SPECIAL COMMUNICATION

Establishing the NeuroRecovery Network: Multisite Rehabilitation Centers That Provide Activity-Based Therapies and Assessments for Neurologic Disorders

Susan J. Harkema, PhD, Mary Schmidt-Read, MS, DPT, Andrea L. Behrman, PhD, PT, Amy Bratta, DPT, Sue Ann Sisto, PT, PhD, V. Reggie Edgerton, PhD

ABSTRACT. Harkema SJ, Schmidt-Read M, Behrman AL, Bratta A, Sisto SA, Edgerton VR. Establishing the NeuroRecovery Network: multisite rehabilitation centers that provide activity-based therapies and assessments for neurologic disorders. Arch Phys Med Rehabil 2012;93:1498-507.

The mission of the NeuroRecovery Network (NRN) is to provide support for the implementation of specialized centers at rehabilitation sites in the United States. Currently, there are 7 NRN centers that provide standardized activity-based interventions designed from scientific and clinical evidence for recovery of mobility, posture, standing, and walking and improvements in health and quality of life in individuals with spinal cord injury. Extensive outcome measures evaluating function, health, and quality of life are used to determine the efficacy of the program. NRN members consist of scientists, clinicians, and administrators who collaborate to achieve the goals and objectives of the network within an organizational structure by designing and implementing a clinical model that provides consistent interventions and evaluations and a general education and training program.

Key Words: Activity-based therapy; Evidence-based therapy; Locomotor training; Recovery; Rehabilitation; Spinal cord injuries.

THE MISSION OF THE Christopher and Dana Reeve Foundation (CDRF) NeuroRecovery Network (NRN) is to support the development of specialized centers that provide activity-based rehabilitation in the clinical environment. The network's primary objective is to evaluate the effect of rehabilitative interventions formulated from scientific and clinical evidence on function, health, and quality of life for people with SCI and other selected neurologic disorders. To achieve these goals, the NRN provides supervisory and financial resources to establish rehabilitative environments that reliably deliver appropriate and standardized interventions for regaining locomotor function by skilled therapists and technicians. A comprehensive battery of quantitative assessment tools are administered to document changes over time and determine the efficacy of the program. The resources provided to each NRN center by the cooperative agreement between the Centers for Disease Control and Prevention and the CDRF are intended specifically for the development of treatment and care programs for individuals with neurologic disorders. The NRN services are funded by a combination of resources, including institutional support, health insurance, and supplemental external research funds, each covering different functions. Furthermore, we anticipate that our centers will continue to seek supplemental funds to develop ancillary translational research projects. We have enrolled and acquired functional, health, and quality-of-life data for 296 participants with SCI (table 1), the neurologic disorder targeted to date based on the extensive amount of research examining the effects of locomotor training on SCI.[1-15]

Locomotor training is an activity-based therapeutic intervention for standing and walking that emphasizes activation of the neuromuscular system below the level of the lesion to induce neuroplasticity and promote recovery of function.[14] The NRN initially focused on implementing locomotor training in individuals with clinically incomplete SCI after their discharge from inpatient rehabilitation. Previously, physical rehabilitation focused predominantly on the neuromuscular system above the level of the lesion as a means of achieving compensation-based strategies to enhance mobility.[16-18] Based on our growing understanding of the residual functional capacity of the neural networks within the spinal cord, clinical strategies based on aggressive activation and reincorporation of the impaired neuromuscular system below the level of the lesion now can be implemented.[2-7,19-26] For example, the sensorimotor circuitry within the spinal cord has significantly greater control over complex movements, such as stepping and standing, than previously recognized.

Mammalian studies have shown that in the case of incomplete SCI lesions, locomotion is controlled at multiple levels of the nervous system and the injury results in a devastating imbalance among these levels of control.[27] Traditionally, the role of supraspinal contributions has been viewed as singularly

List of Abbreviations

CDRF	Christopher and Dana Reeve Foundation
NRN	NeuroRecovery Network

From the Department of Neurological Surgery, Kentucky Spinal Cord Research Center, University of Louisville, Louisville (Harkema); Frazier Rehab Institute, Louisville, KY (Harkema); Magee Rehabilitation Hospital, Philadelphia, PA (Schmidt-Read, Bratta); Department of Physical Therapy, University of Florida, Gainesville (Behrman); Veterans Affairs Brain Rehabilitation Research Center, Malcom Randall Veterans Affairs Medical Center, Gainesville, FL (Behrman); Physical Therapy Department, Division of Rehabilitation Sciences, School of Health Technology and Management, Stony Brook University, Stony Brook, NY (Sisto); and Departments of Integrative Biology and Physiology and Neurobiology and the Brain Research Institute, University of California, Los Angeles, CA (Edgerton).

Supported by the Centers for Disease Control and Prevention and the Christopher and Dana Reeve Foundation (grant/cooperative agreement no. U10/CCU220379).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the CDRF or Centers for Disease Control and Prevention, Department of Veterans Affairs, and the U.S. Government.

Reprint requests to Susan J. Harkema, PhD, 220 Abraham Flexner Way, Ste 1506, Louisville, KY 40202, e-mail: *susan.harkema@jhsmh.org*.

In-press corrected proof published online on Sep 3, 2011, at www.archives-pmr.org.

0003-9993/12/9309-00592$36.00/0
doi:10.1016/j.apmr.2011.01.023

Table 1: Description of Participants Enrolled in the NRN Program

No. of patients enrolled	296
Sex (%)	Men, 74; women, 26
Age (y)	39 (2, 79)
Time since injury (y)	0.9 (0.1,25.8)
No. of therapy per patient	40 (2, 319)

NOTE. Values expressed as median (minimum, maximum) unless noted otherwise.

critical, with little control attributed to spinal mechanisms. The underlying theory of using locomotor training in individuals with clinically incomplete SCI is that the remaining descending pathways have a facilitatory role in the reorganization of spinal circuitry. This occurs during retraining when appropriate sensory information related to locomotion is provided to the spinal circuitry driving activity-dependent plasticity at spinal and supraspinal levels. In cases ranging from extensive to complete loss of supraspinal input to the spinal cord, effective weight-bearing stepping can be generated, but does not translate to overground walking. However, when some descending input is available and the sensorimotor networks within the spinal cord receive afferent input through task-specific locomotor training, gains occur that exceed those seen during spontaneous recovery or with conventional therapy.[1,14,28] This suggests that combined with optimal retraining of spinal circuitry, only very limited residual descending input may be needed for significant functional improvements.

Improvements in multiple physiologic systems also were reported with locomotor training after SCI.[29-35] Individuals with SCI that repetitively performed weight-bearing showed improvements in blood pressure stability,[29] muscle mass,[36] and bone density.[30] Anecdotal clinical observations also showed changes in bowel and bladder activity. Changes in these parameters are being documented using quantitative evaluations under well-controlled conditions within the NRN.

A UNIQUE DELIVERY MODEL FOR TRANSLATION OF EVIDENCE INTO PRACTICE

The NRN is a unique delivery model for evidence-based practice of physical rehabilitation services to individuals with SCI and other neurologic disorders. The network draws on a partnership among stakeholders invested in scientific inquiry, rehabilitation service delivery, health care policy, and medical informatics to expedite translation of basic and applied scientific findings to clinical practice. Scientists, hospital administrators and managers, physical therapists, and physicians provide the leadership. As scientific discovery continues, activity-based therapies will be refined, standardized, evaluated, and integrated into clinical practice. This partnership is bidirectional because the clinical experience may direct researchers on critical paths of inquiry, whereas researchers reciprocally can inform clinical practice.

One of the most challenging obstacles to translation is the lack of standardization during implementation and evaluation of clinical interventions.[11,26] The NRN is designed to ensure that the programs, based on the recommendations and expectations of the network leaders, are implemented uniformly across its centers. Patient selection, evaluation, medical management, plan of treatment, and documentation all have standardized protocols. The resultant data are compiled from all centers into a centralized database. Systemax Corporation[a] has developed a custom-built web-based clinical documentation system that tracks clinical information, such as medical history, treatment plan, intervention documentation, and assessments of health, function, and quality of life, as well as demographic and financial information, including cost of treatment and reimbursement. Information from the central database is available to NRN centers or committees with approval of the directors and is compliant with the Commission on Accreditation of Rehabilitation Facilities, the Joint Commission on Accreditation of Health Care Organizations, and respective local institutional review boards and state regulatory guidelines. In addition to a comprehensive database of clinical information and standardized outcomes supporting program evaluation and clinical decision making, the NRN further bridges the chasm between scientific evidence and clinical practice by addressing other practical aspects of translation,[37,38] including staff training and scheduling. Members are educated through annual national training, monthly conference calls, and regional courses on locomotor training.

NETWORK DESIGN AND ORGANIZATIONAL STRUCTURE

The primary NRN objective is to develop and maintain an infrastructure that implements the network goals into rehabilitation environments and provides consistent care across centers. The design of the NRN is based on the philosophy that the clinicians, scientists, and administrators will be continuously reexamining and identifying new strategies to achieve the mission, goals, and objectives of the network. A consensus on the implementation of all policy and strategic issues identified by team leaders at each center are reached in conjunction with the NRN Advisory Board and the oversight provided by the CDRF and Centers for Disease Control and Prevention. Network annual staff meetings and an ongoing conference call mechanism allow for continual review and upgrading of procedures.

Site Selection of Centers

The CDRF requests applications to join the NRN by using postings on their web site and email distribution from profit and nonprofit organizations, both public and private, such as universities, hospitals, and rehabilitation centers in the United States. The application outlines the NRN requirements, including the center's roles and responsibilities, equipment and facilities, personnel, and institutional commitment. Applicants report institutional and center resources, reimbursement practices, clinical environment, a clinical plan to execute the objectives of the network, and a plan for integration of the rehabilitative therapies into the surrounding community and the clinical research environment. External reviewers not associated with the network with expertise in clinical care, administration of clinical care, and research in the area of SCI review and assign priority scores for the applications. The NRN Advisory Board convenes and selects new centers based on these priority scores and evaluation of the applicant's ability to achieve the goals and objectives of the NRN.

Network Structure and Administration

The network director is responsible for the overall network operation as designated by the CDRF and Advisory Board (fig 1). The co-network directors support the functions of the director. Center directors are responsible for the overall operation of their sites (centers), oversee all financial expenditures and institutional review board procedures, and provide annual progress and financial reports to the network director. The center physician determines the diagnosis, medical eligibility, and other health-related issues of participating individuals dur-

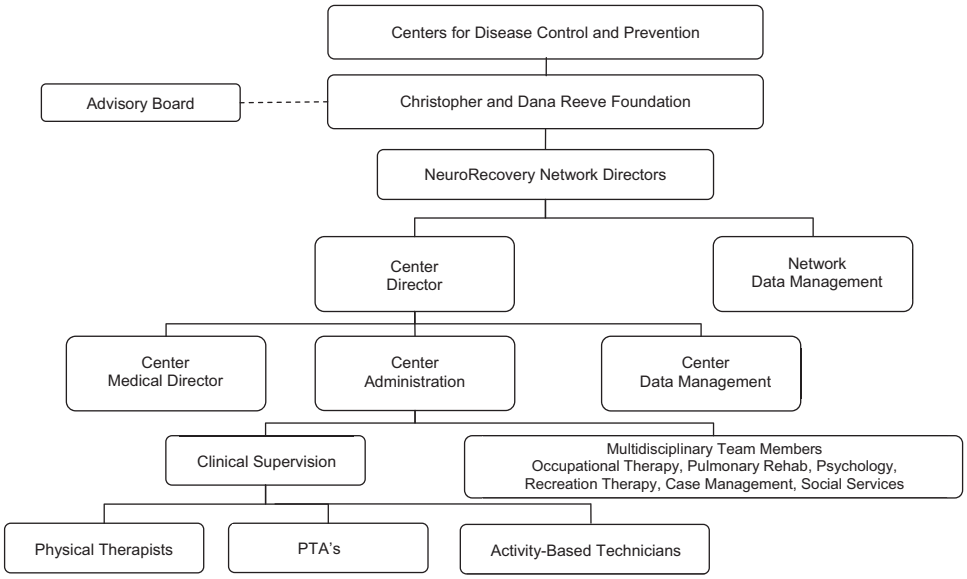

Fig 1. Illustration of the organization of the NRN. Abbreviation: PTA, physical therapist assistant.

ing the treatment intervention. The center administrator manages the authorization and admission processes, interfaces with third-party payers, and manages the facility's staffing, scheduling, and financial processes related to clinical operations. The center clinical supervisor, a licensed physical therapist, oversees the daily functions of the center with primary responsibility to ensure clinically effective delivery of activity-based interventions and valid and reliable collection of outcome measurements. This person interacts with the center administrator regarding authorization and admission processes, third-party payer requirements, facility staffing, and scheduling. The clinical team consists of physical therapists, physical therapist assistants, rehabilitation technicians, students, and volunteers who are trained in activity-based therapy with emphasis on locomotor training. Personnel also are dedicated to managing all aspects of data entry. NRN personnel communicate on a monthly basis by means of a multisite conference call system targeted toward facilitating network functions and also meet annually for a multiday conference.

The network directors maintain the governance policies and procedures as designated by the CDRF and NRN Advisory Board, as well as the clinical policies and procedures developed by consensus of the center directors. The NRN director communicates all new policies and revisions to the center directors and other collaborators. Center directors are responsible for communication with their respective team members and execution of all NRN policies and procedures. New policies and revisions are executed through a committee structure. Consultants are retained by the director of the NRN to provide guidance and advice in their area of expertise.

Standing and ad hoc committees develop and revise policies and procedures as needed and implement the goals and objectives of the network. Standing committees are appointed by the network director and address long-term issues critical to the goals and objectives of the network. The designated standing committees include Health, Data Integrity and Dissemination Oversight, Finance, Education and Training, Quality of Life, and Translation of Interventions to Clinical Practice. The ad hoc committees, which can be initiated by a center director and at least 1 other director, are organized for the purpose of analyzing, interpreting, and publishing data and initiating changes to existing or recommending new policies and procedures. External reviewers not associated with the network, with expertise in clinical care, administration of clinical care, and research in the area of SCI, also may participate in this process.

STANDARDIZED CLINICAL MODEL

Patient Selection Guidelines

Current criteria for patient enrollment in the NRN locomotor training program include the presence of a nonprogressive spinal cord lesion above T11, no current participation in an inpatient rehabilitation program, and medical referral by an NRN physician. Patients must have some lower-limb movement or visible voluntary contraction and the capacity to generate a lower-limb reciprocal alternating flexion/extension stepping pattern in the step training environment using body-weight support on a treadmill with manual facilitation. According to established NRN protocol, the NRN physician also directs the eventual elimination of antispasticity medications to avoid inhibiting neuromuscular activity and monitors other medical issues that may interact with training effectiveness. Also established in the medical protocol, the use of onabotulinumtoxinA or other medications for chemodenervation for spasticity likewise is avoided for the 3 months before NRN admission. Standardization of medical care associated with the locomotor training program is regulated by the health committee, composed of physicians from all centers.

Activity-Based Intervention: Locomotor Training

After physician referral, the screening process continues with the physical therapy evaluation. This evaluation focuses on the potential for recovery and occurs in the overground and body-weight support and treadmill environments. On a standard therapy mat, the patient is asked to execute a series of tasks: sitting and reaching with an upright posture, a reverse sit-up (controlled sitting to supine), sit-up, trunk extension in sitting (from a forward flexed position), sit to stand, stand, and components of walking (eg, lateral weight shift, weight shift in

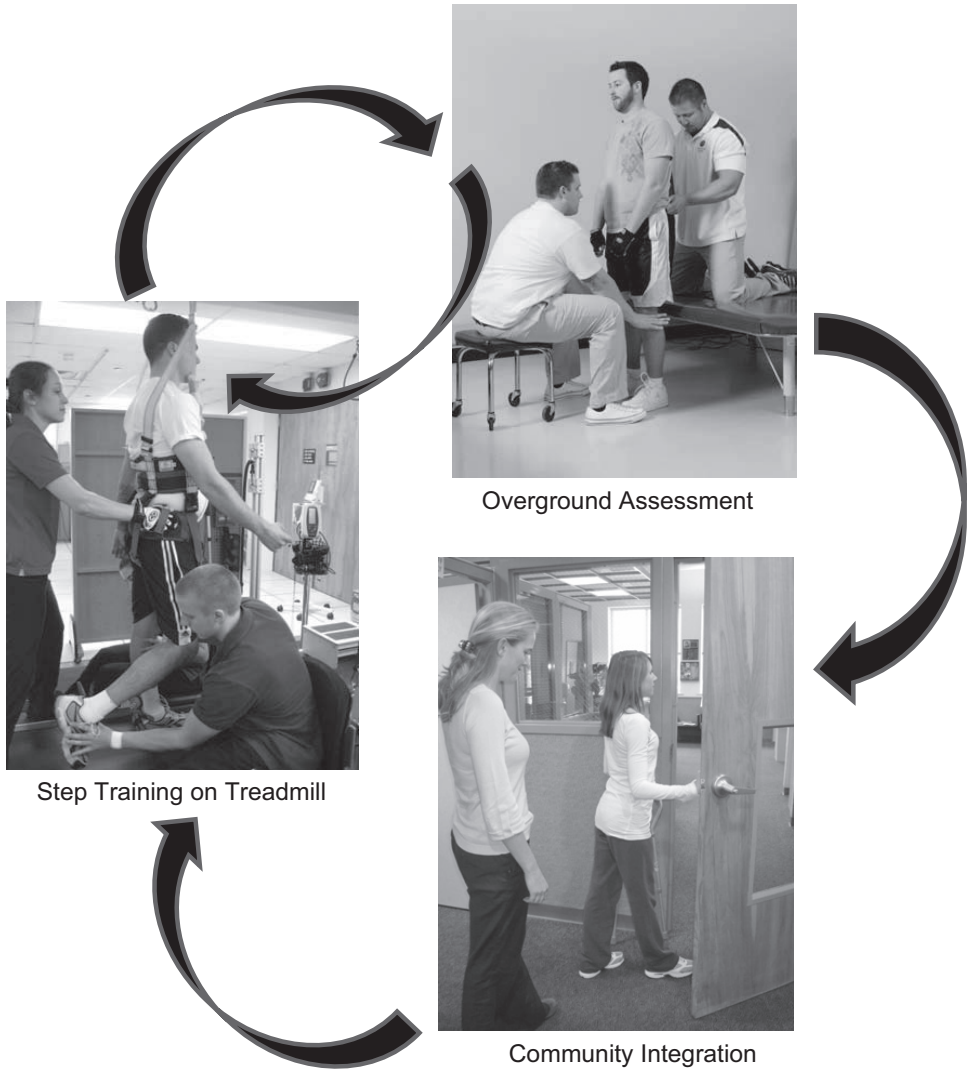

Fig 2. Participants in each of the 3 therapeutic environments.

the diagonal position, stepping). The patient's movements are assessed relative to a description of the preinjury movement pattern specific to the task. Physical assistance is allowed to help the patient into any position needed, but the assistance then is removed at certain body segments (eg, trunk, hips, knees) to determine areas of independent control. Thus, recovery of function is relative to movements that can be executed by the patient without compensation and all tasks are performed without assistive devices or bracing.

When assessment in this overground environment has been concluded, the patient is positioned wearing a trunk and pelvic harness in a body-weight support system over a treadmill. In this environment and with manual assistance of trainers, the therapist tests the capacity and independence of the patient's neuromuscular system to stand and generate steps in a safe and permissive environment. The capacity of the neuromuscular system, termed retraining, is assessed by identifying treadmill speed (stepping only) and body-weight support with manual facilitation to generate the stepping pattern or standing as close to preinjury as possible as judged by the physical therapist and training team. The independence of the neuromuscular system is referred to as adaptability and is assessed by identifying the treadmill speed (stepping only) and body-weight support at which independence from manual facilitation is achieved. Body-weight support and treadmill afford an assessment of physical capacity not available in the overground environment for standing and stepping. Treadmill speed and body-weight support offer systematic control and can be adjusted (decreased or increased) while the patient regains trunk alignment and limb position consistent with premorbid control for the specific task.

Based on the findings of the evaluation, the therapist will establish goals for treatment and implement a standardized plan of care. Therapists and trainers implement well-established locomotor training principles, including (1) maximizing weight bearing on the lower extremities and minimizing it on the upper extremities, (2) optimizing sensory input consistent with each activity, (3) optimizing the proper kinematics for each task, and (4) maximizing independence and recovery of movements while minimizing compensation.[11,39] A typical episode of care includes progressive retraining in functional skills, including balance, transfers, activities of daily living, and ambulation. Compliance to eliminate or minimize lower-limb orthotics also is expected to optimize sensory input to the spinal cord and promote optimal recovery. Initially, intensive therapy occurs in all 3 environments (fig 2), is preferred 5 times a week for

90-minute comprehensive sessions, and goals progress with recovery and functional change.

A typical locomotor training session has 3 components and occurs 5 times a week in the early phases of recovery with a minimum of 3 times a week in the later stages of recovery.[40] The step-training component is composed of task-specific retraining of the nervous system for standing and walking that occurs in a controlled environment using body-weight support on a treadmill with verbal and manual facilitation by trainers. Training is composed of (1) stand retraining, (2) stand adaptability, (3) step retraining, and (4) step adaptability and takes place for a minimum of 55 to 60 minutes. Retraining (stand or step) requires therapist/trainer manual facilitation to optimize the neuromuscular response to the sensorimotor experience. During retraining, the body-weight load is maximized while maintaining the appropriate task-specific kinematics with trainer facilitation for standing and stepping. During step retraining, treadmill speed is set for 2.0mph or greater to promote a stepping pattern as consistent with a preinjury pattern as possible. Step retraining occurs for a minimum of 20 minutes of the total 60-minute session. Adaptability (stand or step) reflects the patient's ability to perform the task independent of trainer facilitation, although body-weight support and treadmill speed are adjusted to grade progression of independence in a preinjury manner. The proportion of retraining and adaptability components of the total session time varies according to the extent of a patient's neuromuscular recovery. Thus, a greater proportion of retraining is necessary for a patient with severely impaired trunk posture and motor control in the trunk and extremities requiring a high percentage of body-weight support (up to 60%) and moderate to maximum amount of facilitation to achieve standing and stepping. As a patient progresses and shows neuromuscular recovery, retraining remains a fundamental component of training. However, time spent in stand and step adaptability increases, affording the practice and development of independent control. Each step training session ends with a bout of step retraining.

The second component is overground assessment that evaluates the transfer of the present capacity of the patient's neuromuscular system to mobility, posture, and walking skills over level ground and establishes priorities for further retraining. This assessment immediately follows the step training component. The patient walks off the treadmill with assistance if feasible or is placed in a wheelchair to move from the treadmill environment. Depending on the patient's current goals targeting recovery, the patient is asked to either stand or step in the overground environment and/or perform the sitting or trunk control tasks identified as a goal during the evaluation. The aim is to assess the immediate effect of locomotor training on the patient's abilities over ground, allow the patient and therapist to assess the patient's recovery, and identify critical elements limiting recovery at this stage. The identified elements become the aim of community integration and the next day's step-training session. Physical assistance is minimized during this assessment, and the evaluation is conducted without the use of assistive devices or bracing.

The third component is community integration that provides instruction for the individual to perform daily activities in the home and community environments and achieve safe efficient mobility. In this component, the individual is able to continually practice and integrate skills and abilities into the everyday routine. Although a locomotor training session takes place during a 1.5-hour session, the potential to advance the recovery of the nervous system continues outside of body-weight support on a treadmill and clinic environments to the patient's activities in the home and community. The patient, in consultation with and guidance from the therapist, applies the locomotor training principles in everyday activities and specific exercises to promote continued recovery. In addition, the use of assistive devices to achieve ambulation is introduced. The least restrictive assistive device is selected for use in the home and community, and instructions are provided for how to use the device consistent with the locomotor training principles. Depending on patient goals, multiple devices may be used. For example, depending on the extent of recovery and the specific recovery goal (eg, endurance in community ambulation vs improved adaptability in the home), a rolling walker and bilateral crutches may be selected and used alternately. Selection of a device is made repeatedly, and choices will change to meet new goals for progression.

Patient Progression

Patients progress through defined phases of recovery related to mobility, standing, and stepping, especially in regard to the level of physical independence for trunk, pelvis, and leg control within the step-training environment and the patient's abilities over ground without compensation. Initially, most of the time spent in a session would be in the step-training environment with physical assistance of up to 3 trained clinicians/aides. Over time, physical assistance may be decreased and more time may be spent on independence during the 90-minute session. Expectations for progression do not take strategies for compensation into account and are used to guide the clinician and participants to achieve higher levels of independent performance, which are critical to optimal recovery. Patients are challenged to advance by progressively changing the parameters of the intervention as appropriate, including treadmill speed, amount of body-weight support versus load, or manual facilitation of legs and hips. A standardized algorithm has been developed to guide physical therapists in which parameter to progress and when and in what order to optimize the work and neuromuscular recovery. Use of lower-extremity orthotics is avoided during locomotor training sessions and is considered only for safety use in the outdoor environment or at home. Patients are encouraged to use orthotic devices as little as possible at home and maximize practice without this alternative stabilization.

Patients are maintained in the program as long as they continue to progress, as shown in the ongoing evaluations performed on admission, discharge, and at approximately every 20 sessions of locomotor training. This reevaluation is a comprehensive battery of outcome measures examining neurologic motor function, balance, autonomic function, functional skills, and gait parameters. A standardized discharge algorithm has been developed to be used across all NRN sites, quantifying changes in neuromuscular activity and functional skills that support the therapist's decision to request more sessions or terminate the episode of care. Durability of outcomes is monitored by scheduling 6- and 12-month follow-up evaluations, including the same outcome measures previously performed. Some patients return to active treatment after a time if their clinical picture appears to have changed or new goals are established.

Staffing

Manually facilitated step training requires the hands-on attention and coordination of a team of personnel, potentially covering each leg and the hips and 1 for computer operation of body-weight support on a treadmill system. All new NRN facilities begin with a maximum of 2 therapists: 2 activity-based technicians staffing model. As staff expertise improves,

they move to a 1 therapist: 3 (or fewer) skilled technicians staffing model. As the patient's treatment progresses, a decrease in direct manual facilitation is expected, potentially decreasing the number of staff required for each session. This parallels other common therapeutic approaches to gait training, in which more than 1 staff member may assist with ambulation and assistive device use, although multiple staff members are not required throughout an entire session. Time spent on preparation and closure of the sessions, as well as overground assessment and community integration components, also may require less staff.

Center clinical staff are trained with skill competencies specific to locomotor training to facilitate efficient and effective service delivery and accurate assessment by using the standardized outcome measurements. A locomotor training manual is used to promote standardization of therapeutic interventions across centers. A comprehensive outcome measures manual was developed to provide standardization to the measurement techniques chosen by the network. All NRN staff members are provided with specific training for the theory and clinical skills of therapeutic application and clinical progression decision making. Intensive training for the skills needed to provide locomotor training is important for proper therapeutic facilitation, as well as from a staff risk management perspective. Improper body mechanics and manipulation of difficult patient types can result in injury to staff or ineffective treatment.

Clinical supervisors' conference calls occur monthly with a representative from each NRN center to foster standardization and clinical problem solving regarding pertinent patient care issues. Video feedback also is provided by clinical supervisors to promote the skill development of trainers and clinical problem solving for challenging patients. Center directors' conference calls also occur monthly to ensure consistency in overall management and promote the clinical, administrative, and dissemination goals of the NRN.

Equipment

The equipment used in the locomotor training program of the NRN includes a closed-loop computer-controlled body-weight support system[b] that allows center of mass movement while controlling forces, controls treadmill speeds from 0.5 to 10mph, and has seating and foot-support systems that include ergonomically appropriate support design for staff safety. Additionally, the NRN uses harnesses[c] of various sizes, front and side mirrors that provide visual feedback, a variety of assistive devices, automatic blood pressure monitoring equipment, a computerized pressure-sensitive walkway that records footfall pattern[d] and provides spatial-temporal parameters of gait, a portable step counter, and supplies that include a stop watch, yardstick, curbs, reclining chair, and automatic blood pressure, heart rate, and oxygen saturation monitor.

ASSESSMENTS

A critical component of the NRN is a Health Insurance Portability and Accountability Act–compliant and institutional review board–approved comprehensive database[a] that includes information from all centers for health, function, and quality-of-life outcomes, as well as financial parameters, such as cost and reimbursement. All outcome measures are collected as part of the NRN initiative at program admission and discharge with patient informed consent approval, and interim assessments occur approximately every 20 sessions. Follow-up assessments are targeted to be performed 6 and 12 months post–therapy discharge. A critical feature of the NRN infrastructure is standardization of assessments used for all outcome measures. This is accomplished through regional training opportunities, a mandatory annual national summit, and regular video review during conference calls that are weekly for new centers and monthly for existing centers. Clinical supervisors have monthly conference calls in which protocols for assessments are clarified and disseminated to their respective clinical teams. All NRN members follow a detailed operations manual to further ensure standardization of assessments. The annual NRN National Conference includes face-to-face practice of outcome measures by physical therapists from each center for continued assurance that standard procedures for outcome measure assessments are followed.

Functional outcomes measured routinely include a variety of neurologic dysfunction, balance, and gait measures that target all aspects of the *International Classification of Function, Disability and Health* model, including outcomes related to impairments in body function or structure, activity outcomes related to the capacity to execute tasks, and participation outcomes related to performance of tasks in the individual's current environment.[41]

Assessment of body structure and function focuses on neurologic dysfunction, completed at admission and discharge from the therapeutic episode of care by using the International Standards for Neurological Classification of SCI[42] examination, American Spinal Injury Association Impairment Scale,[43,44] and health measures, such as blood pressure, heart rate, respiration rate, and oxygen saturation at rest and orthostatic hypotension in response to a sit-up test.[45,46] These measures are used routinely throughout the episode of care to monitor changes in intrathoracic pressure from harness application, exercise tolerance, and incidence of autonomic dysreflexia and to measure changes in cardiovascular activity before and after locomotor training.[29,47] In addition, lipid metabolism is monitored initially and with follow-up if abnormalities are found. Other impairment outcomes measured include the Modified Ashworth Scale,[48] clonus, reflexes, pain, and grip strength tests.

Functional activity outcome measures routinely performed include balance measures, including the Modified Functional Reach (seated reach),[49] Tinetti[50,51] and Berg Balance Scale[52] tests, and functional walking measures, including the 10-Meter Walk Test[53] using a computerized pressure-sensitive mat[54,55] and the 6-Minute Walk Test,[53] along with the SCI Functional Ambulation Inventory.[56] Each is assessed approximately every 20 treatment sessions.

The Modified Functional Reach is performed according to Lynch,[57] Adegoke, and colleagues.[49] The subject is seated with the feet supported and the trunk rested on the back of the chair (reclined 10° from vertical). The subject raises his/her preferred shoulder to 90° and parallel to, but not touching, a wall-mounted yardstick. The location of the ulnar styloid of the raised arm is noted before and after maximal reach. If a patient is unable to raise the arms to 90°, the acromion is used as the point of reference. Two practice trials are followed by 3 scored trials, the mean of which constitutes the Modified Functional Reach score.

Tinetti Balance and Gait scores are assessed according to Tinetti[50] with slight scoring modifications. NRN subjects are instructed to avoid using the hands when rising to standing (item 2) and returning to a seated position (item 9). Also, balance during sitting is scored zero if the subject needs to hold the seat to stay upright for item 1. For Tinetti Gait, the assistive device is allowed for only items 4 (immediate standing balance) and 5 (standing balance) because these are the only items for which an assistive device is mentioned in the possible scores.

The Berg Balance Scale originally was developed to assess fall risk in community-dwelling elders. However, a number of studies have reported data for the SCI population.[39,58-63] NRN standardizations for testing include slight modifications, such as not allowing the participant to use lower-extremity bracing during the test. Item 5 requires transfers from chair to chair, and within the NRN, a therapy mat is not used for this test because it gives an unrealistic stable surface. For item 9, NRN uses a slipper to allow the participant to slide his/her hand easily inside it to pick up the item, which ensures that the test is scoring balance regardless of grip strength.

To perform the 6-Minute Walk Test, a 100-ft (30.48m) walkway is designated at each facility for testing the distance traveled back and forth along the walkway during 6 minutes. Using standardized language, subjects are instructed to walk as far as possible (measured in meters) in this time frame. If the participant requires rest, he/she could do so while standing with the timer still running, but if the participant needs to sit or needs assistance, the test is complete.[53] For the 10-Meter Walk Test, the time to walk the middle 10 meters of a 14-m walkway is recorded in seconds and rounded to the nearest 0.1 second.[53] At re-evaluation, these 2 tests are performed using the baseline/initial ambulation device (eg, walker, cane) first and then repeated using the current ambulation device. However, no lower-extremity bracing is allowed during execution of these ambulatory tests.

The GaitRite[d] computerized pressure-sensitive walkway is used in conjunction with the 10-Meter Walk Test to record footfall patterns and provide spatial-temporal parameters of gait. This information is recorded on a laptop computer and parameters are included in the central database. Because the GaitRite mat is 14 meters long, it affords the opportunity to manage the 2 outcome measures simultaneously.

The SCI Functional Ambulation Inventory[56] is scored during the first 2 minutes of the 6-Minute Walk Test. The Gait subscale assesses qualitative measures of gait (eg, step width, height, clearance on swing); the Assistive Devices subscale quantifies the upper- and lower-extremity assistive devices used (although braces were never used during these assessments); and the Mobility subscale assesses patient report of the extent of ambulatory activity in the home and community relative to use of a wheelchair. All ambulation outcome measures together offer sequential information related to changes in speed, endurance, assistive device use, therapist assistance, and qualitative information about gait parameters and patient perception of ambulation ability.

Finally, participation outcomes include quality-of-life measures, such as the Quality of Life Index for SCI (version III),[64] the Center for Epidemiological Studies Depression Scale,[65] Katz Index of Independence in Activities of Daily Living,[66] and the Craig Handicap Activity Reporting Technique-Short Form.[67] The Quality of Life Index for SCI III asks patients about health, relationships, work, religion, and personal lifestyle. The Center for Epidemiological Studies Depression Scale assesses patients' feelings about aspects of their life during the past week. The Katz addresses the patient's perception of functional activities, such as bathing, dressing, toileting, transfers, continence, and feeding.[68] The Craig Handicap Activity Reporting Technique-Short Form evaluates physical and cognitive independence, mobility, occupation, social integration, and economic self-sufficiency relative to family size versus medical expenses.[69]

FINANCING SERVICE DELIVERY

Another objective of the NRN is to define the financial cost of intensive activity-based therapies for a patient with a given type and severity of sensorimotor dysfunction. Because staff costs are the primary contributor to overall expenses, various staffing algorithms have been tested and refined, along with efficient scheduling and maximum use of equipment. Routine physical therapy charging procedures are used, with standardized Current Procedural Terminology coding based on physical therapy procedures. The subsequent financial analysis of clinical care includes demographic information related to primary and secondary payers and participant volume information, including procedure units and other routine expenses. Revenue tracking includes actual insurance payment, self-pay, or copay revenue. Net revenue is calculated and compared with actual institutionally based costs to produce accurate information for net income and actual charges and costs. The goal is to continually develop and implement strategies that address the unique reimbursement challenges for providing intensive activity-based therapy programs. To that end, the NRN's goal is to effect reimbursement policy for the delivery of activity-based therapies. Additionally, results of outcome measures collected regularly are examined to draw conclusions about cost-effectiveness and the financial impact, calculated through life care planning. Dissemination of these results to various payers is paramount to acceptance of locomotor training in the payer community.

EDUCATION AND TRAINING

One of the basic philosophies of the network is to provide consistent activity-based therapeutic interventions across all facilities based on the best scientific and clinical evidence available. To ensure this goal, consistent education of all NRN staff in locomotor training theory, manual facilitation techniques, progression, and outcome measurement is necessary both within and among NRN centers. To expand the availability of this intervention to as many patients as can potentially benefit from it, the network is committed to sharing this information throughout the community in both clinic- and community-based programs.

New Center Development

As the network has grown, each new center commits to an intensive training regimen that includes on-site skills training, ongoing educational development, regular video review of therapy provision, and weekly conference calls to collaborate with clinical staff from other network sites to further promote skill development and clinical decision making for the comprehensive care of NRN patients. New sites are led through the development process with guidance from network directors, consultant staff, and experienced clinical staff.

Training Opportunities

The NRN fosters a variety of educational and training opportunities for both network and non-network staff. A yearly national conference brings together staff from all NRN sites to review and advance skills in therapeutic delivery and clinical problem solving and progression, as well as reinforce the importance of standardization of the interventions and outcome measures. The committee structure of the NRN provides another ongoing avenue for continued growth and education across the network for such issues as financial management, data management, medical considerations, scheduling, staff training, equipment, and other practical issues. Specific projects defined within the NRN also facilitate continued collabo-

ration of members, including outcome measure development, standardized training tools, and age-specific applications.

Another objective of the NRN is to develop a core of regional clinical centers with highly trained personnel skilled in activity-based rehabilitation therapy. Annually, they provide training and information about the logistics of implementation, such as administration and reimbursement to community clinics in their region to promote dissemination of activity-based rehabilitation strategies rapidly and effectively across the United States. Regional training seminars are held at network centers throughout the year, with enrollment from the therapeutic and wellness communities. Multiple network sites represent geographic diversity in dissemination of education, although the content is standardized within the regional training curriculum. Therapy teams are encouraged to participate in either a 1-day lecture or a combination 4-day lecture series and intensive skills training educational seminar. This information will provide the groundwork for development within their own facility by providing practical implementation of the clinical model, including administration, resource use, and financial aspects of billing and reimbursement.

Finally, the NRN is committed to communicating the scientific evidence of activity-based interventions to the rehabilitation community. Members of the NRN present relevant information at local, regional, national, and international levels in such venues as professional association and multidisciplinary organization meetings, research seminars, and professional and academic school curricula. The NRN also offers clinical internship opportunities for physical therapy professional students at various centers.

NRN AS AN SCI NETWORK

The NRN is similar to other SCI networks, but also has distinct differences. The US SCI Model Systems of Care (see www2.ed.gov/programs/sci for more information), funded by the National Institute on Disability and Rehabilitation Research, has included prominent inpatient rehabilitation centers (currently 14) that gather important demographic and clinical data for the life span of a patient after acute traumatic SCI. Additional goals include conducting site-specific and collaborative research among the sites to advance the treatment and quality of life of those living with SCI. The European Multicenter Study About Spinal Cord Injury (see www.emsci.org for more information) has 18 paraplegic centers for which the goal is to establish a multicenter basis for future therapeutic interventions in human SCI. They conduct a standard set of neurologic, neurophysiologic, and functional assessments that is gathered at a coordinated center and central database. The NRN differs from these centers because it specifically focuses on translation of new rehabilitation therapies with rigorous evaluation of the standardized intervention in a specific patient population. Thus, the information that the European Multicenter Study About Spinal Cord Injury gathers for each individual is more extensive, and is collected during the interval of the intervention and within a 1-year follow-up. The collaboration of these networks can accelerate the achievement of synergistic goals and increase the efficiency of delivery of new therapeutic interventions.

The most recent results of the NRN's current intervention are reported in articles within this issue and indicate the effectiveness of locomotor training as standardized by these centers. These data cannot support whether locomotor training is superior to other rehabilitation interventions and cannot address specific hypotheses of the underlying theory of locomotor training in humans. However, it can provide information regarding a specific population, time frame, and intervention for improvements in function, health, and quality of life and is an example of using these theories to develop new rehabilitation strategies.

CONCLUSIONS

The CDRF NRN is a collaboration of specialized centers dedicated not only to providing activity-based rehabilitation in the clinical environment, but also to evaluating the effect of locomotor training and other evidence-based rehabilitative interventions in clinical environments. The network achieves these goals within established rehabilitative environments with clinicians with specialized training to deliver interventions and document patient progress using standardized protocols. The resultant partnership among basic scientists, clinical scientists, clinicians, and administrators provides a rich resource for continual refinement and analysis of new and promising therapies. The NRN and the development of its various protocols present an opportunity for accelerated translation of basic research to the clinic because the network is a readily available arena for multisite execution of the most current options for intervention after SCI.

Acknowledgments: We thank Joe Canose, BA, MLS, Susan Howley, BA, and Michael Mangienello, MPA, from the CDRF for dedication and support. The extraordinary vision, compassion, and dedication of Christopher and Dana Reeve made the NRN possible. We acknowledge the other current or past NRN Center Directors: Steve Ahr, MSSW, and Linda Shelburne, PT (Frazier Rehab Institute); Steve Williams, MD (Boston Medical Center); Daniel Graves, PhD (Memorial Hermann/The Institute of Rehabilitation and Research); Sarah Morrison, PT, and Keith Tansey, MD, PhD (Shepherd Center); Gail F. Forrest, PhD (Kessler Medical Rehabilitation Research and Education Corporation); and D. Michele Basso, PT, EdD (The Ohio State University Medical Center), plus all other current and previous network members (http://louisville.edu/medschool/neurosurgery/harkema/nrn); the critical review and editorial support of Jessica Hillyer, PhD; and the leadership, foresight, and support of the NRN Advisory Board, V. Reggie Edgerton, PhD, Moses Chao, PhD, Michael Fehlings, MD, PhD, Andrei Krassioukov, MD, PhD, and Shelly Sorani, MA.

References

1. Wernig A, Müller S, Nanassy A, Cagol E. Laufband therapy based on "rules of spinal locomotion" is effective in spinal cord injured persons. Eur J Neurosci 1995;7:823-9.
2. Wernig A, Nanassy A, Müller S. Maintenance of locomotor abilities following Laufband (treadmill) therapy in para- and tetraplegic persons: follow-up studies. Spinal Cord 1998;36:744-9.
3. Harkema SJ, Hurley SL, Patel UK, Requejo PS, Dobkin BH, Edgerton VR. Human lumbosacral spinal cord interprets loading during stepping. J Neurophysiol 1997;77:797-811.
4. Maegele M, Muller S, Wernig A, Edgerton VR, Harkema SJ. Recruitment of spinal motor pools during voluntary movements versus stepping after human spinal cord injury. J Neurotrauma 2002;19:1217-29.
5. Visintin M, Barbeau H. The effects of body weight support on the locomotor pattern of spastic paretic patients. Can J Neurol Sci 1989;16:315-25.
6. Dietz V, Colombo G, Jensen L, Baumgartner L. Locomotor capacity of spinal cord in paraplegic patients. Ann Neurol 1995;37:574-82.
7. Forssberg H, Grillner S, Halbertsma J. The locomotion of the low spinal cat. I. Coordination within a hindlimb. Acta Physiol Scand 1980;108:269-81.
8. Van Hedel HJ, Dietz V. Rehabilitation of locomotion after spinal cord injury. Restor Neurol Neurosci 2010;28:123-34.
9. Wessels M, Lucas C, Eriks I, de Groot S. Body weight-supported gait training for restoration of walking in people with an incom-

plete spinal cord injury: a systematic review. J Rehabil Med 2010;42:513-9.
10. Barbeau H, Nadeau S, Garneau C. Physical determinants, emerging concepts, and training approaches in gait of individuals with spinal cord injury. J Neurotrauma 2006;23:571-85.
11. Behrman AL, Harkema SJ. Physical rehabilitation as an agent for recovery after spinal cord injury. Phys Med Rehabil Clin N Am 2007;18:183-202.
12. Dietz V, Colombo G. Recovery from spinal cord injury—underlying mechanisms and efficacy of rehabilitation. Acta Neurochir Suppl 2004;89:95-100.
13. Dobkin B, Apple D, Barbeau H, et al. Weight-supported treadmill vs over-ground training for walking after acute incomplete SCI. Neurology 2006;66:484-93.
14. Harkema SJ. Plasticity of interneuronal networks of the functionally isolated human spinal cord. Brain Res Rev 2008;57:255-64.
15. Behrman AL, Bowden MG, Nair PM. Neuroplasticity after spinal cord injury and training: an emerging paradigm shift in rehabilitation and walking recovery. Phys Ther 2006;86:1406-25.
16. Somers M. Spinal cord injury: functional rehabilitation. 3rd ed. London: Prentice Hall Inc; 2009.
17. Atrice M, Morrison SA, McDowell S, Ackerman PM, Foy TA. Traumatic spinal cord injury. In: Umphred DA, editor. Neurological rehabilitation. 5th ed. St Louis: Mosby Inc; 2005. p 605-57.
18. Fulk G, Schmitz TJ, Behrman AL. Traumatic spinal cord injury. In: O'Sullivan S, Schmitz T, editors. Physical rehabilitation—assessment and treatment. 5th ed. Philadelphia: F.A. Davis Co; 2006. p 937-98.
19. Edgerton VR, Tillakaratne NJ, Bigbee AJ, de Leon RD, Roy RR. Plasticity of the spinal neural circuitry after injury. Annu Rev Neurosci 2004;27:145-67.
20. Barbeau H, Rossignol S. Recovery of locomotion after chronic spinalization in the adult cat. Brain Res 1987;412:84-95.
21. Barbeau H, Blunt R. A novel interactive locomotor approach using body weight support to retrain gait in spastic paretic subjects. In: Wernig A, editor. Plasticity of motorneuronal connections. Amsterdam: Elsevier Science Publishers; 1991. p 461-74.
22. de Leon RD, Hodgson JA, Roy RR, Edgerton VR. Locomotor capacity attributable to step training versus spontaneous recovery after spinalization in adult cats. J Neurophysiol 1998;79:1329-40.
23. de Leon RD, Hodgson JA, Roy RR, Edgerton VR. Full weight-bearing hindlimb standing following stand training in the adult spinal cat. J Neurophysiol 1998;80:83-91.
24. de Leon RD, Hodgson JA, Roy RR, Edgerton VR. Retention of hindlimb stepping ability in adult spinal cats after the cessation of step training. J Neurophysiol 1999;81:85-94.
25. Grillner S. Control of locomotion in bipeds, tetrapods, and fish. In: Comprehensive Physiology. Bethesda: American Physiological Society; 1981. p 1179-236.
26. Dromerick AW, Lum PS, Hidler J. Activity-based therapies. NeuroRx 2006;3:428-38.
27. Rossignol S, Barriere G, Alluin O, Frigon A. Re-expression of locomotor function after partial spinal cord injury. Physiology (Bethesda) 2009;24:127-39.
28. Tester NJ, Howland DR, Day KV, Suter SP, Cantrell A, Behrman AL. Device use, locomotor training and the presence of arm swing during treadmill walking after spinal cord injury. Spinal Cord 2011;49:451-6.
29. Harkema SJ, Ferreira CK, van den Brand RJ, Krassioukov AV. Improvements in orthostatic instability with stand locomotor training in individuals with spinal cord injury. J Neurotrauma 2008; 25:1467-75.
30. Sisto SA, Forrest GF, Faghri PD. Technology for mobility and quality of life in spinal cord injury. IEEE Eng Med Biol Mag 2008;27:56-68.
31. Hicks AL, Adams MM, Martin Ginis K, et al. Long-term body-weight-supported treadmill training and subsequent follow-up in persons with chronic SCI: effects on functional walking ability and measures of subjective well-being. Spinal Cord 2005;43: 291-8.
32. Giangregorio LM, Hicks AL, Webber CE, et al. Body weight supported treadmill training in acute spinal cord injury: impact on muscle and bone. Spinal Cord 2005;43:649-57.
33. Giangregorio LM, Webber CE, Phillips SM, et al. Can body weight supported treadmill training increase bone mass and reverse muscle atrophy in individuals with chronic incomplete spinal cord injury? Appl Physiol Nutr Metab 2006;31:283-91.
34. Ditor DS, Kamath MV, Macdonald MJ, Bugaresti J, McCartney N, Hicks AL. Effects of body weight-supported treadmill training on heart rate variability and blood pressure variability in individuals with spinal cord injury. J Appl Physiol 2005;98:1519-25.
35. Ditor DS, Macdonald MJ, Kamath MV, et al. The effects of body-weight supported treadmill training on cardiovascular regulation in individuals with motor-complete SCI. Spinal Cord 2005; 43:664-73.
36. Jayaraman A, Shah P, Gregory C, et al. Locomotor training and muscle function after incomplete spinal cord injury: case series. J Spinal Cord Med 2008;31:185-93.
37. Institute of Medicine. Crossing the quality chasm: a new health system for the 21st century. Washington (DC): National Academy Pr; 2001.
38. Jette AM. Invention is hard, but dissemination is even harder. Phys Ther 2005;85:390-1.
39. Behrman AL, Harkema SJ. Locomotor training after human spinal cord injury: a series of case studies. Phys Ther 2000;80:688-700.
40. Harkema S, Behrman A, Barbeau H. Locomotor training: principles and practice. New York: Oxford University Pr; 2011.
41. Ustun TB, Chatterji S, Bickenbach J, Kostanjsek N, Schneider M. The International Classification of Functioning, Disability and Health: a new tool for understanding disability and health. Disabil Rehabil 2003;25:565-71.
42. American Spinal Injury Association. Reference manual for the international standards for neurological classification of spinal cord injury. Chicago: American Spinal Injury Assoc; 2003.
43. Kirshblum S, Donovan W. Neurologic assessment and classification of traumatic spinal cord injury. In: Kirshblum S, Campagnolo D, DeLisa JA, editors. Philadelphia: Lippincott, Williams & Wilkins; 2002. p 82-95.
44. Maynard FM, Bracken MB, Creasey G, et al. International standards for neurological and functional classification of spinal cord injury. Spinal Cord 1997;35:266-74.
45. Krassioukov AV, Karlsson AK, Wecht JM, Wuermser LA, Mathias CJ, Marino RJ. Assessment of autonomic dysfunction following spinal cord injury: rationale for additions to International Standards for Neurological Assessment. J Rehabil Res Dev 2007; 44:103-12.
46. Claydon VE, Krassioukov AV. Orthostatic hypotension and autonomic pathways after spinal cord injury. J Neurotrauma 2006; 23:1713-25.
47. Krassioukov AV, Harkema SJ. Effect of harness application and postural changes on cardiovascular parameters of individuals with spinal cord injury. Spinal Cord 2006;44:780-6.
48. Pandyan AD, Johnson GR, Price CI, Curless RH, Barnes MP, Rodgers H. A review of the properties and limitations of the Ashworth and Modified Ashworth Scales as measures of spasticity. Clin Rehabil 1999;13:373-83.
49. Adegoke BO, Ogwumike OO, Olatemiju A. Dynamic balance and level of lesion in spinal cord injured patients. Afr J Med Sci 2002;31:357-60.
50. Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. J Am Geriatr Soc 1986;34:119-26.

51. Tinetti ME, Ginter SF. Identifying mobility dysfunctions in elderly patients. Standard neuromuscular examination or direct assessment? JAMA 1988;259:1190-3.
52. Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil 1992;73:1073-80.
53. Van Hedel HJ, Wirz M, Dietz V. Assessing walking ability in subjects with spinal cord injury: validity and reliability of 3 walking tests. Arch Phys Med Rehabil 2005;86:190-6.
54. Menz HB, Latt MD, Tiedemann A, Mun SK, Lord SR. Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. Gait Posture 2004;20:20-5.
55. Webster KE, Wittwer JE, Feller JA. Validity of the GAITRite walkway system for the measurement of averaged and individual step parameters of gait. Gait Posture 2005;22:317-21.
56. Field-Fote EC, Fluet GG, Schafer SD, et al. The Spinal Cord Injury Functional Ambulation Inventory (SCI-FAI). J Rehabil Med 2001;33:177-81.
57. Lynch SM, Leahy P, Barker SP. Reliability of measurements obtained with a modified functional reach test in subjects with spinal cord injury. Phys Ther 1998;78:128-33.
58. Dobkin BH, Curt A, Guest J. Cellular transplants in China: observational study from the largest human experiment in chronic spinal cord injury. Neurorehabil Neural Repair 2006;20:5-13.
59. Lemay JF, Nadeau S. Standing balance assessment in ASIA D paraplegic and tetraplegic participants: concurrent validity of the Berg Balance Scale. Spinal Cord 2010;48:245-50.
60. Gorgey AS, Poarch H, Miller J, Castillo T, Gater DR. Locomotor and resistance training restore walking in an elderly person with a chronic incomplete spinal cord injury. NeuroRehabilitation 2010; 26:127-33.
61. Datta S, Lorenz DJ, Morrison S, Ardolino E, Harkema SJ. A multivariate examination of temporal changes in Berg Balance Scale items for patients with ASIA Impairment Scale C and D spinal cord injuries. Arch Phys Med Rehabil 2009;90:1208-17.
62. Musselman KE, Fouad K, Misiaszek JE, Yang JF. Training of walking skills overground and on the treadmill: case series on individuals with incomplete spinal cord injury. Phys Ther 2009; 89:601-11.
63. Wirz M, Muller R, Bastiaenen C. Falls in persons with spinal cord injury: validity and reliability of the Berg Balance Scale. Neurorehabil Neural Repair 2010;24:70-7.
64. Ferrans C, Powers M. Quality of life index: Spinal Cord Injury Version III. 1998. Available at: www.uic.edu/orgs/qli/questionaires/pdf/spinalcordinjuryversionIII/Spinal3qli.PDF. Accessed March 30, 2011.
65. Kuptniratsaikul V, Chulakadabba S, Ratanavijitrasil S. An instrument for assessment of depression among spinal cord injury patients: comparison between the CES-D and TDI. J Med Assoc Thai 2002;85:978-83.
66. Katz S, Downs T, Cash H, Grotz RC. Progress in development of the index of ADL. Gerontologist 1970;10:20-30.
67. Whiteneck GG, Brooks C, Charlifue S, et al. Craig Handicap and Assessment Reporting Technique. Englewood: Craig Hospital; 1992.
68. Katz S. The Index of Independence in Activites of Daily Living, or Index of ADL. In: McDowell I, Newell C, editors. Measuring health—a guide to rating scales and questionnaires. New York: Oxford Univ Pr; 1996. p 63-7.
69. Whiteneck GG, Charlifue SW, Gerhart KA, Overholser JD, Richardson GN. Quantifying handicap: a new measure of long-term rehabilitation outcomes. Arch Phys Med Rehabil 1992;73:519-26.

Suppliers

a. Systemax Corp, 9509 Hwy 42, Ste 100, PO Box 907, Prospect, KY 40059.
b. Therastride, Innoventor 3600 Rider Trail South, St Louis, MO 63045.
c. Robertson Harness, PO Box 90086, Henderson, NV 89009-0086.
d. CIR Systems, Inc, 60 Garlor Dr, Havertown, PA 19083.