THE SPINAL CORD INJURY FUNCTIONAL AMBULATION INVENTORY (SCI-FAI)

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The development and testing of an observational gait assessment instrument, the Spinal Cord Injury Functional Ambulation Inventory (SCI-FAI) is described. To assess validity and reliability, 22 subjects with incomplete spinal cord injury were scored by four raters. Raters scored each subject three times, once live (LS) and twice from videotaped records (VS1, VS2). A moderate-good negative correlation ($r = -0.742$ and -0.700, for VS1 and VS2, respectively) was found between the gait score and time required to walk a demarcated path. Inter-rater reliability was moderate–good for the live score and the videotaped records (ICC = 0.703, 0.800, and 0.840, respectively). Intra-rater reliability was good (ICC = 0.903, 0.960, 0.942, and 0.850 for Raters 1–4, respectively). To assess sensitivity, another group of 19 subjects with SCI were assessed prior to and following participation in an intensive walking program. A moderate correlation was found between change in gait score and change in lower extremity strength (Pearson $r = 0.58$). These results indicate that the SCI-FAI is a reliable, valid and sensitive measure of walking ability in individuals with spinal cord injury. In addition, the results suggest that gait analysis using this instrument is equally reliable whether the observation is performed live or from videotaped records.

Key words: gait analysis, spinal cord injury, ambulation, walking.

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INTRODUCTION

In recent years, there has been renewed interest in locomotor rehabilitation of individuals with spinal cord injury (SCI) as investigators and clinicians have begun to employ interventions such as body-weight support and functional electrical stimulation. While outcome measures using kinematic, kinetic, metabolic and electromyographic variables are routinely used in the research setting, these instruments are not universally amenable to use in the clinical setting. On the other hand, measures of mobility that are commonly used in the clinical setting for evaluation of neurologically involved patients, such as the Functional Independence Measure (FIM) (1), and the Barthel Index (2), lack the detail regarding performance parameters required to give real insight into gait abnormalities (3). Others, such as the Rancho Los Amigos Observational gait analysis system, are inclusive but cumbersome and time-consuming to use (4). While there is no shortage of observational gait analysis instruments (see Malouin et al. for review) (5), none of these encompass the varied aspects of gait impairment experienced by individuals with SCI.

Some authors have suggested that ambulatory function should be assessed purely on the basis of assistive device requirements (6) while others promote the use of temporal-distance measures (e.g. speed and distance) (3, 7, 8). While assistive device usage and walking speed/distance can provide simple measures of whether gait is functional (e.g. How much assistance does the individual need? Can the individual walk far enough and fast enough to cross the street before the light changes?), these parameters alone provide no information regarding how the gait is achieved. As such, these measures cannot provide a basis from which to develop individualized interventions. In the SCI population, the use of ambulatory motor index (AMI) (9) and lower extremity motor scores (LEMS) (10) have also been advocated for use as indicators of walking function based on the correlation between lower extremity strength and walking function. None of these measures, however, relate specifically to walking function and quality of gait.

Individuals with neurological disorders face many challenges to functional ambulation. Inefficient gait patterns (11–13), decreased muscle strength (4) and orthotic needs (11,14), can substantially increase energy demands (14). Asymmetry of limb function (15), inability to effectively transfer weight between legs (16), decreased step width (4) and length (7, 10 13 17) and abnormal step rhythm (18) are all factors associated with lower extremity spasticity and which negatively affect walking function. Other common gait deviations, such as decreased step height (13) and width and excessive plantar flexion during swing phase (19) may affect gait safety as well as efficiency. These are all factors that should be assessed when evaluating walking function in ambulatory individuals with SCI so that interventions can be directed at the needs of the individual.

When all of the above have been considered, walking function

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Table I. *Subject characteristics (reliability/validity testing)*

Subject number	Age/sex	Neurologic level	Gait score mean (SD)	Walking mobility score	Timed walk (seconds/10 ft walk)	Assistive device(s)	Orthotics device(s)
1	28/M	C3	14 (2.0)	3	19.5	2FC	R AFO
2	33/M	T12	18.5 (0.6)	4	15.1	walker	R KAFO
3	75/M	C4	12.75 (1.5)	1	42.9	walker	R KAFO
4	56/F	L1	18.25 (1.7)	3	22.9	2 canes	None
5	39/F	C6	18.25 (1.3)	4	18.3	2FC	R AFO
6	22/F	T10	16.5 (1.3)	3	19.5	walker	B KAFO
7	24/M	L1	19.25 (1.0)	5	5.5	2 canes	B AFO
8	19/M	T6	12.25 (1.0)	1	20.7	walker	None
9	42/M	C4	19.5 (0.6)	4	8.8	2FC	None
10	26/M	T12	15.25 (2.2)	1	38.7	p bars	B KAFO
11	32/M	L1	14.5 (1.3)	2	19.0	walker	R AFO
12	33/M	C7	13.25 (1.7)	3	29.6	walker	L AFO
13	32/F	C6	12.75 (1.0)	3	11.3	2FC	None
14	24/M	C5	16.75 (1.0)	3	12.5	walker	L AFO
15	35/F	C4	19.25 (1.5)	3	15.4	2 canes	L AFO
16	24/M	C6	17.75 (1.3)	4	11.5	walker	R AFO
17	38/M	C8	15.75 (1.0)	4	10.9	2FC	None
18	24/M	C5	5.5 (1.3)	1	46.2	walker	R AFO
19	27/M	C6	13.5 (1.3)	1	37.5	walker	R KAFO
20	34/M	C5	15.5 (1.0)	4	17.9	q cane	L AFO
21	25/M	C6	11.75 (1.7)	1	49.2	2FC	B KAFO
22	26/M	T4	13 (2.2)	3	24.4	walker	B AFO

FC = forearm crutches, p bars = parallel bars, q cane = quad cane, R = right, L = left, B = bilateral, AFO = ankle-foot orthosis, KAFO = knee-ankle-foot orthosis.

in individuals with SCI appears to be determined by three main categories of performance: gait parameters/symmetry, assistive device use and temporal-distance measures. The present report describes the development and the reliability, validity and sensitivity testing of an observational gait assessment instrument, the SCI Functional Ambulation Inventory (SCI-FAI) that addresses these three key domains of walking function in individuals with SCI.

METHODS

Development of the assessment form

To develop the gait parameter section of the assessment form, 10 physical therapists with at least 5 years of experience in the rehabilitation of individuals with SCI identified and ranked six parameters that were considered critical to functional walking performance in this population. The parameters identified as elements of this gait score were: weight shift, step width, step rhythm, step height, foot contact, and step length. These parameters were incorporated into a rating scale (see items A–F in Appendix A) that allowed each limb to be scored individually, such that the same score for each limb indicated symmetry between the bilateral limbs. Heavier weighting was given to parameters that were considered more critical to gait performance. The item rankings were developed and progressively refined based on viewing and ranking of videotaped walking sessions. The subjects of the videotapes were 10 different individuals with SCI having different gait patterns, using different assistive devices, and having different levels of walking mobility. The gait score parameters were arranged such that the subject could be viewed/rated from the frontal plane, then from the sagittal plane.

Assistive device use was divided into separate sections for lower extremity orthotics and for upper extremity balance/weight bearing devices. Devices were ranked according to degree of assistance provided by each. Walking speed and distance were assessed by two different measures: the Walking Mobility Scale and simple walking speed. The Walking Mobility Scale (Appendix B), modified from a scale published by Perry et al. (20), was directed at assessing typical walking practice. The average time required to walk a 10 ft segment of the demarcated path was scored from the video record.

Each of these areas was included in the final version of the form, resulting in three domains (i.e. gait parameters, assistive device use, walking mobility score) in which higher scores indicated higher levels of function. Scores within each domain were summed to create a composite score for that domain; the greatest possible score being 20 points for the gait score (parameters/symmetry; items A–F), 14 points for assistive device use, and 5 points for the walking mobility score. Because composite scores for each domain are intended to measure different realms of function it was not meaningful to combine these into an overall composite score.

Reliability and validity testing of the assessment form

Twenty-two healthy individuals, 5 women and 17 men (mean age 32 ± 13 years) with incomplete SCI agreed to participate (see Table I for subject characteristics). Inclusion criteria included the ability to independently maintain stance on the weight-bearing limb (with or without the use of an upper extremity weight-bearing device) and the ability to take at least eight steps using whatever assistive device(s) was necessary. All procedures were approved by the University of Miami Institutional Research Review Board. All subjects were informed of the study procedures and signed an informed consent form prior to participation. Each subject was also asked to read the walking mobility descriptors (Appendix B) and rate his/her typical walking practice.

During the walking trials, each subject was timed and evaluated by four physical therapist raters using the assessment form. Each trial was also videotaped (Sony Model #CCDFX330) from all four attitudes (anterior, posterior, left, right). The raters were instructed to select the Gait Parameter description (items A–F in Appendix A) that was most characteristic of the subject's gait pattern. In addition to scoring the subject on-site (Live Session [LS]) each rater scored the same subject two more times from the video record (video session 1 [VS1] and video session 2 [VS2]). Each scoring session (LS, VS1, VS2) was performed with at least 7 days intervening since the prior session.

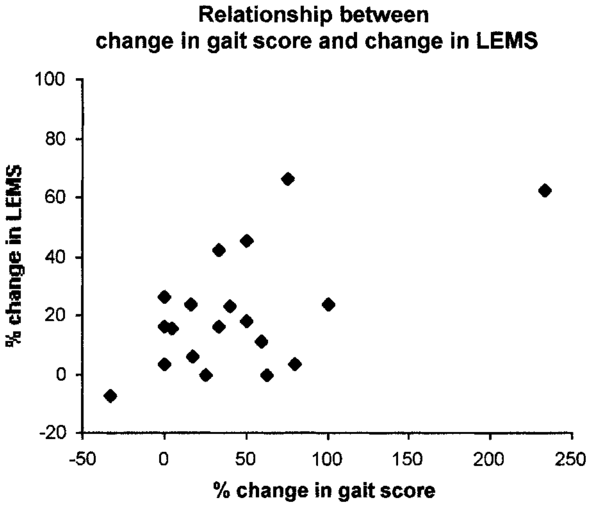

Fig. 1. In subjects who participated in an intervention, the percentage change in gait score is related to the change in lower extremity motor scores (LEMS).

Testing sensitivity of the assessment form

Following reliability/validity testing, sensitivity of the instrument was examined in a second group of subjects who were participants in an experimental walking rehabilitation program. Nineteen subjects, (6 women, 13 men; mean age 31.7 ± 9.4 years) participated in this segment of the study; 13 of these subjects presented with tetraplegia, 6 with paraplegia. None of these were subjects who had previously participated in testing. The training program consisted of a 3 days per week, 12-week program of treadmill walking assisted by body weight support (BWS) and functional electrical stimulation (FES), the full results of this study are reported elsewhere (21). All subjects were scored using the SCI-FAI, prior to and following participation in the training program. Scoring was performed by a single rater who had participated in the reliability/validity testing. The strength of the five key muscles (illopsoas, quadriceps, tibialis anterior, extensor hallucis longus, triceps surae) of each lower extremity was graded with a score of 1–5 according to standards of the American Spinal Injury Association (ASIA) (22). This resulted in a LEMS score with a maximum value of 50 for both lower extremities combined.

Statistical analyses were performed using the SAS Statistical Package (SAS Institute, Inc., Cary, NC) and Microsoft Excel (Excel 97 SR-2 Statistical Tool Pac).

RESULTS

Reliability and validity testing

There was 100% agreement among raters for the objective sections of the inventory (assistive device use and temporal distance measures). Inter-rater reliability of the gait score, tested by comparing scores of the four raters obtained during a rating session, was moderate–good (ICC [2.1] = 0.703, 0.800 and 0.840 for the LS, VS1 and VS2, respectively). Intra-rater reliability, determined by comparing a rater's score of the LS to the same rater's scores for VS1, was good (ICC [3.1] = 0.903, 0.956, 0.942, and 0.850 for raters 1–4, respectively). The average differences between mean gait scores for LS versus VS1 and for LS versus VS2 were not significant (*t*-test, $p = 0.919$ and 0.600, respectively). The gait score had a moderate–good correlation with walking speed (Pearson r = −0.742 and −0.700 for VS1 and VS2, respectively) and with subjects' self-report of walking mobility (Pearson r = 0.697, for VS1). Finally, while the sample size precluded grouping of subjects by walking mobility score, examination of these scores suggests that higher gait scores may be associated with higher walking mobility scores (e.g. higher levels of ambulatory function—see Table I).

Sensitivity testing

In those subjects who participated in the experimental walking rehabilitation intervention, the change in walking ability was reflected in a 44.7% increase in the mean gait score following training. This change was statistically significant (*t*-test, $p < 0.001$). There was a moderate correlation between the percentage change in gait score and in change LEMS (Pearson r = 0.58), as illustrated in Fig. 1. Further, the gait score showed a moderate–good correlation with LEMS prior to training (Pearson r = 0.74), and a moderate correlation following training (Pearson r = 0.64).

DISCUSSION

The SCI-FAI provides a reliable, valid and sensitive measure of functional walking ability in ambulatory individuals with SCI. Reliability is demonstrated by the findings that there was complete agreement among raters for the objective domains of the inventory and a respectable level of agreement within and between raters in scoring of gait parameters. The results also indicate that equally accurate assessments can be made under either the live or the videotaped viewing condition. Validity of the instrument is demonstrated by the finding that the gait score is correlated with walking speed (which, despite its limitations, is thought by some to be the most valid means of assessing functional ability walking (3, 7, 8), suggesting convergent validity between these two measures. The results indicating that there is a correlation between the gait score and LEMS further substantiates the validity of this measure. The finding that there was a significant difference in gait score following participation in a walking rehabilitation program, verifies that the inventory is sensitive to change in walking function. That there is a correlation between the change in gait scores and the change in LEMS, is further support of this conclusion.

The SCI-FAI has a distinct advantage over simple measures that consider only walking speed or assistive device use. These latter measures do not evaluate parameters of the locomotor task that affect quality of movement, therefore they do not indicate which aspects of the task the individual is able to perform, nor the level to which the individual is able to perform. In order for walking to be an efficient means of locomotion, certain parameters of gait must be under the individual's control; the efficiency of gait decreases as the control over these parameters decreases. In individuals with SCI who possess some ambulatory function, the ability to perform the movement elements associated with functional gait is affected by a number of factors including deficits in strength and voluntary motor control. For these reasons, the SCI-FAI includes an assessment domain that addresses the deficits in gait quality that most commonly result from the decreased motor control experienced by individuals with SCI.

While we differ with other authors (6) in our view that documentation of assistive device requirements is not in itself sufficient to assess walking function, the extent to which an individual relies upon these does provide an indication of how dependent the individual is on external support. Such devices may provide assistance for balance, for weight bearing via the upper extremities (e.g. walker, crutches) (23), or a means of compensating for loss of lower extremity strength and control (e.g. ankle-foot orthosis) (24). Waters et al. (10) found that individuals with SCI who required the use of two knee-ankle-foot orthoses (KAFO) had a higher energy cost of walking than did individuals who used an ankle–foot orthosis(es) (AFO) with no KAFO or with one KAFO. In addition, these individuals relied to a greater extent on their upper extremities for weight bearing. Documentation of assistive device use is important and it was therefore included in the SCI-FAI. Numerical values assigned to these devices are based on the level of assistance they provide with lower values indicating less intrusive devices (and hence more independent walking function).

The Two-Minute Walk Test was included as a measure of walking speed and endurance as it has been shown to be a reproducible measure of exercise tolerance (25). In addition to providing a functional time period over which to calculate walking speed, preliminary work also suggests that two minutes is the minimum time required for an individual with SCI to reach a metabolic steady-state during ambulation (Patrick L. Jacobs, PhD, exercise physiologist, written communication, September 1999).

In summary, our results indicate that the SCI-FAI is a reliable, valid and sensitive instrument for assessment of walking function in individuals with SCI who possess some ambulatory function. This instrument provides a straightforward method by which to document all domains that are critical to walking performance.

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APPENDIX A

SCI Functional Ambulation Inventory (SCI-FAI)

Name: Session: Date:

PARAMETER	CRITERION	L	R	
A. Weight shift	shifts weight to stance limb	1	1	
	weight shift absent or only onto assistive device	0	0	
B. Step width	swing foot clears stance foot on limb advancement	1	1	
	stance foot obstructs swing foot on limb advancement	0	0	
	final foot placement does not obstruct swing limb	1	1	
	final foot placement obstructs swing limb	0	0	
C. Step rhythm (relative time needed to advance swing limb)	at heel strike of stance limb, the swing limb:			
	begins to advance in <1 second *or*	2	2	
	requires 1–3 seconds to begin advancing *or*	1	1	
	requires >3 seconds to begin advancing	0	0	
D. Step height	toe clears floor throughout swing phase *or*	2	2	
	toe drags at initiation of swing phase only *or*	1	1	
	toe drags throughout swing phase	0	0	
E. Foot contact	heel contacts floor before forefoot *or*	1	1	
	forefoot or foot flat first contact with floor	0	0	
F. Step length	swing heel placed forward of stance toe *or*	2	2	
	swing toe placed forward of stance toe *or*	1	1	
	swing toe placed rearward of stance toe	0	0	
	Parameter total			Sum /20

ASSISTIVE DEVICES		L	R	
Upper extremity balance/weightbearing devices	None	4	4	
	Cane(s)	3	3	
	Quad cane(s), Crutch(es) (forearm/axillary)	2	2	
	Walker	2		
	Parallel bars	0		
Lower extremity assistive devices	None	3	3	
	AFO	2	2	
	KAFO	1	1	
	RGO	0	0	
	Assistive device total			Sum /14

TEMPORAL/DISTANCE MEASURES			
Walking mobility (typical walking practice as opposed to W/C use)	Walks …		
	regularly in community (rarely/never use W/C)	5	
	regularly in home/occasionally in community	4	
	occasionally in home/rarely in community	3	
	rarely in home/never in community	2	
	for exercise only	1	
	does not walk	0	
	Walking mobility score		Sum /5
Two-minute walk test (distance walked in 2 minutes)	Distance walked in 2 minutes = ...	feet/minute	meters/minute

AFO: ankle-foot orthosis; KAFO: knee-ankle-foot orthosis.

APPENDIX B

WALKING MOBILITY: CRITERIA FOR LEVELS OF AMBULATION

1. *Physiologic ambulation:* endurance, strength, or level of assistance required, make the ambulation not functional. May require assistance to stand. (Walks for exercise only.)
2. *Limited household ambulation:* able to walk in the home but limited by endurance, strength or safety. (Walks rarely in the home/never in community.)
3. *Independent household ambulation:* walks continuously for distances that are considered reasonable for inside the home. May require assistance with stairs inside and curbs, ramps outside the home. A wheelchair may be used outdoors. (Walks occasionally in home/rarely in community.)
4. *Limited community ambulation:* walks outside the home and can manage, doors, low curbs and ramps. A wheelchair may be used for long distances. (Walks regularly in the home/occasionally in community.)
5. *Independent community ambulator:* walks for distances of approximately 400 meters (1/4 mile) at a speed at least 50% of normal. Can manage all aspects of walking safely, including curbs, stairs and doors. (Walks regularly in the community [rarely/never uses W/C].)

Adapted from: Perry J, Garrett M, Gronely JK, Mulroy SJ. Classification of walking handicap in the stroke population. Stroke 1995; 26: 982–989.