ORIGINAL ARTICLE

Comparison of lower extremity motor score parameters for patients with motor incomplete spinal cord injury using gait parameters

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Study design: Retrospective investigation using gait analysis and medical records.

Objective: To evaluate the relationship between ambulatory function improvement and an increase in lower-limb motor scores in persons with motor incomplete spinal cord injury (SCI) and to compare the efficiency of lower extremity motor score (LEMS) and ambulatory motor index (AMI) in representation of ambulatory function improvement using gait analysis.

Setting: SCI Unit, Yonsei Rehabilitation Hospital, Seoul, Korea.

Methods: The gait analysis from 43 patients with SCI (paraplegic, $n = 22$, tetraplegic $n = 21$) were reviewed. The gait analysis data were obtained with Vicon 370 system. The LEMS and AMI were assessed before the gait analysis and the influence of an increase in lower-limb motor scores were investigated with linear parameters of gait analysis.

Results: For group including both tetraplegic and paraplegic patients, both AMI and LEMS were statistically correlated with gait speed, step length and negative correlation with double-limb support. However, only LEMS was correlated with cadence. For the paraplegic group, with AMI and LEMS, there were correlation with gait speed, step length and right single-limb support and negative correlation with right double-limb support. However, only LEMS was correlated with left cadence and negative correlation with double-limb support. For the tetraplegic group, only left cadence was statistically correlated with AMI.

Conclusion: Both AMI and LEMS were useful in terms of providing information for capability of ambulatory function for the paraplegic group. However, for the tetraplegic group, both AMI and LEMS do not provide sufficient information for ambulatory function of the incomplete SCI patients.

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Keywords: spinal cord injury; ambulation; muscle strength; three-dimensional motion analysis

Introduction

A significant number of persons with incomplete spinal cord injury (ISCI) retain or regain the ability to walk; however, because of limitations in gait speed and endurance, walking may not be the practical method of mobility in the community.^{1,2} Muscle strengthening is one of the principal interventions following ISCI aimed at improving functional abilities such as walking.³ Crozier⁴ found that persons who recovered a greater than grade 3 strength in their less affected quadriceps by 2 months following ISCI had an excellent prognosis for ambulation. Composite scores of lower extremity muscle strength, such as ambulatory motor

index (AMI) and the American Spinal Injury Association (ASIA) lower extremity motor scores (LEMSs), have been found to correlate with gait speed and ambulatory capacity both in persons with acute and chronic ISCI.⁵ Although clinically these LEMSs have been used as indicators for ambulatory function of ISCI patients, there has been no comparison with functional ambulatory parameters using gait analysis.

Walking at different speeds is achieved by simultaneously varying the stride length and frequency.⁶ The level of impairment following ISCI varies greatly among individuals and can be represented as a spectrum of deficits, as presented by the ASIA scale.⁷ Muscle weakness is one of the major deficits observed in SCI subjects⁸ and in most subjects, the preferred as well as the maximal walking speed is usually greatly reduced. Similarly, it was reported that in stroke patients the strength of lower limb is related to gait velocity

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and cadence, and that the maximal gait speed is correlated with hip flexor and plantarflexor strength in adult subjects with stroke.⁹

In terms of ambulatory function, there is difference between patients with tetraplegia and paraplegia clinically. For tetraplegic patients, not only the lower extremities and trunk muscles are affected but also muscles of the upper extremities, so that the supportive function of arms is weak. Wirz¹⁰ found that even with the LEMS remaining below a certain level, patients with paraplegia become ambulatory while patients with tetraplegia remain wheelchair-bound.

The purpose of this study was to compare the efficiency of LEMS and AMI in representation of ambulatory function improvement using gait analysis.

Patients and methods

Patients

Neurological levels and impairment scales were determined according to the ASIA standards. Criteria for inclusion in the study were as follows; (1) have some residual lower extremity motor strength after an ISCI (ASIA C or D), (2) be able to walk independently or with supervision for at least 3 min or at least 5 m without assistive device. This study was approved by the medical ethical committee at our hospital.

We excluded patients who were aged under 15 or over 65 or with an incomplete database record. Subjects who had orthopedic or neurologic conditions in addition to the SCI were excluded from this study as well.

There were 26 male and 17 female patients. The mean age was 39.8 years (15–60 years) and the mean time from injury was 12.8 months (1–136.5 months). There were 22 paraplegic and 21 tetraplegic SCI patients. The mean LEMS was 38.1 points (6–50 points) on the basis of a total of 50 points (Table 1). The mean AMI was 25.1 points (14–30 points) on the basis of a total of 30 points (Table 1).

Methods

Analysis of general characteristics. Patient data were obtained retrospectively using chart reviews. Age, sex, duration from time of injury, level of injury, cause of injury, ASIA LEMS and AMI were evaluated.

Table 1 Comparison of general characteristics between patients with tetraplegia and paraplegia

Variables	Paraplegia (n = 22)	Tetraplegia (n = 21)	P-value
Age (years) ^a	37.2 ± 18.2 ^b	42.4 ± 18.6 ^b	0.354
Sex (male:female) ^c	9:13	11:10	0.451
Duration of injury (months) ^a	15.4 ± 30.7 ^b	9.9 ± 17.1 ^b	0.484
Lower extremity motor score ^a	37.8 ± 8.4 ^b	38.4 ± 8.3 ^b	0.798
Ambulatory motor index ^a	24.1 ± 5.7 ^b	26.1 ± 4.4 ^b	0.179

^aAnalyzed by independent *t*-test.

^bValues are means ± s.d.

^cAnalyzed by χ^2 -test.

Procedure of gait analysis. Gait analysis was performed using a computerized gait analysis system (Vicon 370 Motion Analysis System with six infrared cameras, Oxford Metrics Inc., Oxford, UK) to measure the linear data and the kinematic data during the gait cycle. According to the modified Davis¹¹ biomechanical model, a trained investigator placed 15 reflective markers on the first sacrum, the anterior superior iliac spines, the mid-points of lateral femur, the lateral knee joint axis, the midpoints of the lateral tibia, the lateral malleolus, the heel and the dorsal foot between metatarsal heads 2 and 3. All subjects walked barefoot at a self-determined speed along an 8-m path with the marked in place.

Analysis of clinical parameters. Examinations were performed before the gait analysis by experienced physicians. For lower extremity muscle score (LEMS), in accordance with the standard neurologic assessment developed by ASIA, the voluntary muscle strength of five key muscles (hip flexors, knee extensors, ankle dorsiflexors, long toe extensors and ankle plantarflexors) of both lower extremities was tested.¹² Each muscle was given a value between 0 and 5 according to the strength of voluntary muscle contraction. Maximum and minimum LEMS were 50 and 0, respectively.

For AMI, the voluntary muscle strength of five muscles (hip flexors, hip extensors, hip abductors, knee extensors and knee flexors) of both lower extremities was also tested. Each muscle was given a value between 0 and 3 according to the strength of voluntary muscle contraction. Maximum and minimum AMI were 30 and 0, respectively.²

Statistical analysis

For statistical analysis, SPSS 17.0 windows version (IBM Corp., Somers, NY, USA) was used. To compare general characteristics of patients with paraplegia and tetraplegia, the independent *t*-test and the χ^2 were performed. Pearson's correlations were performed between changes in LEMS and AMI with gait parameters. Magnitude of correlation were defined as poor ($r < 0.4$), moderate ($0.4 < r < 0.6$) and strong ($r > 0.6$).

Results

A total of 43 patients suffering from an ISCI were included in this study. Among the patients, 22 (51.1%) patients were classified as the paraplegic group and 21 (48.9%) patients were classified as the tetraplegic group (Table 1).

Comparison of general characteristics between the two groups

There was no statistically significant difference observed between the two groups with respect to age, sex, duration of time from injury, LEMS, AMI or gait analysis parameters (Tables 1 and 2).

Comparison of gait analysis parameters between the two groups

For the group including both tetraplegic and paraplegic patients, with increases in both AMI and LEMS, gait speed (m sec⁻¹) was increased and was moderately correlated. With

Table 2 Comparison of gait analysis parameters between patients with tetraplegia and paraplegia

Variables	Paraplegia (n = 22)	Tetraplegia (n = 21)	P-value
Cadence Lt (step min ⁻¹)	86.9 ± 25.9	79.2 ± 26.3	P = 0.343
Cadence Rt (step min ⁻¹)	88.6 ± 26.7	78.9 ± 25.6	P = 0.237
Speed Lt (m s ⁻¹)	0.5 ± 0.3	0.5 ± 0.3	P = 0.512
Speed Rt (m s ⁻¹)	0.5 ± 0.3	0.5 ± 0.3	P = 0.449
Step length Lt (m)	0.3 ± 0.1	0.3 ± 0.1	P = 0.799
Step length Rt (m)	0.3 ± 0.1	0.3 ± 0.1	P = 0.632
Step time Lt (s)	0.7 ± 0.2	0.8 ± 0.3	P = 0.318
Step time Rt (s)	0.8 ± 0.4	0.9 ± 0.3	P = 0.433
Single-limb support Lt (%)	29.0 ± 5.7	24.0 ± 10.6	P = 0.066
Single-limb support Rt (%)	29.3 ± 5.7	25.3 ± 9.7	P = 0.107
Double-limb support Lt (%)	41.5 ± 11.0	46.3 ± 18.8	P = 0.326
Double-limb support Rt (%)	42.1 ± 11.2	46.4 ± 19.0	P = 0.381

Abbreviations: Lt, left; Rt, right.
Values are means ± s.d.

Table 3 Relative improvements of LEMS, AMI and gait analysis parameters in patients with tetraplegia and paraplegia

Variables	LEMS	AMI
Cadence Lt (step min ⁻¹)	0.380*	0.253
Cadence Rt (step min ⁻¹)	0.348*	0.207
Speed Lt (m s ⁻¹)	0.482**	0.434**
Speed Rt (m s ⁻¹)	0.460**	0.403**
Step length Lt (m)	0.358*	0.395**
Step length Rt (m)	0.410**	0.304**
Step time Lt (s)	-0.261	-0.153
Step time Rt (s)	-0.267	-0.154
Single-limb support Lt (%)	0.208	0.151
Single-limb support Rt (%)	0.185	0.115
Double-limb support Lt (%)	-0.371*	-0.305*
Double-limb support Rt (%)	-0.329*	-0.275

Abbreviations: AMI, ambulatory motor index; LEMS, lower extremity motor score; Lt, left; Rt, right.

*P < 0.05 by Pearson's correlation.

**P < 0.01 by Pearson's correlation.

Values are means ± s.d.

increased in LEMS, right step length (m) was increased and this showed moderate correlation. Double-limb support (%) was diminished with increases in AMI and LEMS and was statistically correlated. Increases in cadence (stepmin⁻¹) were correlated only with increases in LEMS (Table 3).

For paraplegic group, for LEMS, there was a strong correlation with increases in gait speed (Figures 1 and 2). And for AMI, there was a moderate correlation with increases in gait speed. With step length and right single-limb support (%), both AMI and LEMS were correlated to these parameters. In addition, both AMI and LEMS showed negative correlation with right double-limb support. However, increases in left cadence and left double-limb support were correlated only with increases in LEMS (Table 4).

For tetraplegic group, with LEMS, there was no significant correlation with any of parameters of gait analysis. Also with AMI, there was no significant correlation with changes in gait speed, step length, step time, single-limb support and double-limb support. With increases in AMI, only left cadence was increased and showed moderate correlation (Table 4).

Figure 1 Correlation between LEMS and left (Lt) gait speed of paraplegic group.

Figure 2 Correlation between LEMS and right (Rt) gait speed of paraplegic group.

Discussion

The ASIA protocol has been extensively used as a standardized assessment tool to document the neurologic deficit after an SCI.¹³ Additional assessment of the activity limitation has to be applied for assessment of the activity limitation in order to enhance comprehensive outcome assessment. For that specific reason, LEMS and AMI has been used as an indicator of muscle strength and walking function. Previous studies reported positive correlation between motor score improvement and ambulatory function. They reported that particular muscles around the hip¹⁴ or knee extensor strength are associated with ambulatory function.⁴ Kim¹⁴ found that the long toe extensor, the more affected knee extensor and the less affected ankle dorsiflexors were not significantly related to gait speed or 6-min-walk distance. They suggested for the gait speed and 6-min-walk distance, the strongest correlations were

Table 4 Relative improvements of LEMS, AMI and gait analysis parameters in patients with paraplegia and tetraplegia

Variables	LEMS		AMI	
	Paraplegia	Tetraplegia	Paraplegia	Tetraplegia
Cadence Lt (step min ⁻¹)	0.429*	0.348	0.194	0.434*
Cadence Rt (step min ⁻¹)	0.386	0.332	0.162	0.391
Speed Lt (m s ⁻¹)	0.660**	0.316	0.549**	0.376
Speed Rt (m s ⁻¹)	0.652**	0.29	0.532*	0.341
Step length Lt (m)	0.574**	0.136	0.538**	0.251
Step length Rt (m)	0.572*	0.358	0.551**	0.36
Step time Lt (s)	0.399	-0.132	-0.173	-0.216
Step time Rt (s)	0.301	-0.238	-0.14	-0.269
Single-limb support Lt (%)	0.32	0.193	0.24	0.252
Single-limb support Rt (%)	0.585	-0.028	0.452*	-0.019
Double-limb support Lt (%)	-0.571*	-0.285	-0.418	-0.345
Double-limb support Rt (%)	-0.598*	-0.195	-0.423*	-0.271

Abbreviations: AMI, ambulatory motor index; LEMS, lower extremity motor score; Lt, left; Rt, right.

* $P < 0.05$ by Pearson's correlation.

** $P < 0.01$ by Pearson's correlation.

produced by only the hip flexors and hip abductors on both sides.

In this study, for the all group, with LEMS and AMI improvement, gait speed and step length were increased with statistically significance. Similar results were reported for paraplegic group as well. LEMS and AMI were correlated with increases in gait speed and step length. Walking speed being the product of the stride frequency and the stride length, Pepin¹⁵ suggested that SCI subjects adapt to higher walking speeds by favoring an increase in stride length rather than an increase in stride frequency. They suggested that one important problem for SCI subjects in reaching higher walking speeds seem to be their inability to increase their stride frequency. Our study result also shows that with significant improvements in speed, both LEMS and AMI were statistically correlated with step length. However, only LEMS was statistically correlated with increases in cadence. This suggests that as motor function improves, the main reason for gait speed improvement might be because of increases in step lengths rather than increase in cadence. Gait speed is important since in previous studies, even in ISCI patients with good walking ability automatically can improve balance during walking by walking as fast as possible.¹⁶ Also the ability to voluntarily increase walking speed may better reflect the remaining capacity for a community challenge.¹⁷ Previously, studies¹⁵ also reported limitation of SCI partially caused by an increased stiffness of lower-limb joints caused by changes in the mechanical properties of muscles and tendons as well as co-activation of antagonist muscles. In that study, the activity profile of the triceps surae muscles was often flattened, the amplitude reduced and peak activity during push-off were reported to be commonly absent.¹⁸ Another explanation for limitation of maximal stride investigators provided was the lack or the diminished propulsive forces in SCI subjects in a study on ground

reaction forces.¹⁹ As it was reported that although, the first and second vertical peak forces did not change with changes of the stride length by 10% of the leg length, both breaking and propulsive forces were affected by the 10% change.

Previous studies explained that the hip flexors have an important role during the initial swing phase of gait to pull the swinging limb forward, and the hip abductors are important for stability during stance.²⁰ However, Kim¹⁴ suggested that the muscles important for level walking were not always the same muscles important for ambulatory capacity, which may be more involved. In this study, cadence showed significant correlation only with LEMS. This might be explained because AMI represents only hip and knee muscles. However, LEMS represents not only hip and knee motor function but also the ankle and toe extensor muscles as well. Therefore, although hip and knee muscles have major role in ambulatory function of ISCI patients, ankle and long toe muscles might have at least a minor role in improving ambulatory function.

In this study, for both, the all group and paraplegic group, with LEMS and AMI improvement, double-limb support was decreased. In the paraplegic group only, single-limb support was increased with LEMS and AMI. These results are concurrent with previous studies. Pepin¹⁵ suggested their reduced maximal stride frequency in SCI subjects was reflected by longer stance, and double-support durations than those measured within the normal group. The longer time that SCI subjects have to stay in double support in order to perform the task could also be lined to an altered control of balance. It has been shown that electrical stimulation of the weak plantarflexor muscles during walking could improve forward and upward propulsion of the swinging leg and reduce swing duration.¹⁵

For the group including both paraplegic and tetraplegic patients with AMI improvements, only left double-limb support was decreased. For the paraplegic group, with LEMS and AMI improvement, only left cadence and right single-limb support were increased and right double-limb support was decreased. These were statistically correlated with increases in both AMI and LEMS. Differences in left and right sides were reported previous studies as well. Kim¹⁴ reported that the strength of the less affected limb in bilateral weakness patients, as opposed to that of the more affected limb, seems more important in determining the level of functional performance. They suggested that persons with at least one strong limb are able to perhaps compensate for the weakness on the more affected side and thus demonstrate higher functional performance.

In this study, for tetraplegic group, there was no significant correlation with LEMS and the only AMI was significant correlated with left cadence. This result could be explained since clinically tetraplegic patients require not only the lower extremities and trunk muscles are affected but also muscles of the upper extremities and trunk muscles. Therefore, the supportive function of arms is weak. Wirz¹⁰ suggested for patients with tetraplegia, all lower extremity key muscles had to reach a functional level of muscle contraction to permit locomotor function. In contrast, patients with paraplegia may achieve this performance with

limited walking function. They suggested this difference was due to the additional weakness of trunk and upper-limb muscles in patients with tetraplegia, which requires substantially more lower extremity muscles force to compensate for the postural instability. They also suggested that once this stability had been established, ambulatory patients with tetraplegia achieved a higher level of walking function than patients with paraplegia.

On the other hand, it is important to keep in mind that the limitation of gait speed and cadence in SCI patients are not only because of muscle weakness and can be linked to a reduced range of motion at the joints. A reduced hip range of motion and a flexed position of the knee will limit the step length because the foot will not reach as far forward at foot contact, and hence this would affect other parameters as well. This study also was designed only to evaluate the relationships between motor scores and linear parameters of gait analysis. These are limitations of our study. Therefore, further studies will be required to determine the effect of spasticity effects on patients with SCI and also include evaluation of kinematic and kinetic parameter of gait analysis with motor improvements.

Conclusion

To summarize, as an indicator of ambulatory function of ISCI, AMI and LEMS are not sufficient to represent all ISCI group. Both AMI and LEMS were useful in terms of providing information for capability of ambulatory function for the paraplegic group. However, for the tetraplegic group, both AMI and LEMS do not provide sufficient information for ambulatory function of the ISCI patients. In conclusion, in order to provide and evaluate the capability of gait, future studies should include measurements of kinetic and trunk movement as well as assessing the role of balance for gait of SCI patients.

Conflict of interest

The authors declare no conflict of interest.

References

- 1 Krawetz P, Nanace P. Gait analysis of spinal cord injured subjects: effects of injury level and spasticity. *Arch Phys Med Rehabil* 1996; 77: 635–638.
- 2 Waters RL, Yakura JS, Adkins RH. Gait performance after spinal cord injury. *Clin Orthop* 1993; 288: 87–96.
- 3 Lerner-Frankiel M, Vargus S, Brown M, Krusell L, Schoneberger W. Functional community ambulation: what are your criteria? *Clin manage Phys Ther* 1986; 6: 12–15.
- 4 Crozier KS, Cheung LL, Graziani V, Zorn G, Herbison G, Ditunno Jr JF. Spinal cord injury: prognosis for ambulation based on quadriceps recovery. *Paraplegia* 1992; 30: 762–776.
- 5 Curt A, Dietz V. Ambulatory capacity in spinal cord injury: significance of somatosensory evoked potentials and AIA protocol in predicting outcome. *Arch Phys Med Rehabil* 1997; 78: 39–43.
- 6 Grillner S, Halbertsma J, Nilsson J, Thorstensson A. The adaptation to speed in human locomotion. *Brain Res* 1979; 165: 177–182.
- 7 Dietz V, Quintern J, Berger W. Electrophysiological studies of gait in spasticity and rigidity. Evidence that altered mechanical properties of muscle contribute to hypertonia. *Brain* 1981; 104: 431–449.
- 8 Conrad B, Benecke R, Meinck HM. Gait disturbances in paraspastic patients. In: Delwaide PJ, Young RR (eds). *Clinical Neurophysiology in Spasticity*. Elsevier Science Publishers: Amsterdam, 1985, pp 155–174.
- 9 Nadeau S, Arseneault AB, Gravel D, Bourbonnais D. Analysis of the clinical factors determining natural and maximal gait speeds in adults with a stroke. *Am J Phys Med Rehabil* 1999; 78: 123–130.
- 10 Wirz M, van Hedel HJ, Rupp R, Curt A. Muscle force and gait performance: relationships after spinal cord injury. *Arch Phys Med Rehabil* 2006; 87: 1218–1222.
- 11 Davis RB, Onupuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. *Human Movement Sci* 1991; 10: 575–587.
- 12 Maynard Jr FM, Bracken MB, Creasey G, Ditunno Jr JF, Donovan WH, Ducker TB *et al*. International standards for neurological and functional classification of spinal cord injury, American Spinal Injury Association. *Spinal Cord* 1997; 35: 266–274.
- 13 Waters RL, Adkura JS, Sie I. Motor and sensory recovery following incomplete paraplegia. *Arch Phys Med Rehabil* 1994; 75: 67–72.
- 14 Kim CM, Eng JJ, Whittaker MW. Level walking and ambulatory capacity in persons with incomplete spinal cord injury: relationship with muscle strength. *Spinal Cord* 2004; 42: 156–162.
- 15 Pepin A, Barbeau H. Effects of treadmill speed and incline on the walking pattern of normal and spastic paretic subjects. *Soc Neurosci Abstr* 1992; 18: 860.
- 16 Brandt T, Strupp M, Benson J. You are better off running than walking with acute vestibulopathy. *Lancet* 1999; 354: 74.
- 17 Dobkin BH. Short-distance walking speed and timed walking distance: reductant measures for clinical trials? *Neurology* 2006; 66: 584–586.
- 18 Katz RT, Rymer WZ. Spastic hypertonia: mechanisms and measurement. *Arch Phys Med Rehabil* 1989; 70: 144–155.
- 19 Martin PE, Marsh AP. Step length and frequency effects on ground reaction forces during walking. *J Mot Behav* 1983; 15: 302–330.
- 20 Eng JJ, Winter DA. Kinetic analysis of the lower limb during walking: what information can be gained from a three-dimensional model? *J Biomech* 1995; 28: 753–758.