SPECIAL COMMUNICATION

Locomotor Training: As a Treatment of Spinal Cord Injury and in the Progression of Neurologic Rehabilitation

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Scientists, clinicians, administrators, individuals with spinal cord injury (SCI), and caregivers seek a common goal: to improve the outlook and general expectations of the adults and children living with neurologic injury. Important strides have already been accomplished; in fact, some have labeled the changes in neurologic rehabilitation a "paradigm shift." Not only do we recognize the potential of the damaged nervous system, but we also see that "recovery" can and should be valued and defined broadly. Quality-of-life measures and the individual's sense of accomplishment and well-being are now considered important factors. The ongoing challenge from research to clinical translation is the fine line between scientific uncertainty (ie, the tenet that nothing is ever proven) and the necessary burden of proof required by the clinical community. We review the current state of a specific SCI rehabilitation intervention (locomotor training), which has been shown to be efficacious although thoroughly debated, and summarize the findings from a multicenter collaboration, the Christopher and Dana Reeve Foundation's NeuroRecovery Network.

Key Words: Clinical trial; Locomotion; Rehabilitation; Spinal cord injuries.

SCIENTISTS, CLINICIANS, administrators, individuals with spinal cord injury (SCI), and caregivers seek a common goal: to improve the outlook and general expectations of the adults and children living with neurologic injury. Important strides have already been accomplished; in fact, some have labeled the changes in neurologic rehabilitation a paradigm shift.[1] Not only do we recognize the potential of the damaged nervous system, but we also see that "recovery" can occur and should be defined broadly. Success of rehabilitation can be defined by the individual's ability to perform tasks interdependently with physical assistance or independently with compensation and by providing education to patients and caregivers. However, investment by these stakeholders is also needed for the success of recovery of the neuromuscular system, as even incremental changes can significantly improve the quality of life of those with SCI.[2] Also, quality-of-life measures are gaining in significance and influence in our composite understanding of recovery,[3,4] as is the individual's sense of accomplishment and well-being.[5]

The ongoing challenge from research to clinical translation is the fine line between scientific uncertainty (ie, the tenet that nothing is ever proven) and the necessary burden of proof required by the clinical community. One challenge is that the determination of clinical efficacy is designed to allow compensation to reach a "functional" task and does not adequately distinguish actual neuromuscular recovery. SCI rehabilitation certainly is not the only field where this dilemma presents itself, but it is imperative for us to resolve it in order to continue the advancement of recovery interventions for this debilitating condition. In this article, we will review the current state of a specific SCI rehabilitation intervention (locomotor training), which has been shown to be efficacious although thoroughly debated,[1,6-16] and summarize the findings from a multicenter collaboration, the Christopher and Dana Reeve Foundation's NeuroRecovery Network (NRN).[17] Our aim is to discuss the current evidence of locomotor training from the NRN and its context to clinical care, acknowledging that many future studies are needed.

REVIEW OF LOCOMOTOR TRAINING FOR SCI REHABILITATION

Locomotor training is founded on the principles of activity-dependent plasticity and automaticity.[1,6,8,9,12,14,15,18-20] Activity-dependent therapies focus on recovery with an objective to minimize compensation and activate the neuromuscular system below the level of the lesion. The premise of locomotor training is to provide the damaged nervous system with appropriate sensory input to stimulate remaining spinal cord networks to facilitate their continued involvement even when supraspinal input is compromised. In short, the spinal circuitry responds to

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List of Abbreviations

AIS	American Spinal Injury Association Impairment Scale
BWS	body weight support
BWSTT	body weight–supported treadmill training
ISNCSCI	International Standards for Neurological Classification of Spinal Cord Injury
NRN	NeuroRecovery Network
NRS	Neuromuscular Recovery Scale
RCT	randomized controlled trial
SCI	spinal cord injury

sensory input, adapts behavioral output appropriately, and can induce permanent modifications in this system with repetition: the spinal cord can learn.[11] There is essentially a century of basic science experimentation underlying the premise of locomotor training.[21]

Evidence for Functional Recovery After SCI With Locomotor Training

The intent of the early studies of spinal cord activity-dependent plasticity in humans evolved into what we know today as locomotor training.[22-32] However, they were human studies testing hypotheses related to the ability of the human spinal cord to process sensory information and generate locomotion, not designed to assess rehabilitation intervention to improve outcomes. Even more recent studies of humans with SCI have expanded our knowledge of how the nervous system functions after injury and provide insight into the neuromuscular mechanisms used to develop the underlying clinical principles for locomotor training.[12,33-46]

Numerous case studies[47-57] and controlled cohort population reports on locomotor training followed.[4,58-65] Two early reports by Wernig et al[60,61] gave indications that there was potential to use the knowledge emerging from animal and human basic science studies to improve locomotor outcomes in people with incomplete SCI. Wernig[61] trained 44 patients, only 1 of whom did not gain more independence. Assessments of functional tasks (obstacle clearance, stair climbing, and measures such as the Functional Ambulation Category, the Walking Index for SCI, and the Spinal Cord Independence Measures) were also improved with locomotor training.[66-68]

Subsequent reports showed gains in walking speed[47,53,57,59,60,68-78] and increases in distance,[2,47,49,53,55,57,59,60,68,70,74,76,77,79] as well as improvements in balance, body weight support, electromyographic activity, and kinematics.[24,27,30,36,38,48,49,57,59,60,65,71,80-88] The results were highly variable with extreme ranges of improvements reported for walking speeds (.07–0.5m/s) and walking distances (25–191m). Further adding to the variability was the wide range of assistive devices used as well as the types of measures that would improve or not improve in a particular study. For example, Effing et al[89] report that 1 participant showed gains in performance of activities of daily living, 1 improved walking ability, and 1 improved walking speed and Get Up and Go test performance[90,91] but actually decreased in performance of activities of daily living. Each of these gains was, most likely, incredibly significant to each individual, but essentially impossible to compare or translate into a significant statistical result.

In their long-term study, Hicks et al[4] tested walking ability both on the treadmill and overground in individuals with incomplete SCI. After locomotor training, participants showed a 54% reduction in body weight support required, a 180% increase in walking speed, and a 335% increase in distance. At their 8 month follow-up, overground walking was maintained, but treadmill walking and satisfaction in performance were slightly reduced. The authors contend that continued practice is important, and this may explain why participants who are able to progress to overground walking may maintain better function than those who fail to progress during training.

The few follow-up studies that have been conducted generally report high levels of result maintenance. In their pediatric case study, Fox et al[51] conducted a follow-up assessment 2 years after the completion of locomotor training. The patient not only maintained the previously recorded levels of improvement, but actually showed further gains in walking ability and had exhibited normal growth and development during that period. Wernig et al[62] conducted follow-up assessments at different intervals after locomotor training (range, 6mo to 6.5y later) and reported that 31 of 35 patients who had chronic injuries at the commencement of locomotor training maintained their progress (3 of the remaining 4 actually showed further progress, and only 1 lost gains). Of the 41 patients with acute injuries at the commencement of locomotor training, 26 maintained and 15 showed further improvement.

Three randomized controlled trials (RCTs) to date have examined locomotor training (or as termed in 1 report[92] "body weight–supported treadmill training" [BWSTT]) in the SCI population.[69,73,92] Dobkin et al[92] compared BWSTT in individuals with SCI (American Spinal Injury Association Impairment Scale [AIS] C and D) during acute inpatient rehabilitation (enrollment within 8wk postinjury) with 60 interventions sessions to a control group. The final reported analyses found no significant difference in "as fast and safe as possible" walking speed at 6 months postinjury between the combined AIS C and D BWSTT (n=27) and control (n=18) groups. While the outcomes were similar between the groups, the result of achieving a fast walking speed of 1.1m/s is a historically significant outcome because no such gains have previously been reported or were expected.[93] Achievement of this walking speed was a clinically meaningful outcome since a minimum speed of 0.8m/s is required for community ambulation.[94]

In the Dobkin[92] trial, the control group incorporated into "usual care" an additional 60min/d of weight-bearing activity (eg, stand or walk, as appropriate) to control for the time of patient exposure to a therapist and the time weight-bearing in therapy relative to the "experimental" BWSTT group. This addition to "usual care" not only increased the intervention dose beyond that of usual care, but also used a specific principle of the locomotor training intervention—weight-bearing. Dose and weight-bearing may have been critical elements to the success of both interventions—BWSTT and the control group—and may have accounted for the lack of difference in outcomes.

Two recently reported trials in the population with chronic motor incomplete SCI compared the effects of therapeutic interventions that used some of the critical elements of locomotor training (eg, load-bearing, manual-assist, treadmill-based training), as well as other features (eg, functional electrical stimulation to ankle dorsiflexors and robotic assist). Field-Fote and Roache[73] reported mean walking speed increases of .05, .05, .09, and .01m/s for 60 sessions of intervention across 4 groups, respectively, all using body weight support (BWS) (ie, treadmill with manual assist; treadmill with bilateral stimulation to elicit a flexor reflex response; overground with assistive device and stimulation to ankle dorsiflexors; and Lokomat, robotic assist). They also reported walking distance increases of 0.8, 3.8, 14.2, and 1.2m across groups. Alexeeva et al[69] observed mean changes of walking speed of 0.1, .11, and .16m/s across 39 sessions for 3 intervention groups: traditional physical therapy, BWS overground via track, and BWS over treadmill. With common inclusion criteria of the ability to advance a minimum of 1 limb, initial walking speeds for the trials varied, with mean $\pm$ SD walking speeds for each study population of approximately $.018\pm.15$m/s and $.35\pm.29$m/s, respectively.[69,73] Participants' abilities varied with inclusion of persons (n=9) who could not achieve a speed of 0.1m/s to one who walked at 1.2m/s.[69] With these varied training approaches, outcomes for walking speed change ranged from .01 to .16m/s, and for improved distance from 0.8 to 14.2m. All groups had weight-bearing with other variations of training.

Changes in the Anatomy or Physiology of Body Systems

Other benefits of locomotor training that are not directly related to functional movement demonstrate a crucial development in the field. We have learned that even in cases where functional change is nonsignificant, concurrent changes in health, such as cardiovascular function, muscle composition, metabolism, bone and fat mass, quality of life, and depression, may be of considerable value.[3,4,95] Locomotor training has been correlated with increases in muscle and bone mass or at least decreases in their atrophy in several studies.[47,82,96-100] Cotie et al[101] report decreases in skin temperature after only 12 sessions of locomotor training, which they deduce will result in fewer pressure ulcers. Positive cardiovascular and respiratory effects, such as improved heart rate, response to orthostatic challenge, physiologic cost index, blood pressure regulation, locomotor-respiratory coupling, and ventilatory demand, are also reported.[74,75,78,102-104] Phillips et al[105] report that after 68 sessions, patients showed improved glycemic regulation, a change that was not completely caused by changes in muscle mass.

A final category of outcome variables may be the least sensitive or quantitative, but quite possibly critically important qualitatively to persons living with SCI. Changes in the restrictions on activities of daily living and required assistive devices, or really the patient's sense of independence, are vehemently sought. Many studies[2,48,79,106,107] have demonstrated a positive relationship between locomotor training and independence; for example, progression to a less restrictive assistive device (ie, from a wheelchair to a cane). In fact, in 2 separate pediatric case studies,[50,54] the patients (1 chronic and 1 acute post-SCI) progressed from a complete absence of leg use and complete functional dependence to community ambulation. Gorgey et al[52] describe the case of an elderly patient who progressed from a power wheelchair to crutches after only 20 sessions. Wernig[61] trained 44 patients, only 1 of whom did not gain more independence.

Locomotor training is associated with functional improvements in several behaviors and body systems, and can be standardized and implemented efficiently, but it is a skilled paradigm and requires considerable effort from all parties involved. This includes effective clinical decision-making for challenge and progression in order to advance patient outcomes. Individual patients who have participated in locomotor training often enthusiastically report improvements in stress, pain, quality of life, motivation, hope, enjoyment, and confidence whether or not they show concurrent functional gains as measured with routine clinical measures.[5,66,79,89,103,108]

Two reviews of locomotor training have concluded that there is not sufficient evidence to either support or refute its usefulness as an intervention, especially in light of the additional cost above and beyond conventional therapies.[13,16] One review[13] used 1 clinical trial in an acute SCI population and 1 ongoing study (preliminary data were used) of a chronic SCI population that compared different aspects of locomotor training among the groups from preliminary data published for the trial. The other 2 studies reviewed used robotics and functional electrical stimulation. Thirty-one other available studies on locomotor training were not included based on their predetermined selection criteria. The authors' conclusion was that the evidence was insufficient because too few randomized controlled trials (RCTs) were conducted with too few subjects to evaluate the efficacy. Their recommendation was that future studies of locomotor training should identify the subpopulations of people who are benefiting and include a description of the complete intervention strategy. The other review[16] included the same studies plus an additional 13 studies and also reached the conclusion that more RCTs are needed. There is still so much to discover concerning the underlying mechanisms and the optimal uses of locomotor training. For example, who should receive locomotor training, when and what dosage should they receive, and what other interventions would complement the effects? The following section discusses some limitations of the studies that have provided the evidence for locomotor training for recovery after SCI.

Methodologic Issues Related to Locomotor Training Studies

Although this evidence for locomotor training is compelling, several methodologic limitations require consideration. The variability in the outcomes across the studies of locomotor training can be attributed to small samples, nonstandardized protocols, heterogeneity in patient populations, and ineffective assessment measures. Most of the aforementioned studies were conducted on very small samples with only 12 reported on samples of greater than 20 participants undergoing locomotor training.[61,65,67,69,72,73,86,87,92,109-111] Even the RCTs have limited numbers per experimental group (range, 16–26 patients per experimental group[69,73,92]) that do not reach the number of patients recommended by the National Institutes of Health. This may be attributed to the lower prevalence of SCI as compared with other diagnostic groups.

The heterogeneity of the population of the individuals studied also contributes to variability in the studies of locomotor training. Criteria for subject enrollment and group assignment according to AIS category has been the predominant method intended to achieve homogeneity of the participant population. However, the functional status has now been shown to be highly variable. Alternative strategies include stratification by lower extremity motor score[73] or by initial ability to walk,[73] yet recent studies[112,113] have shown that neither of these variables is predictive of recovery with locomotor training. The time since injury is a critical factor to consider during study design in order to properly support the efficacy of any intervention.[92] For SCI, researchers tend to view injuries as chronic after about 1 year when spontaneous recovery is assumed to reach a plateau.[114-118] However, entering patients in the earliest phase after injury introduces the ethical dilemma of withholding treatment from potentially eligible patient groups and designing an appropriate control group. Some investigators have attempted to deal with this problem by collecting data from historical controls or by comparing the results after locomotor training with results seen after conventional physical therapy.[59,61,67,77]

Studies vary considerably in their use of locomotor training, from time after injury, length of sessions, amount of cumulative sessions, density of treatment, use of cotreatments, and type of training. In many studies, training occurs only on the treadmill, while testing is overground, whereas in other studies training occurs on the treadmill with directed translation of skills to overground, with testing of speed and endurance conducted overground.[7,18,73,119] The use of concomitant overground training and/or a conventional physical therapy component is also variable. Others implement these additions (or leave them out) either before or after the treadmill training portion[53] or in separate groups.[59,61,77,86]

The cumulative number of sessions is probably the most variable factor, even within any 1 study. In the reviewed reports alone, the number of sessions ranged from 6[67] to 144.[4,98] Variation of session number can be nearly as great within an individual study. For example, subjects have received 85, 64, 27, or 15 sessions,[48] 15 to 24 sessions,[120] an average of 42 sessions,[36] between 30 and 90 sessions,[37] 30 to 60 sessions,[38] 39 to 60 sessions,[76] 6 to 110 (mean, 25) sessions,[67] approximately 137 sessions,[65] 24 to 40 sessions,[68] or a minimum of 50 sessions.[88] A final consideration regarding locomotor training sessions is their density or schedule.[78,98,107]

Two final standardization issues involve differences in adaptations to the basic locomotor training process. The (dis)advantages of the use of cotreatments have not been thoroughly investigated and, therefore, are often subject to the interests of the investigator. Finally, one of the most pressing standardization issues is the "type" of step training given. The use of manual step training versus robot or electrically stimulated training is rigorously analyzed, but results are generally inconclusive.[121] In support of robot-driven step training, it is clear that the Lokomat and other systems can reduce the therapist's effort, increase intersession reliability, and provide resistance and trajectory guidance.[76,106,122,123] However, the value of manual-assisted step training is actually in its variability because the restrictive nature of robotic assistance does not allow for the same level of variability and can result in passivity of the patient. These 2 factors of robotic movement deviate from important underlying principles of activity-based therapy that facilitate patients to use their own neuromuscular abilities mediated by manual assistance only when needed.[124] Electrical stimulation is also a popular addition to step training, which has been met with reported success.[70,71,74,77,79,125]

Accordingly, a key methodologic issue is the availability of sensitive and quantitative outcome measures. SCI researchers are keenly aware of the paucity of powerful and convincing assessment tools and continue to seek out solutions.[126] For example, while specific outcome measures have been recommended for SCI research and clinical use,[127-129] such measures do not differentiate between successful achievement of function via compensation strategies or recovery of premorbid movement patterns. Further, change is rarely seen in traditional "functional" assessments, such as the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) lower extremity motor score or AIS classification, since they are typically based on volitional movement and are plagued by ceiling and floor effects and insensitive intervals.[48,55,61,74,106]

Walking speed is used most often as the primary outcome measure, although variations in its analysis and presentation exist. For instance, outcomes have been presented as the percentage of walking speed change from baseline,[69,72] the change in functional level of walking speed as a dichotomous variable (eg, household to limited community and limited community to community ambulator), and the statistical change in walking speed as a continuous variable.[73] Walking speed is measured with participants instructed to walk (1) at their comfortable, self-selected, and/or fastest, safe walking speed[73,92]; (2) with their most comfortable assistive device[73] or their original device[72]; and (3) with braces[73] or without braces.[48,49,126]

As clinicians and researchers, we have not clarified the potential difference in the "clinical" meaning of the change in walking speed based on the magnitude of walking speed change, and the relative walking impairment, which is highly dependent on the initial walking speed. The functional impact of a change in walking speed of .05, 0.2, or 0.5m/s may differ for an individual depending on his or her initial ability. Thus, should consideration be given to the initial walking speed when accounting for a minimally important difference (or minimal clinically important difference) for walking speed (or distance) change as a therapeutic outcome?

REVIEW OF LOCOMOTOR TRAINING WITHIN THE NRN

The NRN has focused on standardization of the locomotor training intervention[17] and outcome measures used to evaluate the efficacy of a multicenter clinical physical therapy program for SCI rehabilitation across 7 rehabilitation sites (Boston Medical Center, Boston, MA; Frazier Rehab Institute, Louisville, KY; Kessler Institute for Rehabilitation, West Orange, NJ; Magee Rehabilitation Hospital, Philadelphia, PA; Ohio State University Medical Center, Columbus, OH; Shepherd Center, Atlanta, GA; and The Institute for Rehab and Research, Houston, TX). 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.[17] The clinical program was evaluated using extensive outcome measures of function, health,[130] and quality of life that were taken every 20 therapy sessions throughout the episode of care. This is a billable clinical program, and the dose was determined for each patient individually using a discharge algorithm based on progression of the outcome measures as well as the available funding for therapy.

A case study review[131] presented in this issue illustrates the standardization and continuity of care afforded across the multisite network setting. The patient continued to improve on both treatment parameters and walking function, indicating that standardization across the NRN centers provides a mechanism for delivering consistent and reproducible locomotor training programs across the facilities without disrupting training or recovery progression.

The NRN has shown results that indicate intense locomotor training significantly improved balance and ambulation in 196 individuals diagnosed with a clinically incomplete SCI that occurred months to years after injury.[132] A larger number of AIS D individuals were enrolled most likely because of the generally accepted clinical perspective that they are more likely to improve with continued physical therapy than those with an AIS C classification. However, the results showed that individuals designated AIS C, even months to years after injury, still have the capacity for significant functional improvements. In comparison with 2 recent clinical trials[69,73] of patients with chronic SCI, the increases in walking after locomotor training were magnitudes greater in speed and distance. This greater improvement for a comparable patient population observed in the NRN may be attributed to a higher dose, as well as the comprehensive locomotor training program emphasizing retraining of stepping in combination with implementation of these key principles overground, and integration of new skills into daily life.

These changes in walking measures could not be attributed to improvements in AIS classification or ISNCSCI motor or sensory scores.[112] Although 70% of subjects showed improved gait speed after locomotor training, only 8% showed AIS category conversion. Functional ambulation ability improved to levels sufficient for independent in-home or community ambulation after chronic motor incomplete SCI, but changes in lower extremity motor or sensory scores did not predict responsiveness to locomotor training. Therefore, it was concluded that outcomes derived from the ISNCSCI examination and AIS classification may be poor indicators for recovery of walking ability, and care should be taken when using them to predict treatment efficacy for locomotor training.

The Neuromuscular Recovery Scale (NRS), a new scale developed by the NRN, classifies patients based on their ability to execute motor tasks needed for daily activities without compensation.[126] The NRS improved the distinction of people with motor incomplete SCI into groups with respect to function within AIS classifications. The magnitude of functional improvement among the 3 phase groups (phase 1, phase 2, and phase 3) determined by achievement of motor tasks without compensation was significantly different on the functional outcome measures (walking speed, distance, and balance). This indicated that among patients with incomplete SCI, there are cohorts that can now be predicted to have very different levels of improvement. The NRS provides a tool to select more homogeneous groups than with the AIS classifications, potentially reducing the required sample sizes for clinical research and RCTs, and affords a mechanism to quantify recovery independent of compensatory strategies when achieving a functional task, and may be useful in clinical practice.

The NRN also evaluated the relationships among ambulation and balance outcome measures in 181 individuals with clinically incomplete SCI.[133] The results showed that changes in walking and balance measures reflect different aspects of recovery. The measures are influenced by functional status and the use of assistive devices. Examining the walk tests showed that there is a difference between *functional performance* (as measured by speed, endurance, and indices of performance) and *functional recovery* (as measured by change in measurable outcome evaluations determining rates of recovery). This indicates that speed and distance outcome measures respond differently during different stages of recovery and are not redundant measures. In addition, the utility of the Berg Balance Scale was shown to be limited in patients with motor incomplete SCI in the earliest and more advanced phases of recovery.[134] Thus, a more comprehensive and dynamic instrument is necessary to adequately measure balance across the spectrum of patients with SCI. A new outcome measure, the Activity-based Balance Level Evaluation Scale, is being developed within the NRN to assess balance in the SCI population.[135] For clinicians, evaluating outcome measure utility relative to the stage of recovery can be critically important for capturing change in patients and determining effectiveness of an intervention.

Longitudinal analyses of more than 400 patients with AIS C and D classifications receiving standardized locomotor training indicated that time since injury, unrelated to age, and functional status at time of enrollment were 2 key factors that affected the rate of recovery.[113] The physiologic state of the spinal circuitry may have contributed to the rates of recovery both in regard to time since injury and the extent of recovery. The neuromuscular plasticity conceivably continues to occur over time, including deleterious changes,[136] and restoring the functional reorganization for behavioral changes in response to task-specific training thus would conceivably require more training the longer the intervention was delayed. These models provide information regarding expected recovery patterns for patients with clinically incomplete SCI receiving locomotor training programs, and may be useful for planning rehabilitation programs and designing future clinical studies.

PROGRESSION FROM SCIENCE TO CLINICAL PRACTICE: THE RCT AND CLINICAL NETWORKS

The RCT, originally developed for pharmaceutical assessment, has been viewed as the criterion standard since 1962 when the U.S. Food and Drug Administration required RCTs for examining therapeutic effectiveness.[137] The key strengths of RCTs focus on internal validity with randomization, blinding, and placebo controls, the cornerstones of their success.[138] The premise that RCTs are the only form of evidence and that case-control studies and cohorts are an overestimate of treatment effects seems to be a prevalent one[92,127] but has been challenged in the literature, most often in behavioral studies, a category that seems relevant to rehabilitation.[139]

The key weakness identified for RCTs is their lack of external validity where the inclusion and exclusion criteria are so strict that the participants are not representative of the general population. This may have been a weakness of the SCI Locomotor Trial RCT in which only 11% of those screened were eligible for the trial.[92] The RCT hierarchy is based on the pharmacologic modes of treatment and often is not appropriate for complex interventions such as those in rehabilitation.[138]

One challenge in using RCTs in rehabilitation is that blinding of the physician, therapist, and patient is not feasible, so you are limited to a single-blinded study of the evaluator.[69,73,92] This undermines the important premise of the placebo effect. A control group in rehabilitation is difficult to define without significant overlap of the content of the therapy between groups.[92] In the case of the chronic SCI population where there is no intervention that would be identified as having a therapeutic effect, a relevant control group is difficult to identify or justify.

A common feature of these RCTs is the use of a defined, pre-prescribed dose for the number of intervention sessions received and a single outcome measure. Clinicians and researchers alike recognize that the progression of recovery is nonlinear,[140] and thus periodic measures of outcomes exhibit valleys, peaks, and intervals of plateaus as the patient progresses. While use of a prescribed dose may be standard for an RCT, the ability and option to extend treatment sessions based on continued individual patient progress is what is consistent with rehabilitation clinical practice. Clinically, the decision whether to continue therapy or discharge a patient is based on clinical judgment and expertise in assessing not a single outcome measure, but multiple measures observed over time.

Although desirable as a means of control, the RCT may not be the only means of advancing the evidence necessary for informing clinical decision-making. An RCT typically comprises multiple sites that are brought together for a limited period for conducting a single trial, and then disbanded. An established clinical network, as demonstrated by the NRN, provides a long-term mechanism for deploying new interventions into clinical practice and evaluating program outcomes. Similar strategies of ongoing clinical program evaluation and inquiry have been used to influence practice, although often without the benefit of standardization or a network of clinical sites.[109,141-144]

The intent of program evaluation within the NRN with its standardized protocol, outcomes, and discharge algorithm is to inform clinical practice and develop clinical practice guidelines for improved outcomes on which clinicians, in concert with their patients, can make treatment decisions based on evidence, therapist judgment, and patient preference.[17] The approach to dose and to the development and use of outcome measures demonstrates 2 differences in recent RCTs and the NRN as informative strategies for clinical practice. Both RCTs and program evaluations have their unique advantages and disadvantages, but certainly play important roles in informing practice within their opportunities and limits.[137]

In a clinical network such as the NRN, a key strength is external validity, since patient eligibility criteria may be broader and designed for service delivery models.[17] Issues relevant to clinical practice (eg, financial, staffing model, cost-effectiveness, patient outcomes, staff training, intervention protocol) are addressed by a team of administrators, managers, physicians, supervisors, therapists, and program evaluators. Thus, the translation of the "science to practice" is an active component of the program evaluation process. Multiple outcome measures are used and can provide information regarding the sensitivity, appropriateness, or utility of a specific assessment. Reliance on a sole outcome measure as the primary gauge for clinical meaningfulness of an intervention may neither be sufficient nor consistent with clinical decision-making.[2,133]

Many clinicians and researchers are now suggesting that the data do not support a hierarchy of evidence with the RCT at the pinnacle, but rather a circle of evidence that includes basic science, case studies, cohort studies, program evaluation, and RCTs. The evidence should be evaluated in its entirety in the context of the population, the intervention, and the therapeutic outcome. The most successful approach for optimizing evidence-based clinical care may be to recognize that each type of evidence has its own strengths and weaknesses, and "no single level is completely useful or useless."[145(p9)]

CLINICAL IMPLICATIONS OF LOCOMOTOR TRAINING

The evidence from the articles in this issue and reviewed in this summary suggests that we are undergoing a paradigm shift in rehabilitation. The incorporation of activity-based therapy, particularly locomotor training, into the rehabilitation program provides clinicians with an added approach to focus on recovery. The patient is then able to participate more fully in premorbid activities, with a reduced requirement for the use of assistive devices or compensatory modifications and a decrease in secondary complications that can be exacerbated by compensatory strategies. However, prioritizing recovery over compensation requires clinicians to reassess how they evaluate and treat patients with neurologic injuries, and in particular SCI. While the focus of the topical focus articles in this issue was on promoting recovery after SCI, locomotor training can conceivably be applied to patients with any neurologic injury that results in paralysis (ie, upper motor neuron). Adaptations to locomotor training may be relevant based on injury etiology, such as multiple sclerosis[146] or stroke,[147] and require continued investigation as to the optimal strategy for implementation.

The clinician may want to carefully consider that the outcome measures that are typically used allow for the use of compensation. These compensation techniques may mask the patient's true extent of recovery and may not highlight the patient's current limitations in his/her nervous system. Classification by functional recovery using the NRS can provide clinicians with more homogeneous patient groups and can be useful in effectively setting specific goals, developing treatment plans, and reporting progress for third-party payers.

Once the clinician has an accurate assessment of a patient's phase of recovery after SCI, activity-based interventions can be used to help the patient progress. The therapist should consider the most appropriate interventions for implementing the 4 guiding principles of locomotor training, which include maximizing weight-bearing on the lower extremities and minimizing it on the upper extremities, optimizing sensory input consistent with each activity, optimizing the proper kinematics for each task, and maximizing independence and recovery of movements while minimizing compensation. While most often the ideal environment for implementing these principles is the retraining using BWS on a treadmill, the clinician must also consider how to apply these principles in the overground and community environments as well. Implementing locomotor training successfully requires skills and knowledge specific to activity-based therapies, so we recommend that clinicians pursue continuing education courses in this area.

The most successful approach for evidence-based practice may be to evaluate all levels of evidence, taking the strengths of each study with caution of their weaknesses. Rehabilitation, especially in the SCI population, would seem to greatly benefit from comprehensive program evaluation, especially in the challenging financial environment we now face within the health care system. Evidence must accumulate before new ways of thinking and approaches to rehabilitation can emerge, and this evidence can come from basic experimentation, case studies of clinical experience, controlled cohort studies, RCTs, and clinical program evaluation.

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