Spinal Cord (2005) 43, 27–33

www.nature.com/sc

Original Article

Walking index for spinal cord injury (WISCI): criterion validation

B Morganti[1,*], G Scivoletto[1], P Ditunno[2], JF Ditunno[3] and M Molinari[1,4]

[1]*Spinal Cord Unit, IRCCS Fondazione S. Lucia, Rome, Italy;* [2]*University of the Sciences in Philadelphia, Philadelphia, PA, USA;* [3]*Department of Rehabilitation Medicine, Thomas Jefferson University, Philadelphia, PA, USA;* [4]*Institute of Neurology, Catholic University, Rome, Italy*

Study design: Retrospective examination.
Objectives: To compare the Walking Index for Spinal Cord Injury (WISCI) and current scales for their sensitivity to walking changes in subjects with a spinal cord lesion (SCL) and further validate the WISCI for use in clinical trails.
Setting: A large rehabilitation hospital in the center of Italy.
Patients and methods: Retrospective review was performed on 284 patient records with an SCL. Measurements included neurological evaluation with Lower Extremity Motor Scores (LEMS) according to the American Spinal Injury Association (ASIA) and walking status assessed by Barthel Index (BI (0–15)), Rivermead Mobility Index (RMI (three levels)), Functional Independence Measure (FIM (1–7)), Spinal Cord Independence Measure (SCIM (0–8)), and WISCI (0–20). The WISCI is a 21-level hierarchical scale which incorporates gradations of physical assistance and devices required for walking. Improvement in walking is based on the change of scores from admission to discharge. Statistical analysis included Spearman rank correlation and χ^2 test; $P<0.05$.
Results: There was a significant positive correlation between WISCI and other scales (WISCI and BI $r=0.67$, $P<0.001$; WISCI and RMI $r=0.67$, $P<0.001$; WISCI and SCIM $r=0.97$, $P<0.001$; WISCI and FIM $r=0.7$, $P<0.001$). The initial ASIA grade was predictive of mobility outcome on the WISCI: of the 78 ASIA A patients, only five achieved independent walking *versus* 4/17 ASIA B ($P=0.02$), 56/109 ASIA C ($P<0.001$) and 39/44 ASIA D ($P<0.001$). The correlation of LEMS to the WISCI was 0.58 ($P<0.001$). At discharge, patients were distributed into 12 WISCI levels *versus* four FIM, three BI, two RMI and five SCIM levels. The most frequent WISCI levels at discharge were 13 (walker, no braces or assistance), 16 (two crutches, no braces or assistance) and 20 (no devices or assistance).
Conclusions: Similar correlation between the WISCI and the other scales indicates that all these measures address the same concept, mobility, which is a measure of concurrent validity. The correlation is not 100% because of conceptual differences (the WISCI incorporates gradations of physical assistance and devices required for walking while most of the other scales focus on burden of care or mobility in the environment). The WISCI is more detailed and appears more sensitive to walking recovery than the other scales, as demonstrated by our patients' score distribution at discharge. Within each of the most frequent WISCI levels (13, 16, 20) LEMS and other walking features varied; therefore the scale would benefit from further refinement based on speed, distance and energy cost.
Spinal Cord (2005) **43,** 27–33. doi:10.1038/sj.sc.3101658; Published online 2 November 2004

Keywords: spinal cord lesion; ambulation; Walking Index for Spinal Cord Injury (WISCI); Barthel Index; Functional Independence Measure; Spinal Cord Independence Measure; Rivermead Mobility Index

Introduction

Spinal cord lesions (SCLs), which include those due to trauma and those resulting from disease (nontrauma), are a major clinical and social problem.[1] The incidence of spinal cord injury (SCI) has been reported to be between 20 and 50 cases per million per year.[2,3] SCIs usually involve young individuals (half of the cases are under 30 years of age), while diseases usually affect an

*Correspondence: B Morganti, Spinal Cord Unit, IRCCS Fondazione S. Lucia, Via Ardeatina 306, 00179 Rome, Italy

older population. Walking function, however, is frequently impaired in both groups.[4] Recent epidemiological studies[5] demonstrated that a larger proportion of new traumatic cases presented as incomplete spinal cord lesions (eg some preservation of sensory and/or motor function below the lesion level) and therefore are more likely to regain walking function. Furthermore, advances in emergency medical care and the acute treatment of spinal cord lesions, for example, with methylprednisolone[6,7] suggests efficacy in reducing the severity of neurological impairment, which may also increase the proportion of incomplete lesions with resultant increased probability of recovery of walking function.

Recent reports show that recovery of walking after paralysis of lower extremities muscles, particularly following acute spinal cord injury, is one of the primary goals of the patients. In fact, while individuals with complete SCI may rank bladder and bowel control at their first preference for independence in self-care, independent walking was ranked first by patients, who have the capacity to walk.[8] A recent report shows that recovery of walking function in individuals with incomplete SCI was ranked equal with bowel and bladder recover.[9]

Recovery of locomotion, therefore, has become a primary goal of both pharmacological and rehabilitative treatment. In the last decade, pharmacological treatment[10] and rehabilitative approaches[11,12] have been initiated to enhance locomotion capacity of SCI patients. Basic science advances[13] in regeneration of the central nervous system hold promise of further neurological and functional recovery to be studied in clinical trials.[14]

In view of these advances, it has become of increased importance to develop new instruments for the precise measure of walking, such as the Walking Index for Spinal Cord Injury (WISCI), for use in clinical trials.[15,16]

Unfortunately, there is limited information in the literature on the outcome of walking function in large populations following SCI. In recent large clinical trials such as NASCIS III and Model Systems Data Base,[17,18] the Functional Independence Measure (FIM) has been utilized to determine ambulation status following acute SCI, but the FIM has limitations in sensitivity.[16] Walking outcome has also been reported recently[19] utilizing the Benzel Scale,[20] which is a modification of the Frankel Grade, but is yet to be validated.

Several scales such as the Barthel Index (BI),[21] the Rivermead Mobility Index (RMI),[22] and the FIM[23] were developed as functional measurements, which include a component of walking for stroke and other disabilities, but have not been validated for SCI. The Modified Barthel Index (MBI) for SCI has been reported by Yarkony *et al*[24] in a large group of subjects from one center, but the MBI has not been utilized in multicenter studies. The Spinal Cord Independent Measure (SCIM) initially reported in 1997[25] is currently being studied in international studies and is a global scale, with better precision than the FIM and a more detailed description of walking than the RMI, BI and FIM. The WISCI incorporates gradations of physical assistance and devices required for walking and has been shown to have face, criterion and construct validity and is more detailed than the SCIM for walking function.[26] We recently reported[4] differences in age and spinal cord disease/injury utilizing the WISCI, RMI and BI, which suggested the need for more critical comparison of different walking scales as valid outcome measures.

This study examines the response to change in walking status for subjects with the acute onset of spinal cord disease or trauma during the initial rehabilitation stay by comparing five walking scales and correlating these findings with Lower Extremity Motor Scores (LEMS) and the ASIA impairment Scale (AIS). Our hypothesis is that the WISCI scale will show more incremental change than current scales, and therefore demonstrate criterion validation for use in future clinical trials.

Patients and methods

Subjects

The sample is composed of 284 patients with a recent onset of traumatic and nontraumatic SCLs admitted to the spinal unit of a rehabilitation hospital in Italy between 1997 and 2001. Patients without the cognitive ability to participate in the rehabilitation program were excluded.

Measures

The following general information was collected retrospectively.

- Onset of lesion-to-admission (LTA) to the hospital refers to onset of trauma or onset of disease at first admission to the acute hospital.
- Injury variables included etiology, associated injury, medical complications and surgical intervention.
- Length of stay (LOS) as in-patients has been considered as an outcome measure as well as an independent determinant of other outcomes.

The following admission and discharge data were collected retrospectively from the charts:

- Neurological evaluation had been performed according to the American Spinal Injury Association (ASIA) Standards,[27] including AIS, right and left motor and sensory levels. A subsample of 200/249 subjects was evaluated for total and LEMS. Neurological recovery was defined on the basis of improvement of motor scores (total and LEMS) and AIS.
- The global FIM[24] is an 18-item scale with seven possible functional levels. Only the locomotor (walking/wheelchair) item, which is scored from 1 to 7, was assigned.
- The BI[22] is a global scale with scores that range from 0 to 100, higher scores denoting greater levels of

Table 1 Walking Index for Spinal Cord Injury (WISCI II)

Level	*Description*
00	Patient is unable to stand and/or participate in assisted walking.
01	Ambulates in parallel bars, with braces and physical assistance of two persons, less than 10 m.
02	Ambulates in parallel bars, with braces and physical assistance of two persons, 10 m.
03	Ambulates in parallel bars, with braces and physical assistance of one person, 10 m.
04	Ambulates in parallel bars, no braces and physical assistance of one person, 10 m.
05	Ambulates in parallel bars, with braces and no physical assistance, 10 m.
06	Ambulates with walker, with braces and physical assistance of one person, 10 m.
07	Ambulates with two crutches, with braces and physical assistance of one person, 10 m.
08	Ambulates with walker, no braces and physical assistance of one person, 10 m.
09	Ambulates with walker, with braces and no physical assistance, 10 m.
10	Ambulates with one cane/crutch, with braces and physical assistance of one person, 10 m.
11	Ambulates with two crutches, no braces and physical assistance of one person, 10 m.
12	Ambulates with two crutches, with braces and no physical assistance, 10 m.
13	Ambulates with walker, no braces and no physical assistance, 10 m.
14	Ambulates with one cane/crutch, no braces and physical assistance of one person, 10 m.
15	Ambulates with one cane/crutch, with braces and no physical assistance, 10 m.
16	Ambulates with two crutches, no braces and no physical assistance, 10 m.
17	Ambulates with no devices, no braces and physical assistance of one person, 10 m.
18	Ambulates with no devices, with braces and no physical assistance, 10 m.
19	Ambulates with one cane/crutch, no braces and no physical assistance, 10 m.
20	Ambulates with no devices, no braces and physical assistance, 10 m.

independence. The ambulation item for walking function, which is scored from 0 to 15, was recorded.
- The RMI[23] is a 15-item mobility scale in which some items of the scale evaluate patients' bed mobility and postural transfers, while other items assess patients' walking. Ambulation items, which are scored in three categories (0, 7, 10), were recorded.
- The SCIM[25] assesses three functional domains: self-care, respiration and sphincter management and mobility. Scores for the mobility indoor function range from 0 to 8, and were assigned.
- The WISCI[16] is a new 0–20 level scale, which evaluates walking based on physical assistance, the need of braces and devices. The levels are scored from 0 (patient unable to walk) to 20 (patient walking without braces and/or devices and without physical assistance for at least 10 m (Table 1). In scoring, the level in which the patient is safe as judged by the therapist was assigned.

The BI and RMI had been prospectively recorded on charts. SCIM, FIM and WISCI were retrospectively scored based on the description of walking in the charts by three independent observers (correlations were run with the means of observations by two physical therapists specialized in SCL and one physician neurologist specialized in SCL); such data were available for a subsample of 249/284 patients.

Statistical analysis
The following data were calculated:

- LEMS, BI, RMI, FIM, SCIM and WISCI changes were calculated based on the difference between rehabilitation discharge and admission.
- LEMS, BI and RMI efficiency scores were calculated by dividing changes in scores by the respective LOS.
- Spearman rank correlations were calculated between observers from SCIM, FIM and WISCI demonstrating interrater reliability.
- For the correlation between ASIA impairment at admission and WISCI at discharge, WISCI scores were divided into three groups according to patients' walking capacity: (1) patients not able to walk; (2) patients walking with physical assistance and (3) patients with independent walking.
- For concurrent validation, Spearman rank correlations were performed for a subsample ($N=76$) of those patients with WISCI scores >0 and <20 (0 being unable to stand or participate and 20 being complete independence) and scores on all other scales.
- Significance was set at $P<0.05$.

Results

Demographics
The sample consisted of 184 males and 100 females; mean age was 50.4 ± 19.3 years (range 12–86). Mean interval from lesion to admission was 56.9 ± 43.9 days; admission was within 30 days in 96 patients, within 60 days in 90, within 90 days in 47 and over 90 days in 51. Mean length of stay was 98.7 ± 68.13 days. A nontraumatic etiology was present in the majority of the patients (177/284): inflammatory (40), vascular (36), neoplastic (39), degenerative (62); traumatic lesions (107/284): car accident (38), motorcycle accident (15), sport accident (7), acts of violence (6), suicide attempts (6), accidental falls (31). Lesion level: 81 had cervical lesions, 148 thoracic lesions and 55 had lumbar-sacral lesions

(including cauda equina damage). At admission, 84 patients had ASIA impairment A, 19 ASIA B, 129 ASIA C and 52 ASIA D.

Concurrent validation
Inter-rater reliability for retrospective data interpretation for SCIM, FIM and WISCI are as follows: for the WISCI and the SCIM, the correlations were 1.00 and for the FIM 0.9 ($P<0.001$). For the subsample of 76 patients, who were discharged at WISCI level between 1 and 19, the more frequent levels were levels 13 and 16 (see Table 2 for all scale scores).

Spearman rank correlation between the various scales for this subsample is shown in Table 3.

Correlation ASIA impairment/locomotion (WISCI)
In the subsample of 249 patients with all scale scores, the initial ASIA grade was predictive of mobility outcome in WISCI (Table 4a and b).

Correlation WISCI/LEMS
In the subgroup of 200/249 patients examined with LEMS there was a positive correlation between WISCI (0–20) and LEMS of 0.58 ($P<0.001$). A subset of 63 of the subsample of 76 (WISCI levels 1–19, eliminating WISCI levels 0 and 20 to control for floor and ceiling effects) had LEMS, which showed a correlation with locomotion outcome at discharge of 0.57 ($P<0.001$). In addition, there was a positive correlation of LEMS and WISCI levels at discharge for young patients of 0.50 ($P<0.01$) ($N=35<50$ years) and for older patients of 0.64 ($P<0.01$) ($N=28\geqslant 50$ years).

A positive correlation of motor scores at discharge and WISCI at discharge for nontrauma ($N=26$) of 0.58 ($P<0.01$) and trauma ($N=37$) of 0.49 ($P<0.01$) is shown (one patient was lost to the correlation for incomplete data).

Distribution of LEMS and WISCI levels at discharge
Scattergram showing motor score distribution is displayed in Figure 1.

Table 2 Description of the various locomotion scale scores $N=249$

# *Subjects*	*WISCI*	*FIM*	*RMI*	*SCIM*	*BI*
42	20	7	10	8	15–39; 10–3
04	19	6	7	6	15–3; 10–1
04	18	6	7	7	15
32	16	6	7	5	15–31; 10–1
18	13	6	7		15–13; 10–5
01	12	6	7	5	15
02	11	4	0	3	10
02	9	6	7	3	15–1;10–1
03	8	4	0	3	15–1; 5–2
01	6	4	0	3	10
02	5	5	7		5
07	4	4	0	3	10–4; 5–3
131	0				5

Discussion

This study supports our hypothesis and demonstrates that the WISCI scale is more sensitive to incremental change than the RMI, BI, FIM and SCIM and has enhanced concurrent criterion validation.

Table 3 comparing the scales shows that all scale correlations with WISCI fall between 0.67 and 0.97. There is overlap as all scales conceptually measure the domain of mobility; however, each scale differs on criterion of score assignment.

The FIM scale[24] (which does not integrate use of devices or braces) was originally developed as a measurement tool assessing burden of care for all types of disability. The locomotion item describes walking and wheelchair locomotion along seven levels of function from total assistance to independence with emphasis on amount of physical assistance needed (for further in-depth discussion see Ditunno *et al* 2000). The BI[22] (which also does not integrate devices or braces) as a total score was developed as a tool for burden of care (feeding, hygene, tranfers, mobility) and recovery scale for bladder and bowel management for stroke patients. The ambulation item describes walking or ambulation along four levels: unable to ambulate, use of wheelchair for 45 m, ambulation with assistance for 45 m and ambulation independent for 45 m. The RMI[23] (which is not continuous and does not specify differences in braces or devices) was developed for functional levels of mobility primarily for stroke patients. The walking function items describe three categories (cannot walk, walk with devices and no assistance and walk independent). These three scales (FIM, BI, RMI) show

Table 3 Spearmann rank order correlation between the various scales $N=76$

	WISCI	*RMI*	*BIM*	*SCIM*	*FIM*
WISCI					
RMI	0.67 ($P<0.001$)				
BIM	0.67 ($P<0.001$)	0.6 ($P<0.001$)			
SCIM	0.97 ($P<0.001$)	0.75 ($P<0.001$)	0.7 ($P<0.001$)		
FIM	0.7 ($P<0.001$)	0.9 ($P<0.001$)	0.7 ($P<0.001$)	0.8 ($P<0.001$)	

Table 4 (a) ASIA impairment (AIS) at admission and WISCI levels at discharge and (b) Correlation between ASIA impairment at admission and WISCI levels at discharge

(a)

AIS	*Not walking (WISCI 0)*	*Walking with physical assistance (WISCI 1, 2, 3, 4, 6, 7, 10, 11, 14, 17)*	*Independent walking (WISCI 5, 9, 12, 13, 15, 16, 18, 19, 20)*
ASIA A	70	3	5
ASIA B	12	1	4
ASIA C	46	7	56
ASIA D	3	2	40

(b)

AIS	*Walking with physical assistance (WISCI 1, 2, 3, 4, 6, 7, 10, 11, 14, 17)*	*Independent walking (WISCI 5, 9, 12, 13, 15, 16, 18, 19, 20)*
A *versus* B	0.573	0.02
AB *versus* C	0.07	<0.001
AB *versus* D	0.002	<0.001
C *versus* D	0.1	<0.001

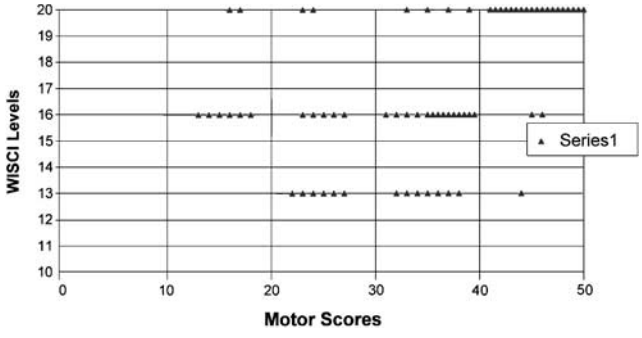

Figure 1 LEMS and WISCI levels distribution

correlations of 0.67–0.70, which is lower than the SCIM at 0.97. This may be due to the primary focus of the scales during the time of original development, which lacked the integration of devices/braces.

The SCIM,[25] however, does integrate wheelchair, crutches, canes, leg orthosis, etc, and was developed as a functional level scale specifically for SCI patients. As such, it offers an overall ADL assessment, and the mobility indoors item allows scores from 0 to 8 and shows the highest correlation with the WISCI (0.97), but lacks one of the WISCI levels. In reviewing the pattern of score distributions for the SCIM, we find that although there was a high correlation with the WISCI, there is a large segment of subjects (18/76 about 24%) with WISCI level 13 (ambulates with walker, no braces and no physical assistance) with no comparable SCIM score. In addition, there is a differential hierarchical ranking on WISCI item 18 (ambulates with no devices, with braces and no physical assistance), reflecting an inversion of monotonic function. These issues present concerns regarding the SCIM scale validity for ambulation assessment.

These findings do not invalidate the above scales for global assessment of function, but do emphasize that they are not specific for ambulation. Overall, the WISCI is a more precise and sensitive scale for documenting change in levels of walking along a hierarchical order, integrating devices, braces and physical assistance.

The pattern of the recovery of walking function as measured by the WISCI scale demonstrates some interesting features. First, the majority of subjects fall into three levels, levels 13, 16 and 20 (92/117 or 116), probably because the discharge status from rehabilitation typically is at an independent level. This eliminates levels 1–8, 10, 11, 14 and 17, because these levels are not independent walking function. Our data, which is retrospective, however, shows some of these nonindependent levels (14/117) requiring some assistance at the time of discharge, because this was the maximum walking level achieved after 4–6 months of rehabilitation, but the subjects would need to function in a wheelchair after they were discharged. The 133 subjects discharged at the 0 WISCI level, never progressed beyond the wheelchair.

The strong correlations of the ASIA grades with the WISCI levels (Table 4a and b) further support the construct validity of the scale. The highest correlation is for subjects who are ASIA C and D, thus demonstrating that the WISCI scale primarily is applicable to these subjects and to some ASIA A and B who convert to C. Several subjects remained complete (ASIA A 3/117), but ambulated with a reciprocal gait in long leg braces. Most motor complete subjects (ASIA A and B), who remain motor complete, will only ambulate with braces and will not use reciprocal ambulation unless the legs are locked at the knees and/or they have RGOs. This

represents only a small percentage of all SCI subjects, who walk at high-energy requirements.[28] These findings are consistent with the restrospective data, reported in the modification of the original WISCI scale from 20 to 21 levels.[29]

The correlation of LEMS with WISCI levels in this study is in line with the data recently reported by Marino in chronic SCI subjects[30] and both support the construct validity of the scale. The concept that walking function should improve as strength in the legs increases after SCI is consistent with validating the hierarchy of the WISCI levels. Waters demonstrated that a threshold of 30 for the LEMS was necessary to achieve community ambulation. Walking function, however, is a very complicated activity, which may be affected by many factors.[12] Motor scores alone do not correlate completely with increased walking function, because other factors such as age,[4] pain,[30,31] balance,[32,33] spasticity,[34] overweight[35] and possibly duration of training may effect walking function. In fact in our patients, motor scores alone show a significant ($r = 0.57$, $P < 0.001$), but not complete correlation with the WISCI.

A subset of 21 patients (mostly young with traumatic lesions) with low LEMS (<30) achieved WISCI levels 13 (walker, no braces, no assistance), 16 (two crutches, no braces, no assistance) and 20 (no devices and no assistance) (see Scattergram, Figure 1), a finding which could have several explanations. Owing to the longer length of stay (4–6 months) of subjects in this study as compared to subjects in the USA, patients may have progressed to higher WISCI levels. A longer length of stay in rehabilitation may result in a higher WISCI level due to training rather than improvement in strength. Perhaps these subjects need to be differentiated by distance, speed and energy requirements as recently reported for different WISCI levels.[30,36] These issues will be examined in studies currently in progress.[37] Another explanation of differences in response based on different motor scores may be related to the pattern of lower extremity weakness. People with good proximal strength perform better despite low total motor score (hip flexors and knee extensors are the most important muscles for walking).[38,39] Finally, it should be noted that Waters[38] found that subjects with motor scores below 30 for the lower extremity scores did not achieve community ambulation; he did not examine motor scores for household ambulation. The WISCI levels, however, are based on a 10 m distance (33 ft), which is closer to household ambulation (50 ft) than to community ambulation, which is 150 ft. Therefore, motor scores lower than 30 for the lower extremities may permit household distances, especially if the subjects are young and have had the benefit of additional training time. In these cases, there may be a difference in speed and efficiency for the same WISCI levels and the subjects will need to be examined by methods recently reported in chronic subjects based on velocity and physiologic cost index.[30,36] Furthermore, it has been recently reported that, while with training (body weight support), footmotion of SCI patients tends to recover the shape and the step-by-step reproducibility that characterize normal gait, the specific activation of individual muscles often differs substantially from the normal ones and include the activation of several trunk muscles which are not included in ASIA key muscles evaluation.[40]

On the other hand, a subset of seven subjects, who performed at lower WISCI levels (4–11) than expected with LEMS of an average of 26, had associated problems of age, weak upper extremities, pain, balance problems and overweight. The effect of age is particularly worthy to note: Burns *et al*[41] and Penrod *et al*[42] reported that subjects over 50 years with ASIA C within a week of injury when compared to younger individuals, did much poorer in recovery of walking function, and speculated that this may have been due to associated medical problems. Scivoletto *et al*[4] analyzed matched cohorts from the same sample of subjects of the present study and found neurologic recovery and ambulation were less in those over 50 years as compared to younger subjects irrespecitve of etiology.

References

1 DeVivo MJ. Causes and costs of spinal cord injury in the United States. *Spinal Cord* 1997; **35:** 809–813.
2 Go BK, DeVivo MJ, Richards JS. The epidemiology of spinal cord injury. In: Stover SL, Delisa JA, Whiteneck GG (eds). *Spinal Cord Injury: Clinical Outcomes from the Model Systems*. Gaithersburg, MD: Aspen Publishers, Inc. 1995, pp 21–55.
3 DeVivo MJ, Krause JS, Lammertse DP. Recent trends in mortality and causes of death among persons with spinal cord injury. *Arch Phys Med Rehabil* 1999; **80:** 1411–1419.
4 Scivoletto G, Morganti B, Ditunno PL, Ditunno Jr JF, Molinari M. Effects of age on spinal cord lesion patients' rehabilitation. *Spinal Cord* 2003; **41:** 457–464.
5 Marino RJ, Ditunno Jr JF, Donovan WH, Maynard Jr F. Neurologic recovery after traumatic spinal cord injury: data from the Model Spinal Cord Injury Systems. *Arch Phys Med Rehabil* 1999; **80:** 1391–1396.
6 Bracken MB *et al*. A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal cord injury. *New Eng J Med* 1990; **322:** 1405–1411.
7 Bracken MB, Holford TR. Neurological and functional status 1 year after acute spinal cord injury: estimates of functional recovery in National Acute Spinal Cord Injury Study II from results modeled in National Acute Spinal Cord Injury Study III. *J Neurosurg* 2002; **96**(Suppl)**:** 259–266.
8 Fraser MH. Personal communication, 1999.
9 Patrick M, Ditunno PL, Ditunno Jr JF. A comparison of spinal cord injury (SCI) consumers/staff preference for walking: a pilot study. *J Spinal Cord Med* 2003; **26**(Suppl)**:** S41.
10 Hansebout RB. 4-Aminopyridine in chronic spinal cord injury: a controlled, double-blind, crossover study in eight patients. *J Neurotrauma* 1993; **10:** 1–18.
11 Wernig A, Muller S. Laufband locomotion with body weight support improved walking in persons with severe spinal cord injuries. *Paraplegia* 1992; **30:** 229–238.
12 Barbeau H, Ladouceur M, Norman KE, Pepin A, Leroux A. Walking after spinal cord injury: evaluation, treatment,

and functional recovery. *Arch Phys Med Rehabil* 1999; **80:** 225–235.
13 Selzer ME. Promotion of axonal regeneration in the injured CNS. *Lancet Neurol* 2003; **2:** 157–166.
14 Ditunno Jr JF *et al*. A view of the future Model Spinal Cord Injury Systems (MSCIS) through the prism of past achievements and current challenges. *J Spinal Cord Med* 2003; **26:** 110–115.
15 Dodkin BH, Apple D, Barbeau H, Basso M. Methods for a randomized trial of weight-supported treadmill training *versus* conventional training for walking during inpatient rehabilitation after incomplete traumatic spinal cord injury. *Neurorehab Neural Repair* 2003; **17:** 153–167.
16 Ditunno JF *et al*. Walking index for spinal cord injury (WISCI): an international multicenter validity and reliability study. *Spinal Cord* 2000; **38:** 234–243.
17 Bracken MB *et al*. Administration of methylprednisolone for 24 or 48 hours or tirilazad mesylate for 48 hours in the treatment of acute spinal cord injury. Results of the Third National Acute Spinal Cord Injury Randomized Controlled Trial. National Acute Spinal Cord Injury Study. *JAMA* 1997; **277:** 1597–1604.
18 Stover SL, DeLisa JA, Whiteneck GG. *Spinal Cord Injury: Clinical Outcomes from the Model Systems*. Gaithersburg, MD: Aspen Publishers, Inc. 1995.
19 Geisler FH, Coleman WP, Grieco G, Poonian D. The Sygen multicenter acute spinal cord injury study. *Spine* 2001; **26**(Suppl)**:** S87–S98.
20 Benzel EC, Larson SJ. Functional recovery after decompressive spine operation for cervical spine fractures. *Neurosurgery* 1987; **20:** 742–746.
21 Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. *Mar State Med J* 1965; **14:** 61–65.
22 Collen FM, Wade DT, Robb GF, Bradshaw CM. Rivermead Mobility Index: a further development of the Rivermead Motor Assessment. *Int Disabil Stud* 1991; **13:** 50–54.
23 Keith RA, Granger CV, Hamilton BB, Sherwin FS. The functional independence measure: a new tool for rehabilitation. *Adv Clin Rehabil* 1987; **1:** 6–18.
24 Yarkony GM, Roth EJ, Meyer Jr PR, Lovell L, Heinemann AW, Betts HB. Spinal cord injury care system: fifteen-year experience at the Rehabilitation Institute of Chicago. *Paraplegia* 1990; **28:** 321–329.
25 Catz A, Itzkovich M, Agranov E, Ring H, Tamir A. SCIM – spinal cord independence measure: a new disability scale for patients with spinal cord lesions. *Spinal Cord* 1997; **35:** 850–856.
26 Itzkovich M *et al*. Reliability of the Catz–Itzkovich Spinal Cord Independence Measure assessment by interview and comparison with observation. *Am J Phys Med Rehabil* 2003; **82:** 267–272.
27 Maynard FM *et al*. International standards for neurological and functional classification of spinal cord injury patients (revised). *Spinal Cord* 1997; **35:** 266–274.
28 Bernardi M *et al*. Cost of walking and locomotor impairment. *J Electromyogr Kinesiol* 1999; **9:** 149–157.
29 Ditunno PL, Ditunno Jr J, (listed as Dittuno in Medline). Walking index for spinal cord injury (WISCI II): scale revision. *Spinal Cord* 2001; **39:** 654–656.
30 Marino RJ, Burns AS, Coward C, Ditunno Jr JF. Relation between Walking Index in Spinal Cord Injury (WISCI) level, neurological status, walking speed in SCI. *J Spinal Cord Med* 2003; **26**(Suppl I)**:** S38.
31 Jonsson B, Annertz M, Sjorberg C, Stromqvist B. A Prospective and consecutive study of surgically treated lumbar spinal stenosis. Part I: clinical features related to radiographic findings. *Spine* 1997; **22:** 2932–2937.
32 Karcnik T, Kralj A. Stability and energy criteria in healthy and paraplegic subject gait. *Artif Organs* 1997; **21:** 191–194.
33 Karcnik T, Kralj A. Stability and velocity in incomplete spinal cord injured subject gaits. *Artif Organs* 1999; **23:** 421–423.
34 Mirbagheri MM, Barbeau H, Kearney RE. Intrinsic and reflex contributions to human ankle stiffness: variation with activation level and position. *Exp Brain Res* 2000; **135:** 423–436.
35 Asher M, Olson J. Factors affecting the ambulatory status of patients with spina bifida cystica. *J Bone Joint Surg Am* 1983; **65:** 350–356.
36 Ditunno Jr JF. Personal communication, 2003.
37 Burns AS, Coward C, Ditunno Jr JF, Marino RJ. Relation of ambulation speed and Physiologic Cost Index (PCI) to Walking Index in Spinal Cord Injury (WISCI) level in chronic spinal cord injury. *J Spinal Cord Med* 2003; **26**(Supply 1)**:** S43.
38 Waters RL, Adkins R, Yakura J, Vigil D. Prediction of ambulatory performance based on motor scores derived from standards of the American Spinal Injury Association. *Arch Phys Med Rehabil* 1994; **75:** 756–760.
39 Hussey RW, Stauffer ES. Spinal cord injury: requirements for ambulation. *Arch Phys Med Rehabil* 1973; **54:** 544–547.
40 Ivanenko YP *et al*. Temporal components of the motor patterns expressed by the human spinal cord reflect global kinematic goals. *J Neurophysiol* 2003; **90:** 3555–3565.
41 Burns SP, Golding DG, Rolle Jr WA, Graziani V, Ditunno Jr JF. Recovery of ambulation in motor-incomplete tetraplegia. *Arch Phys Med Rehabil* 1997; **78:** 1169–1172.
42 Penrod LE, Hedge SK, Ditunno Jr JF. Age effect on prognosis for functional recovery in acute, traumatic central cord syndrome. *Arch Phys Med Rehabil* 1990; **71:** 963–968.