Spinal Cord (2007) 45, 57–63
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Original Article

Prediction of gait outcome with the knee–ankle–foot orthosis with medial hip joint in patients with spinal cord injuries: a study using recursive partitioning analysis

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Study design: Retrospective study of the degree of gait independence achieved by persons with spinal cord injury (SCI) using knee–ankle–foot orthosis with a medial single hip joint (MSH-KAFO).
Objective: To examine the effects of the neurological level, degree of paresis, age, and inhibitory physical/other factors on the gait with a MSH-KAFO in patients with SCIs.
Setting: Three university hospitals and two rehabilitation hospitals in Japan.
Methods: The 45 patients (36 men, nine women) examined included 10 with injuries in the cervical cord between C6 and C8 (group C), 20 with injuries in the upper-middle thoracic cord between T4 and T10 (group UT), and 15 with injuries in the lower thoracic-lumbar cord between T12 and L1 (group TL). Mean age was 34.0 years (range 16–68 years). Of these patients, 13 used the Walkabout, four used the gear joint, and 28 used the Primewalk as the medial hip joint. Recursive partitioning, which predicted the final status of gait from the level, degree of paresis, age, and inhibitory factors, was performed, and a decision tree for gait was constructed. Inhibitory factors were spasticity, involuntary spasms or muscle contractions, pain, contracture, weakness of the upper extremities, and decreased motivation to perform gait exercise. The degree of gait independence was rated on the following five-point scale: outdoor independent gait (5 points), indoor independent gait (4 points), indoor supervised gait (3 points), indoor assisted gait (2 points), and gait within parallel bars (1 point). New branches were added to the decision tree for gait based on the clinical experience, thereby constructing a new decision tree.
Results: The coincident ratio between the value predicted on the basis of the decision tree of gait and the value actually observed was 53.3%. The coincident ratio between the value predicted on the basis of the modified decision tree of gait and the actually observed value was 68.9%.
Conclusion: The results provide valuable information to medical teams that may assist prescription of gait orthoses.
Spinal Cord (2007) **45,** 57–63. doi:10.1038/sj.sc.3101955; published online 4 July 2006

Keywords: spinal cord injury; gait; orthoses; recursive partitioning; prediction

Introduction

Restoration of gait in patients with spinal cord injuries (SCIs) has several advantages. From the medical viewpoint, a wheelchair-bound life can lead to a large number of morbid states, such as osteoporosis, constipation, urinary tract infection, and cardiovascular deconditioning.[1–3] From the psychological viewpoint, advantages such as increased self-esteem through standing and being at eye level with others as well as through walking, even if only a little, cannot be neglected.[4,5]

To restore gait in patients with SCI, orthoses[6–11] are available.

Orthoses are classified as the bilateral external joint type and the medial single hip joint type according to the

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position of the orthotic hip joint. The most often used in European countries and the United States is the reciprocating gait orthosis (RGO)[6–9] and the hip guidance orthosis (HGO),[10,11] both of which are hip–knee–ankle–foot orthoses (HKAFO) of the bilateral external joint type. As these orthoses have orthotic hip joints on both sides, they enable patients with SCI to accomplish gaits faster than the Walkabout system.[12,13]

The Walkabout system reported in 1992 is classified as a knee–ankle–foot orthosis (KAFO) with a medial single hip joint (MSH-KAFO). The Walkabout system has a removable medial single hip joint and wheelchair compatibility, and provides high standing stability.[12,13] Disadvantages are a low walking speed and a large burden on the upper extremities, because of the large distance between the hip joint of the user and the orthotic hip joint.[12,13]

In an effort to overcome the disadvantages of the walkabout orthosis, the Primewalk® (TIMS Co., 1067-17 Fukamiiwahana, fujioka-cho, Nisikamo, Aichi 470-0441, Japan) system was developed in 1998,[14] with a medial single sliding hip joint linking two KAFOs. The Primewalk orthosis has a sliding hip joint, which allows the imaginary axis of the hip joint to be positioned 60 mm above the real joint (Figure 1). The imaginary axis in the Primewalk orthosis is consequently nearer to the natural hip joint than that in the Walkabout orthosis. The gear joint orthosis is also a type of orthosis developed to heighten the imaginary axis and has been fabricated only for research purposes.[15]

For effective rehabilitation, it is important to be able to reasonably predict the final outcome of treatment on the basis of an initial assessment as well as other relevant factors in order to correctly direct training towards achievement of the desired outcome. Effects of the following factors on the degree of gait independence that patients with SCI can attain when they attempt to restore gait have been separately studied: neurological level,[16–19] severity of injury,[20] strength of arms and motivation,[20,21] age,[19,22] degree of spasticity,[19,22] contracture,[19,22] body weight, inherent agility, and coordination of movement.[22] No studies have been performed, however, to predict the final outcome in consideration of the combined effect of all of those factors listed above. In this study, we examined the effects of age, sex, degree of paresis, and inhibitory factors on the degree of gait independence of SCI patients wearing a MSH-KAFO and attempted to predict the final outcome.

Subjects and methods

Subjects

Subjects were 45 patients with SCI who were provided with MSH-KAFO at one of the three university hospitals or a rehabilitation hospital and underwent walking exercise between 1990 and 2004. Subjects had to fulfill the following inclusion criteria: (1) ASIA Impairment Scale grades A, B, or C and wheelchair-dependent in daily living, (2) training periods of at least 1 month for orthotic gait as an in-patient, (3) completion of gait training during in-patient rehabilitation, and (4) the presence of no comorbidity that forced patients to lessen the training dose.[23]

The subject group consisted of 36 men and nine women with a mean age of 34.0 years (range 16–68 years). Of these patients, 13 used the Walkabout, four used the gear joint orthosis, and 28 used the Primewalk as the medial hip joint. The three groups did not differ significantly in age.

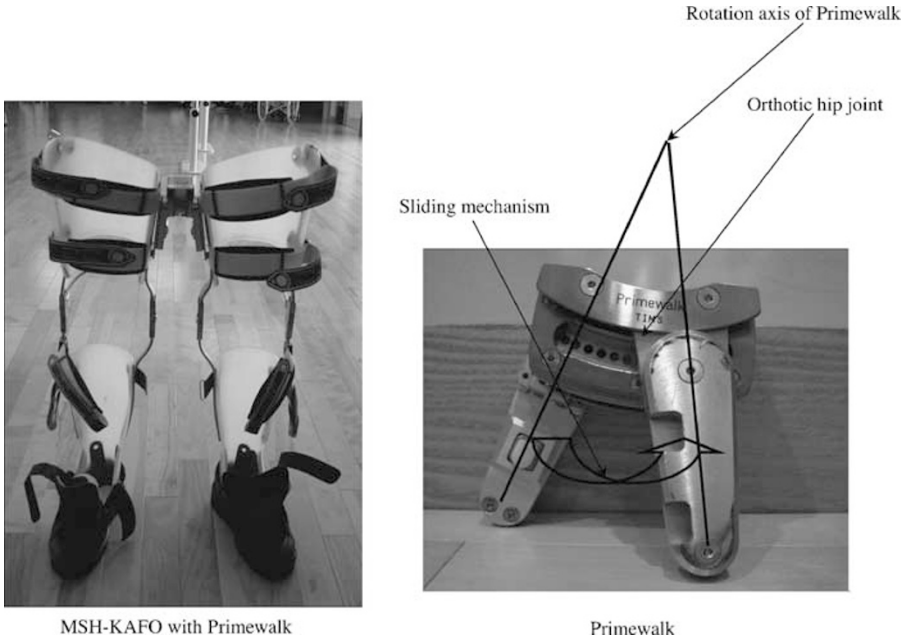

Figure 1 Primewalk

Methods
Medical records of the subjects were examined retrospectively and the number of steps and the time necessary for 10-m walking, walking speed, step length, and cadence were recorded.

Level of neurological impairment was classified into three groups: a cervical group (C) with neurological levels between C6 and C8; an upper-middle thoracic group (UT) with T4–T10 levels, and a thoracolumbar group (TL) (T12–L1 levels). There were no subjects with T1–T3 paraplegia. With regard to the degree of paresis, that of grade A on the ASIA scale was defined as complete paresis and those of grades B and C were defined as incomplete paresis.

The degree of gait independence was rated by the following five-point scale: outdoor independent gait (5 points), indoor independent gait (4 points), indoor supervised gait (3 points), indoor assisted gait (2 points), and gait within parallel bars (1 point). As walking aids, patients with injuries at the C8 level and below used Lofstrand crutches, whereas patients with lesions at the C6 and C7 level used a walker owing to difficulties in grasping.

Inhibitory factors that could interfere with achievement of gait independence were identified from the literature, including spasticity, involuntary spasms, pain, contracture, weakness of the upper extremities, and decreased motivation for performing gait exercise. The effect of each was evaluated as 'present' when it inhibited walking exercise and as 'absent' when it did not inhibit walking exercise. Spasticity was defined as hypertonus of muscles at rest, and involuntary spasms or muscle contractions were defined as abrupt movements during walking exercise. Recursive partitioning[24] was used to predict the final status of gait expected at the end of walking training on the basis of age, sex, neurological level, complete or incomplete paresis, type of orthotic hip joint (Walkabout, gear joint, or Primewalk), and inhibitory factors. MacIntosh-edited JMP version 5.1.1 (SAS Institute Japan, Inui Bldg., Kachidoki, 1-13-1 Kachidoki, Chuo-ku, Tokyo 104-0054, Japan) software was used. We constructed a decision tree of goals for gait while allowing branching as many times as possible.

We added new branches based on our clinical experiences to the decision tree for gait described above, and thereby constructed a modified decision tree for gait.

In view of results of recursive partitioning and the average of gait independence scores at each final branching of the modified decision tree for the goals of gait, the mode was taken as the predicted degree of gait independence. The coincident ratio between the predicted value and the value actually observed was calculated.

Results

Table 1 shows the neurological levels and other information on the subjects. The relationship between the neurological level and the degree of gait independence is demonstrated in Table 2. Five of 10 patients (50%) in group C were able to walk without assistance, but only one was independent indoors without supervision. In the UT group, the majority of patients (75%) did not require any assistance and as the thoracic level moved caudally, more patients became independent indoors without supervision (ie one of 10 in T4–T7 subgroup *versus* four of five in T8–T10 subgroup). In the TL group, only one out of 15 required any assistance with less than half of remaining 14 requiring supervision, and five of 15 achieving independence outdoors.

Table 1 Patient information

	Cases	*Mean age ± SD*	*Sex*	*Orthosis (WA/gear/P)*[a]
Cervical group (C)	10	30.2 ± 143	9/1	1/0/9
Upper thoracic group (UT)	20	37.8 ± 14.2	15/5	6/2/12
Thoracolumbar group (TL)	15	31.4 ± 10.1	12/3	6/2/7
All	45	34.0 ± 13.2	36/9	13/4/28

[a]WA, Walkabout; P, Primewalk

Table 2 Degree of independence of gait according to neurological level

Levels of injury	*C6*	*C7*	*C8*	*T4*	*T5*	*T6*	*T7*	*T8*	*T9*	*T10*	*T12*	*L1*
Degree of independence of gait												
Outdoor independent											1	4
Indoor independent			1	1				1		3	1	2
Indoor supervised	2	2		2	2	3	2			1	3	3
Indoor assisted	2	1			1					2		1
Within parallel bar	1	1		1			1					

C, cervical cord injury; T, thoracic cord injury; L, lumbar cord injury

For patients able to walk in orthosis without any assistance, the lower the level of neurological impairment and the higher the degree of gait independence, the greater were walking speed, step length, and cadence (Table 3).

The ratio of presence of inhibitory factors were 20% (one of five) in outdoor-independent patients, 44.4% (four of nine) in indoor-independent patients, 80% (18 of 20) in indoor-supervision patients, and 72.7% (8 of 11) in parallel bar level patients. The number of inhibitory factors were one in five outdoor-independent patients, nine in nine indoor-independent patients, 26 in indoor-supervision patients, and 31 in 11 parallel bar level patients.

The decision tree for goals of gait constructed for the subjects in this study is shown in Figure 2. The neurological level was the first decisive factor. In the second step, age was extracted in groups C and UT, whereas decreased motivation was extracted in group TL. Patients in group TL were generally high in walking ability. In this group, five of 10 patients with high motivation attained the outdoor-independent level, where all patients with decreased motivation remained at the level of indoor-supervision or less. The remaining patient stayed at the indoor-assisted level. Among patients in groups C and UT and under the age 50, weakness of upper extremities was a decisive factor in gait independence in addition to the neurological level

Table 3 Walking parameters according to neurological level and goals of gait

	Speed (m/min)	*Step length (cm)*	*Cadence (step/min)*
Cervical group ($n=3$)	7.6±5.3	15.8±7.6	45.5±12.5
Upper thoracic group ($n=13$)	113±7.5	23.7±12.2	47.0±16.5
Thoracolumbar group ($n=10$)	18.0±8.8	31.2±12.8	57.7±16.9
Indoor supervised ($n=15$) (C: 2; UT: 9; TL: 4)	9.0±5.5	18.7±6.9	47.2±19.9
Indoor independent ($n=7$) (C: 1; UT: 4; TL: 2)	15.1±6.5	29.4±12.2	53.8±213
Outdoor independent ($n=4$) (C: 0; UT: 0; TL: 4)	23.0±9.8	37.9±14.0	59.9±5.0

C, cervical group; UT, upper thoracic group; TL, thoracolumbar group

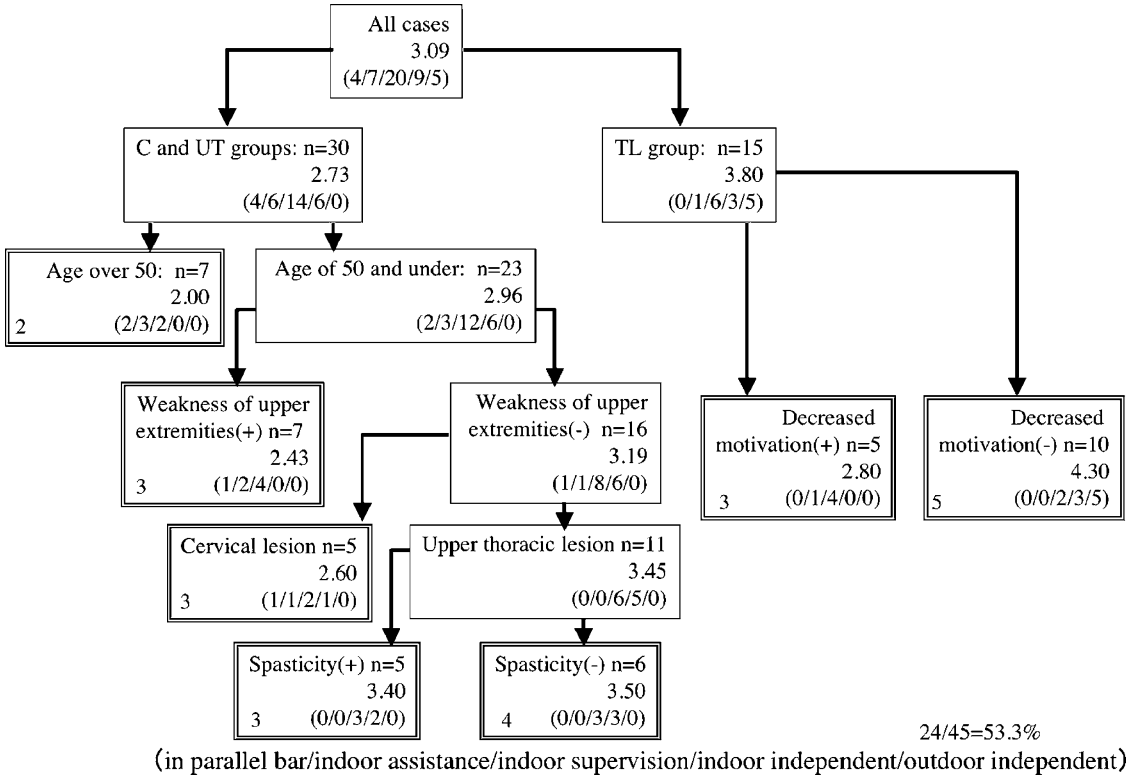

Figure 2 Decision tree for goals of gait using recursive partitioning

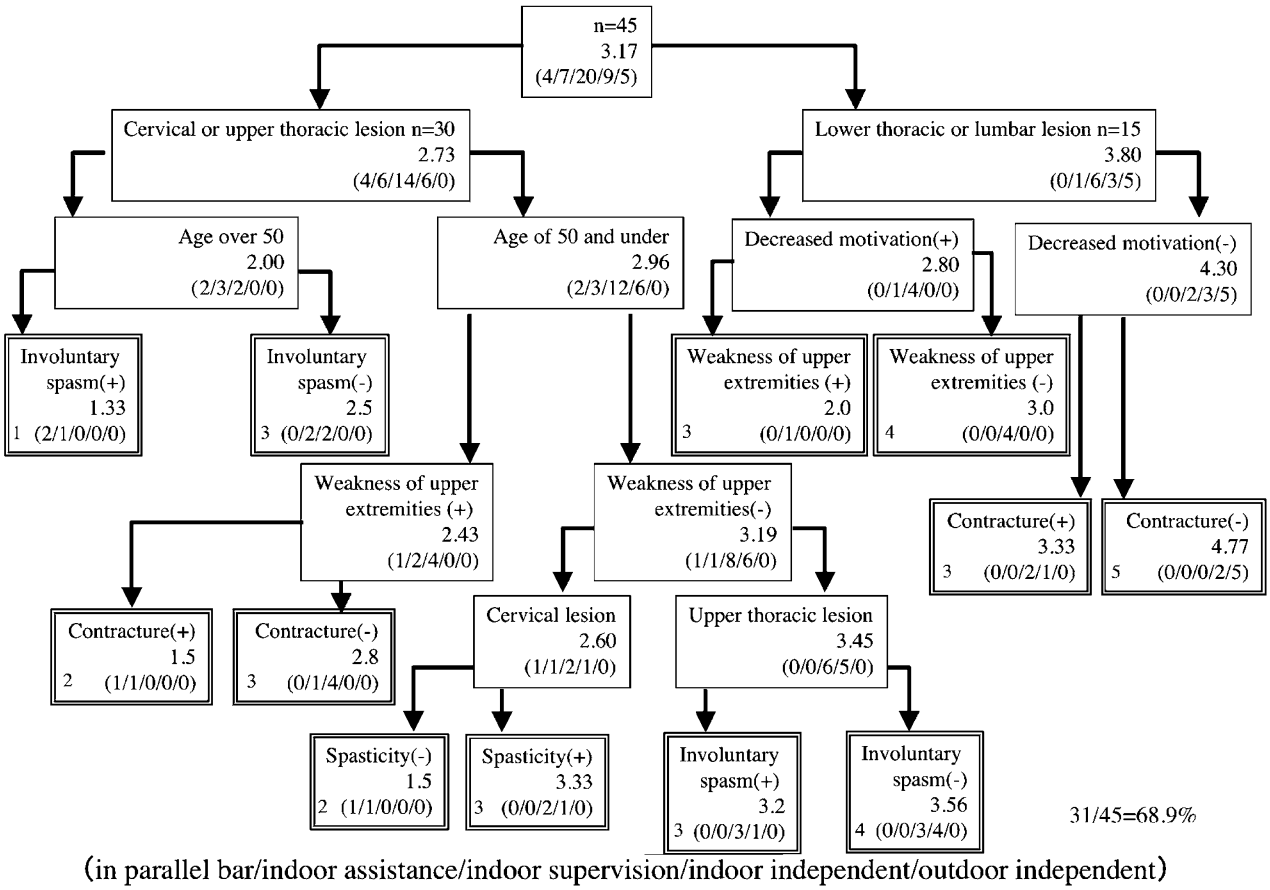

Figure 3 Modified decision tree for goals of gait

and the presence/absence of spasticity. The coincident ratio between the value estimated on the basis of the decision tree of gait and the value actually observed was 53.3%.

The modified decision tree for gait is shown in Figure 3. The coincident ratio between the value predicted from the modified decision tree of gait and the value actually observed was 68.9%.

Discussion

The purpose of this study was to examine the final gait outcome attained by patients having various profiles with the aid of MSH-KAFO. For this purpose, we used recursive partitioning and obtained a coincident ratio of 53.3% between predicted and actually observed values.

The reason why recursive partitioning was used as the statistical method was that factors inhibiting gait independence were anticipated to be plural and their effects were expected to overlap with each other frequently. Such a system cannot be correctly analyzed with a statistical method such as multiple linear regression analysis, which postulates a linear relation between predictive and dependent variables. As recursive partitioning is, in a sense, a classification method, it easily deals with repetition in inhibitory factors.

In this study, the proportions of subjects who could walk without assistance were 50% in group C, 80% in group UT, and 93.3% in group TL. These values were almost in agreement with corresponding values obtained in the patients who underwent gait training with RGO.[17] The walking speed of the subjects in this study was almost comparable with that of patients using an HKAFO such as RGO.[17,25,26] We believe, therefore, that the subjects whose final outcome of gait was predicted in this study belonged to a typical group of patients who underwent appropriate exercise and acquired appropriate ability.

Predictive factors extracted by recursive partitioning were the neurological level, age, motivation, strength of upper extremities, and presence/absence of spasticity. The coincident ratio between predicted and actually observed values of the degree of gait independence was as low as 53.3%. Such a low ratio seems partly to have resulted from the small number of subjects. With progressive branching, the number of subjects in each branch decreased to such an extent that further branching was impossible. To overcome this shortcoming of the decision tree, which was drawn purely theoretically, we added variables used clinically for the assessment of movement abilities in SCI patients (clinical factors) to the decision tree and constructed

a modified decision tree. Added branches were involuntary movement, spasticity, and contracture. In the following paragraphs, we discuss how the factors described above correlate with the goal of gait.

Patients with SCI at lower levels can control the pelvis and hip joints more effectively than those neurologically higher levels.[18,19] Walking speed is higher and energy expenditure is lower in the former than in the latter.[24,26,27] The lower the neurological level, the more easily can patients acquire walking ability with orthoses.[17,18,20] As this seems to hold true for MSH-KAFO, it is not surprising that the neurological level was extracted as a main branching factor in recursive partitioning in this study.

Aging increases the probability of occurrence of cardiovascular deconditioning, weakness of upper extremities, and contracture of lower extremities. In addition, aging possibly lowers motor learning ability and leads to decreased motivation.[28] Strong motivation is necessary for gait independence in disabled persons.[22] In particular, gait exercise with orthoses in patients with SCI is similar to learning a new sport. The goal of gait is consequently attained more easily by younger patients. Strong motivation also seems to be indispensable to attain this goal.

When patients with SCI walk with the aid of orthoses having no external power source, they must maintain balance and transfer the center of gravity using their upper extremities.[21] For this purpose, they need sufficient muscular strength in the upper extremities.

Spasticity has two sides contradictory to each other. One is that it is an inhibitory factor, in that it obstructs the hip and knee joints from extension and causes malalignment of lower extremities within the orthoses.[18] The other side is that it increases standing stability because spasticity is accompanied by hypertonus of muscles, and that hypertonus of muscles providing a 'spastic brace' effect. The latter effect of spasticity is particularly outstanding in patients with SCI, who have weakness of the extremities. We consider that addition of the latter feature of spasticity to factors for prediction of the final status of gait resulted in the increase in the coincident ratio. Involuntary spasms decrease standing stability,[22] and consequently seem to have an effect similar to the unfavorable effect of spasticity.

Fixed flexion contractures in the lower extremities (commonly at hip and/or ankle joints) interferes with maintenance of a stable standing position and makes it difficult to maintain balance during reciprocal walking. We consequently consider that the presence or absence of contracture profoundly influences gait independence.

It is considered reasonable, therefore, that the neurological level, age, motivation, strength of the upper extremities, presence or absence of contracture, spasticity, and involuntary spasms, all of which were extracted in recursive partitioning in this study, were included in prediction of the final outcome of gaits.

The orthotic gait in patients with SCI has been studied merely for research purposes but not as routine clinical practice. This is probably the reason why, as far as we know, prediction of final outcome concerning gait independence has not been examined yet. Results of this study would seem to provide useful information to medical teams that prescribe orthoses to assist upright mobility. A shortcoming of this study is that it was retrospective. It was not possible consequently to examine appropriateness of the prediction. We will apply the method devised in this study to a new group of patients to determine if data collected prospectively would support results reported in this current study and validate the clinical utility of the modified decision tree.

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