seven MD students were supported with the K08 mechanism, which is designated for clinically trained individuals who wish to get exposure to more basic research approaches. Five MDs were also supported by other K mechanisms (e.g., K11, K23, K24) to develop their careers in medical rehabilitation research.

As a group, the NCMRR-funded K awardees have been productive researchers. Almost all of them have continued to publish in peer-reviewed research journals, some with several first-author publications already to their credit. Just over half have submitted research proposals to the NIH (e.g., R01s, R03s, and other mechanisms), and five are already funded as independent

investigators. These numbers will increase, as this cohort gets further into their independent careers.

The K12 mechanism, which has been used successfully in other medical specialties, supports a national network of established researchers to mentor clinically trained individuals in scientific research and academic medicine. Because many of the relevant scientific disciplines and professional specialties are found in departments of PM&R, the NCMRR program has focused initially on these two departments. With explicit expectations and career milestones, the National Rehabilitation Scientist Development Program supports a small number of trainees for two-to-three years in a mentored basic science environment (generally outside their intended PM&R department), followed by two years of oversight at the beginning of their PM&R faculty appointment. In the initial five-year funded period, the K12 program supported nine individuals. All have contributed to the research literature, in some cases with several first-author publications. In addition, almost all the trainees have assumed faculty positions. About half have applied to the NIH for research grants, while three of them have already been funded as independent investigators.

The National Medical Rehabilitation Scientist Development Program recently came up for competitive renewal. By assuming a more active role in recruitment and training oversight, as well as a renewed commitment from the Association of Academic Physiatrists, the K12 program competed successfully in peer review and was recently renewed for a second five-year cycle.

INSTITUTIONAL TRAINING GRANTS

Currently, the NCMRR funds 16 institutional training grants (T32), which support a total of 23 predoctoral and 32 doctoral students (about 70 percent PhD, 30 percent MD). Institutional training programs in medical rehabilitation span the gamut from cell/molecular biology and bioengineering, to behavior, to social and policy issues. Research studies are well-distributed across the various level of analysis: pathophysiology, impairment, function, disability, and societal limitations, although impairment and function appear to be most prevalent. The vast majority of these trainees (>90 percent) have remained in academic research, progressing into mentored research positions and on to faculty appointments. Particular research studies occur at various levels of analysis; pathophysiology, impairment, function, disability, and societal limitations are all represented, although the first three appear to be most prevalent.

FUTURE DIRECTIONS FOR THE NCMRR

Functional neuroimaging has already made a major impact on theories of rehabilitation. Recent work has elucidated functional specialization in the frontal lobes, especially in those areas frequently damaged in TBI. This technology will be especially useful in monitoring the recovery of function that occurs in response to therapies, and in guiding the design of new interventions. A rapidly increasing body of work is documenting the precise changes in the brain caused by specific therapies. For example, investigators have demonstrated that areas of the motor cortex adjacent to infracted areas can assume control of motor functions previously subserved by the damaged areas. Similarly, regions of brain, that do not normally support language functions, including areas in the contralateral hemisphere, can assume these functions in the face of neurological injury. Much of the impetus for this field of investigation has developed from detailed neurophysiological studies of the plasticity of cortical maps in primates.

Similar advances are anticipated in understanding the pharmacology that controls plasticity in the nervous system. Over 20 years ago, the combination of exercise and administration of amphetamines was shown to improve rats' motor recovery from cortical lesions. The physiological basis for this effect was only recently demonstrated to require participation of the noradrenergic bundle in the brainstem. The pharmacodynamics of the effect, are quite complex and are still under investigation in humans. However, preliminary results have been promising. Powerful methods recently developed to identify differential gene expression (i.e., gene chips) has allowed investigators to identify genes that control synaptic plasticity in *drosophila*. Many of these genes appear to be highly conserved across species, which could lead to the emergence of many new candidate receptors for the manipulation of synaptic plasticity.

Tissue and cellular engineering also hold great promise for the amelioration of disabilities, with a vast range of potential applications. Investigators have been making steady progress in determining which molecules inhibit and control the re-growth of axons within the central nervous system. Artificial skin is now widely available and routinely used in the clinical care of patients with severe burns. Use of cultured cartilage is under active investigation, as are multiple strategies for growing new bone tissue. The discovery of pleuri-potential stem cells in adult, as well as fetal tissues has fueled enormous interest in the use of these cells to generate replacement tissues. However, many significant scientific problems must be solved before scientists can actually grow replacement organs and limbs.

Neural prosthesis has the potential to play a crucial role in this respect. Currently, neural prostheses are in clinical use, chiefly by individuals with spinal cord injury. Such prostheses can provide individuals who have high cervical cord lesions with effective arm and grasping movements. For individuals with paraplegia, FES can provide the ability to stand, and in some cases, walk. Bladder function can also be restored with this method. Perhaps the most widely successful neural prosthesis is the cochlear stimulator, a device that can restore hearing to individuals with middle ear disease. Active work is currently underway on similar prostheses to provide artificial vision for individuals who have lost sight. However, as science gains sophistication in its abilities to grow and implant replacement tissues, the role of neural prostheses is likely to change to one of training replacement tissues, rather than substituting for them. The architecture of nervous tissue, as well as muscle and bone, depends crucially on

experience. Neural stimulation may provide an effective means with which to sculpt new replacement tissues into the forms needed to provide optimal function.

Increasing mastery of nanotechnology and materials science at the molecular level will have important implications for a new generation of prosthetics. Application of biomimetic peptides to artificial materials will enhance the acceptance of these materials by body tissues and minimize inflammation and infection. Development of solid-state micromechanical devices on a microscopic scale will provide the potential to implement highly reliable, extremely low-power devices that can be implanted to augment the control of weakened body systems.

In addition, simulation and modeling techniques hold great promise in helping in the development of new and more effective rehabilitation interventions. Highly accurate biomechanical models are just coming into use; simulations can be run on these models to investigate the effects of orthotics, strengthening particular muscle groups, and surgical interventions, such as tendon lengthening and transpositions. Initial results with these models have shown some highly counterintuitive results. Clinical intuition may be highly inaccurate in predicting outcomes for individuals with anatomies that have been disturbed by pathological processes. Thus, for example, the moments around hip joints in individuals with diplegia caused by CP appear to differ from those of normal individuals, which means the effects of surgical interventions may be predicted by the specific moments of the muscles operated upon.

Behavioral and cognitive deficits following neurological injuries may affect individuals and families more deeply than physical disabilities and may be far more deleterious in preventing individuals from returning to employment and full participation in the community. Behavioral and cognitive deficits receive less recognition by the public and by third-party payers because they are less visible and have been more difficult to treat than physical disabilities. The emergence of new tools, such as functional imaging and advanced computer software, including artificial intelligence, holds out the promise of developing more effective methods of behavioral and cognitive rehabilitation. However, the benefits of enhanced behavioral modification extend far beyond this arena. Lifestyle modification, with appropriate diet and exercise, can have profound consequences for the prevention of secondary disabilities and enhancement of function, often exceeding the benefits achievable with medical interventions alone. New approaches to enhancing participation in these modifications by individuals with disabilities are sorely needed.

Ultimately, the effects of rehabilitation interventions must be measured in how they change people's lives. Rehabilitation providers pioneered the use of functional measurement in clinical practice with such tools as the Barthel Index and Functional Independence Measure, among many others. However useful these tools may be in clinical practice, outcome assessment for rehabilitation interventions is still difficult. It is not clear whether general purpose measures are adequately sensitive to the issues confronting individuals with specific long-term disabilities, such as TBI. Specific measures developed for these populations have often been unwieldy and lacking in psychometric validity. The development of computerized dynamic assessment holds the promise of developing outcome assessment tools that can be rapidly and economically administered, have good test-retest reliability, and are valid for a wide range of populations.

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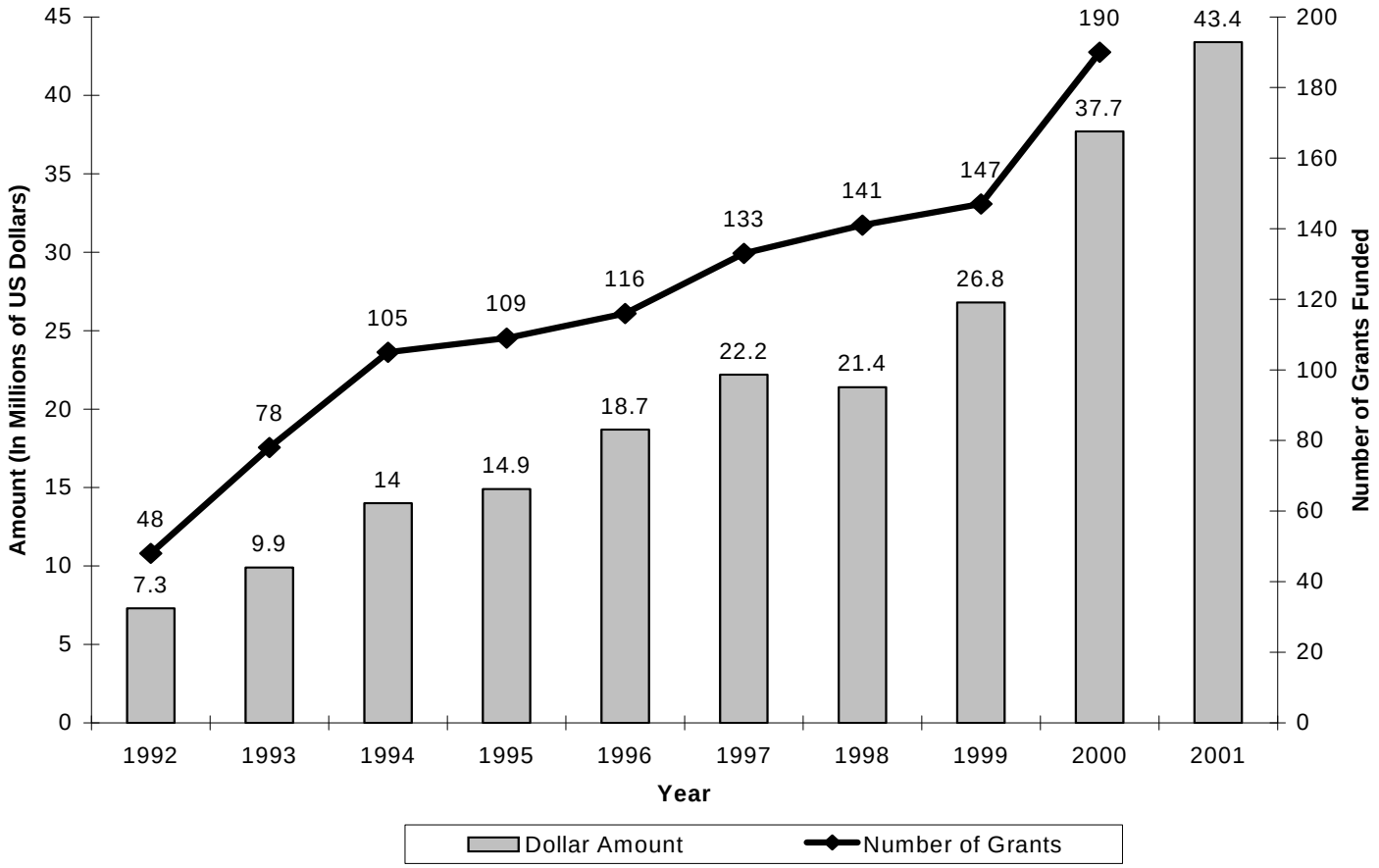
FIGURES

FIGURE 1: NCMRR FUNDING, FISCAL YEARS 1992 TO 2001



(Please note that the number indicated for fiscal year 2001 is an estimate.)

FIGURE 2: BREAKDOWN OF NCMRR FUNDING

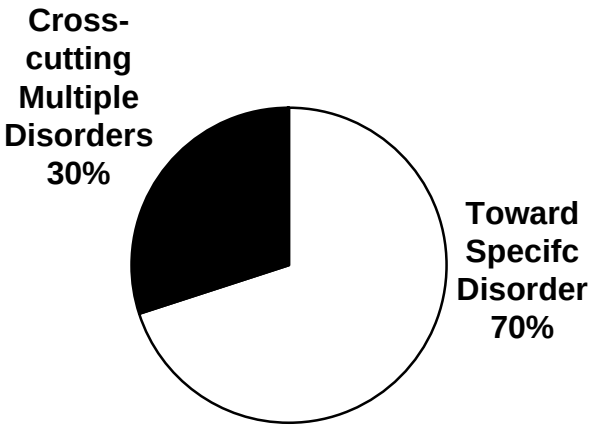
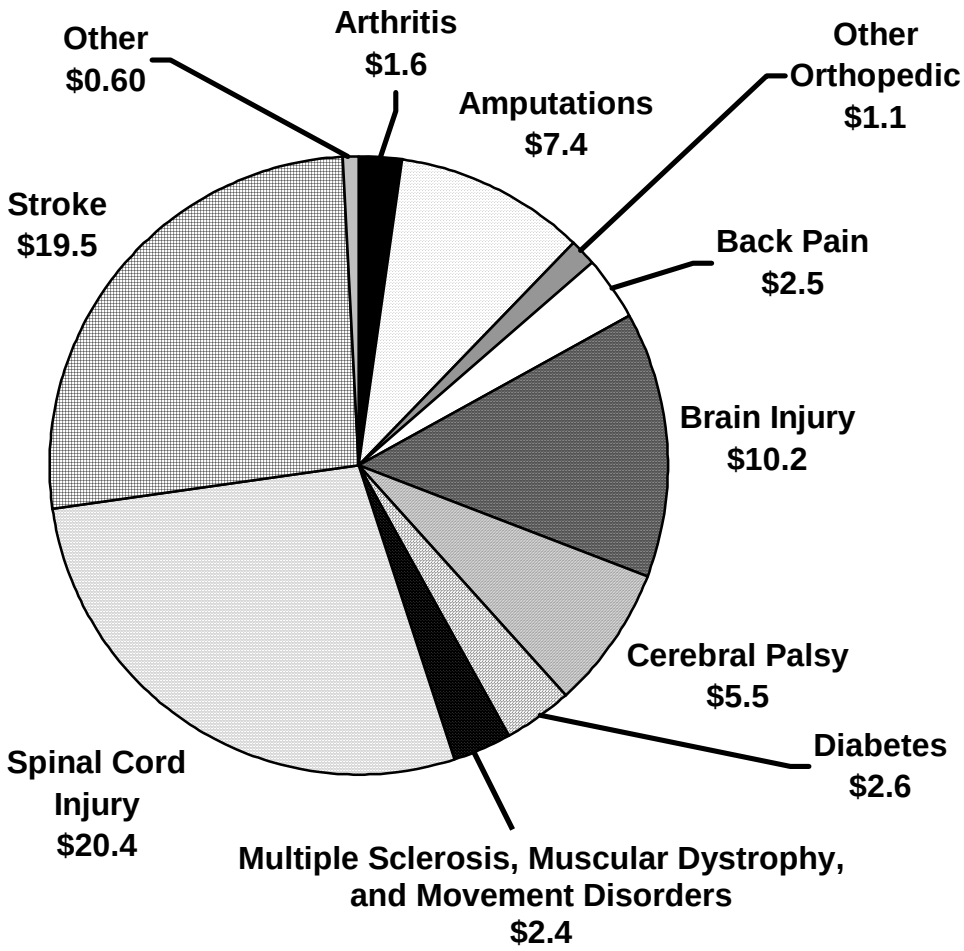


FIGURE 3: TOTAL NCMRR DOLLARS SPENT, CATEGORIZED BY DISORDER

(Note: Amounts in Millions of US Dollars)



APPENDIX A: NCMRR PERSONNEL

Beth M. Ansel, PhD, CCC-SLP, joined the Center in 2000, as director of the Clinical Practice Program. Dr. Ansel received her undergraduate education in biology at State University of New York (SUNY) Stony Brook. She completed her master's and doctoral education in Speech-Language Pathology at the University of Wisconsin-Madison, and her postdoctoral research and clinical fellowship at the Johns Hopkins University School of Medicine and the Kennedy Institute of Handicapped Children. During this time, she worked extensively with children as a member of an interdisciplinary pediatric rehabilitation team that considered the assessment, treatment, and long-term care of trauma patients. Prior to joining the NIH, she served on the faculty of Purdue University's Department of Audiology and Speech Sciences.

Ralph Nitkin, PhD, is director of the Biological Sciences and Career Development Program in the NCMRR. He received his undergraduate and master's degrees from the Massachusetts Institute of Technology in the area of biological sciences, and his PhD from the University of California, San Diego, in cellular neurobiology. His postdoctoral studies at Stanford University and his later work as an assistant professor at Rutgers University focused on the cellular and molecular basis of nerve-muscle synapse formation. For the past 11 years he has worked as a science administrator within the NICHD, first in the area of mental retardation and developmental disabilities and, more recently, in medical rehabilitation research.

Louis A. Quantrano, PhD, is a psychologist who joined the Center in 1991. Dr. Quantrano's undergraduate education was at SUNY at Geneseo, and he received his doctorate degree from Northwestern University. He initially joined the NIH as a health scientist administrator in the Prevention, Education, and Manpower Branch of the Division of Lung Diseases in the NHLBI where he was involved in transferring basic science into clinical practice and in directing the training program in pulmonary research. He went on to become the scientific review administrator for the Human Development and Aging Study Section and the Referral Officer for Small Business Innovative Research applications in the Division of Research Grants. Dr. Quantrano is director of the Center's Behavioral Sciences and Rehabilitation Engineering Program.

Carol Ann Sheredos, PT, MA, joined the Center in November 2000, as a program support specialist and policy fellow. She graduated from Ithaca College-Albert Einstein College of Medicine with a bachelor of science degree in physical therapy and received her master of arts degree in Adulthood and Aging from the College of Notre Dame of Maryland. She practiced physical therapy in New York, and then joined the VA Prosthetics Center as a research physical therapist, where she performed gait analyses and clinical application studies. Ms. Sheredos is chairperson of the Maryland Governor's Advisory Council on Individuals with Disabilities and is active in the disability community.

Michael Weinrich, MD, assumed directorship of the NCMRR in February 2000. He received his undergraduate and medical degrees from Harvard University, and was also trained in neurology at the University of Chicago, and in neurophysiology at the NIH. Dr. Weinrich has served on the faculties of Stanford University and the University of Maryland. Prior to joining the NCMRR, Dr. Weinrich was professor of neurology at University of Maryland and medical

director for rehabilitation at Kernan Hospital. From 1998-99, he served on the staff of Congressman Benjamin Cardin as a health policy fellow. His research has focused on application of computer technology to problems in rehabilitation, and on health policy for vulnerable populations.

Ms. Kristy Alston joined the NCMRR in April 2001, as a secretary.

Ms. Chrisoula Jennings joined the NCMRR in June of 2000, as secretary.

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APPENDIX B: CONFERENCES AND WORKSHOPS, 1998-2001

February 27-28, 1998	*Bioengineering—Building the Future of Biology and Medicine**
December 2-4, 1998	*Workshop on Clinical Trials in Rehabilitation*
June 16-20, 1999	*Workshop on EEG-Based Computer Interfaces*
July 29-30, 1999	*Developing Scientists for the Year 2000 and Beyond**
November 15-16, 1999	*Adaptive Learning: Interventions for Verbal and Motor Deficits**
December 7-8, 1999	*NCMRR Training Meeting*
August 4, 2000	*Rehabilitation For Stroke & Hip Fracture: Timing, Intensity, Duration*
October 20, 2000	*Protecting the Most Vulnerable: Home Mechanical Ventilation as a Case Study in Disability and Medical Care*
November 10-12, 2000	*Measurement Workshop on Child Disability*
January 4-5, 2001	*Medical Rehabilitation the Move: Spotlight on Mobility*
June 25, 2001	*Prosthetics Roundtable**

*co-sponsored meetings

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APPENDIX C: ROSTER FOR THE NATIONAL ADVISORY BOARD ON MEDICAL REHABILITATION RESEARCH, 2001

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