Prediction of lower limb functional recovery after laminoplasty for cervical myelopathy: focusing on the 10-s step test

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Abstract

Objective Operative decompression is indicated for progressive neurological deterioration in patients with cervical compressive myelopathy (CCM). However, the best timing to ensure clinical recovery has not been determined because of the lack of a suitable method. 10 s step (“step”) test is an easily performed physical test to assess the severity of CCM, particularly for the severity of lower limb dysfunction. The purpose of this study was to analyze the predictive value of preoperative step test results in relation to the results of expansive laminoplasty in patients with CCM.

Materials and methods Clinical and imaging data were prospectively collected from 101 patients who underwent cervical expansive laminoplasty for CCM. The Japanese Orthopedic Association (JOA) score and the lower limb function section of the Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ-L) were used to evaluate surgical outcomes. Cutoff value was determined by receiver operating characteristic curve analysis to predict clinical recovery after surgery. JOA recovery rate exceeding 50% was defined as an

effective clinical result. The treatment was judged to be effective in 30 patients based on the JOACMEQ-L. The cutoff value of the step test was 14.5 in cases of an effective judgment with JOA and JOACMEQ-L. Multivariate analysis showed that preoperative patient age and duration of symptoms were predictive parameters for effectively judging JOA scores. A preoperative step test result of greater than or equal to 14.5 and male gender were significant predictive parameters for an effective judgment with JOACMEQ-L.

Conclusions Preoperative step test results significantly reflected the effective results of JOACMEQ-L and were predictive of improved lower limb function after laminoplasty in patients with CCM. Patients with a score of greater than or equal to 14.5 can experience effective lower limb functional recovery.

Keywords Cervical compressive myelopathy · Step test · Laminoplasty · Physical test · Outcome

Introduction

Cervical compressive myelopathy (CCM) is the most common cause of spinal cord dysfunction due to spondylosis, disc herniation, and ossification of longitudinal ligaments in the elderly. The disease usually has an insidious course and weakness and clumsiness of hands, hand paresthesias, gait disturbances, and urinary incontinence slowly progress [4]. In cases of severe compression or a progressive course, operative decompression is the accepted treatment for CCM. Because irreversible changes may occur in the spinal cord, the best timing for surgery to ensure neurological recovery has been discussed [1, 14]. Therefore, a clear incentive exists to find a simple clinical

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method to predict neurological recovery after surgical intervention.

We developed the 10-s step (“step”) test as an easily performable quantitative test for patients with CCM. This test is useful to achieve a common understanding of the severity of myelopathy, particularly the severity of lower extremity dysfunction secondary to CCM [16, 26]. However, until date, the prognostic value of the step test regarding effective clinical recovery after surgical intervention in patients with CCM has not been fully examined. Moreover, few reports have identified the factors that most seriously affect the postoperative clinical results of CCM, which include gender, age, duration of symptoms, and magnetic resonance imaging (MRI) findings [3, 22, 25].

The purposes of this study were to investigate the relationship between preoperative step test results and postoperative neurological recovery (particularly for lower limb function), and ascertain the crucial determinants of surgical outcomes using statistical analyses.

Materials and methods

Patient population

This prospective study evaluated preoperative imaging parameters and clinical data from patients who underwent cervical expansive laminoplasty. In total, 168 consecutive patients with CCM were prospectively enrolled from January to December 2008. Forty patients who had symptomatic neurological disorders or joint osteoarthritis were excluded from this study; their specific illnesses included cerebral palsy, rheumatoid arthritis, hip or knee osteoarthritis, or other spinal diseases as well as traumatic cervical spinal cord injury. An additional 27 patients, while indistinguishable in terms of symptoms from the others included in the study, became unavailable for postoperative follow-up within the 12 months after surgery because of various personal problems unrelated to their CCM. The remaining 101 patients (61 men and 40 women; mean age 63.6 ± 11.8 years), who could be tracked for more than 12 months after surgery, were included in this study. Diagnoses were confirmed by neurological examinations and imaging studies such as MRI and a computed tomography myelogram; the cause of CCM was cervical spondylotic myelopathy in 87 patients and ossification of the posterior longitudinal ligament in 14 patients.

Surgical technique

A double-door laminoplasty was performed according to Kurokawa's method [13] with some modifications in all

patients (C3–7, 86 cases; C2–7, 7 cases; C3–6, 3 cases; C4–7, 3 cases; and C2–T1, 2 cases). The center of the laminae was cut using a high-speed drill. Bilateral gutters were created as hinges at the border of laminae and facets. After the halves of the laminae were elevated, the bone graft strut (length 16–18 mm), made from the spinous process, was tied to bridge the bilateral edges of the laminae.

Step test

Patients were asked to take a step by lifting their thighs parallel to the floor (hip and knee joints in 90° flexion) in the same place, without holding on to anything for balance, for as many steps as they could take in 10 s. Patients who were not able to lift their thighs parallel to the floor were asked to just lift their thighs as much as possible. Each patient was requested to perform the test at maximum speed. If the patients appeared to be at risk of falling, the test was performed close to a hand bar that could be grabbed for balance. This test was assessed twice by physical therapists before surgery and 1 year after surgery, and the mean of the data was analyzed.

Radiographic assessment

The C2–C7 lordotic angle was measured on lateral radiographs with patients in a neutral position [10]. The C7 plumb line was measured on whole spinal lateral views.

Spinal cord signal intensity changes were evaluated on T2-weighted MRI images in sagittal and axial planes [22].

Neurological assessment

The preoperative and postoperative neurological function 1 year after surgery was evaluated using the JOA score [8] and the lower limb function section of the Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ-L) (Table 1) [5–7].

The recovery rate of the JOA score was calculated using Hirabayashi's method [9] and was based on the following formula: recovery rate (%) = (postoperative JOA score – preoperative JOA score) $\times$ 100/(17 – preoperative JOA score). A recovery rate exceeding 50% was defined as an effective clinical result in the JOA score [17, 22].

For JOACMEQ, if either of the following conditions was satisfied, the treatment was judged to be an effective clinical result: (1) the post-treatment score was higher than the pretreatment score by 20 points or more and (2) the pretreatment score was less than 90, and the post-treatment score reached 90 points or more. Patients with pre- and postoperative scores of more than 90 were excluded from

Table 1 Lower limb function in the JOA cervical myelopathy evaluation

Calculating formula for lower limb function

$$(Q3-1 \times 10 + Q3-2 \times 10 + Q3-3 \times 15 + Q3-4 \times 5 + Q3-5 \times 5 - 45) \times 100/110$$

Questionnaire

Q3-1 Can you walk on a flat surface?

1. Impossible
2. Possible, but slowly even with support
3. Possible only with the support of a handrail, a cane, or a walker
4. Possible, but slowly without any support
5. Possible without difficulty

Q3-2 Can you stand on either leg without the support of your hand?

(the need to support yourself)

1. Impossible with either leg
2. Possible on either leg for more than 10 s
3. Possible on both legs individually for more than 10 s

Q3-3 Do you have difficulty in going up the stairs?

1. I have great difficulty
2. I have some difficulty
3. I have no difficulty

Q3-4 Do you have difficulty in one of the following motions: bending forward, kneeling, or stooping?

1. I have great difficulty
2. I have some difficulty
3. I have no difficulty

Q3-5 Do you have difficulty in walking more than 15 min?

1. I have great difficulty
 2. I have some difficulty
 3. I have no difficulty
-

this analysis. The other patients' treatment was judged to be ineffective.

Statistical analyses

Statistical analyses were performed using the SPSS version 17 software (SPSS Inc, Chicago, IL, USA). We plotted receiver operating characteristic (ROC) curves to investigate the cutoff value of the step test to predict effective clinical recovery after surgery in terms of the JOA score and JOACMEQ-L.

The Mann–Whitney *U* test and Student's *t* test were used to evaluate the association between the two groups. Differences were considered significant at $P < 0.05$. We used multivariate logistic analysis to investigate the significant factors contributing to the effective clinical results both in terms of JOA score and JOACMEQ-L. The significance of parameters was evaluated by univariate logistic analysis. Factors with a *P* value of less than 0.20 in univariate analysis were entered into the multivariable logistic model.

Results

Surgical results

The average JOA score was 11.1 points (range 4–16) before surgery and 14.3 points (range 5–17) 1 year after surgery. The JOA recovery rate averaged 56.2% (range 0–100); 63 patients had effective surgical outcomes, with recovery rates exceeding 50%, while 38 patients had poor surgical outcomes with recovery rates less than 50%. The average motor function of the lower limb in that part of the JOA score before surgery was 2.6 ± 1.0 points and 3.2 ± 0.9 points 1 year after surgery.

The average JOACMEQ-L score was 71.0 points (range 9.1–100) before surgery and 80.5 points (range 18.2–100) 1 year after surgery. The treatment was judged to have been effective in 30 patients based on the JOACMEQ score.

The average step test results were 14.2 ± 4.7 times before surgery and 16.1 ± 4.5 times 1 year after surgery.

Baseline clinical variables for the low/high step test groups

We determined a cutoff value to further clarify the importance of the step test. ROC curve analysis showed 14.5 to be the value to maximize the power of a step test result as a predictor of effective clinical results for the JOA score (area under the curve = 0.539) and of obtaining a rating of the effective use of JOACMEQ-L (area under the curve = 0.598) (Fig. 1). The patients were categorized into two groups according to the results of their preoperative step test; the low step test group comprised 51 patients with preoperative step test scores of less than 14.5 (mean 10.6 ± 3.2), and the high step test group comprised 50 patients with scores of 14.5 or more (mean 17.8 ± 3.0). Baseline characteristics are shown in Table 2. Patients in the low step test group were older (67.9 ± 10.6 years) than those in the high step test group (59.2 ± 11.6 years; $P < 0.001$); the percentage of males was lower in the former group than in the latter. Furthermore, the preoperative JOA scores and JOACMEQ-L were lower for the patients in the low step test group ($P < 0.001$). The percentage of signal intensity change on MRI, C2–7 lordotic angle, and the C7 plumb line were higher for patients in the low step test group.

Factors associated with effective clinical results in JOA scores

Factors associated with effective improvement in JOA scores are shown in Table 3. In univariate analysis, improvement in JOA scores was significantly associated

with the results of the step test, age (years), male gender (%), and duration of symptoms (years). In multivariate regression analysis, age and duration of symptoms were

identified as independent predictors of improvement in JOA scores (Table 3).

Factors associated with effective clinical results on JOACMEQ-L

Factors associated with effective ratings using JOACMEQ-L are shown in Table 4. In univariate analysis, effectiveness was assessed by JOACMEQ-L as significantly associated with the results of the step test, male gender (%), and signal intensity change on MRI. In multivariate regression analysis, the results of the step test and male gender (%) were identified as independent predictors of effectiveness as assessed by JOACMEQ-L (Table 4).

Discussion

This study was conducted to analyze the predictive value of preoperative step test results in relation to the results after surgery in patients with CCM and investigate the factors determining surgical outcomes. The results of this study showed that preoperative step test results correlated significantly with the recovery of lower limb function after laminoplasty. Thus, the preoperative step test was shown to be a simple predictive parameter for lower limb functional recovery after surgery.

Previous studies have reported that preoperative neurological status affects clinical outcomes in patients with CCM [3]. This could be attributable to the fact that functional recovery of the spinal cord depends on irreversible change. Therefore, it has been suggested that it is important to perform surgery before the occurrence of irreversible changes in the spinal cord, or while clinical symptoms are still mild [3]. However, few critical reports concerning the appropriate timing of surgery for ensuring sufficient neurological recovery are available.

Up to now, numerous factors have been reported to affect postoperative outcomes in patients with CCM. Prognostic factors after laminoplasty for CCM have been

Fig. 1 ROC curves analyzing cutoff values. **a** Cutoff value for JOA score >50%. **b** Cutoff value for an “effective” rating using the JOACMEQ-L. Arrows indicate the plotted points that determine cutoff values

Table 2 Baseline characteristics of the low/high step test groups

	All patients (<i>n</i> = 101)	Low step test group (step < 14.5) (<i>n</i> = 51)	High step test group (step ≥ 14.5) (<i>n</i> = 50)	<i>P</i> value
Age (years)	63.6 ± 11.9	67.9 ± 10.6	59.2 ± 11.6	<0.001
Male gender (%)	61 (60.4)	28 (54.9)	33 (66.0)	<0.001
Duration of symptoms (years)	2.6 ± 3.6	2.4 ± 3.2	2.9 ± 4.0	NS
Preoperative JOA score	11.1 ± 2.6	9.9 ± 2.5	12.0 ± 2.1	<0.001
Preoperative JOACMEQ-L	71.0 ± 26.0	57.3 ± 25.7	84.8 ± 18.1	<0.001
Signal intensity change on MRI (%)	59 (58.4)	32 (62.7)	27 (54.0)	<0.001
C2–C7 lordotic angle	8.7 ± 10.7	11.6 ± 11.6	5.9 ± 8.9	<0.01
C7 plumb line (mm)	22.66 ± 29.3	28.6 ± 28.0	16.9 ± 29.7	<0.05

Table 3 Significant parameters for improvement in JOA score

	Univariate		Multivariate	
	HR (95% CI)	<i>P</i> value	HR (95% CI)	<i>P</i> value
Step test ≥ 14.5	1.75 (0.76–4.00)	0.19	1.30 (0.49–3.41)	0.59
Age (years)	0.95 (0.91–0.98)	0.011	0.95 (0.90–1.00)	0.040
Male gender	2.40 (1.04–5.58)	0.041	1.87 (0.75–4.69)	0.18
Duration of symptoms (years)	0.87 (0.76–0.99)	0.029	0.84 (0.73–0.97)	0.016
Preoperative JOA score	1.08 (0.92–1.27)	0.36		
Signal intensity change on MRI	0.85 (0.37–1.96)	0.69		
C2–C7 angle	0.98 (0.94–1.02)	0.28		
C7 plumb line (mm)	0.99 (0.98–1.01)	0.65		

Multivariate model includes variable with $P < 0.20$ by univariate analysis

Table 4 Significant parameters for an “effective” rating with JOACMEQ-L

	Univariate		Multivariate	
	HR (95% CI)	<i>P</i> value	HR (95% CI)	<i>P</i> value
Step test ≥ 14.5	3.31 (1.20–9.15)	0.021	3.41 (1.16–10.03)	0.025
Age (years)	0.98 (0.93–1.02)	0.28		
Male	2.88 (1.07–7.75)	0.037	3.78 (1.23–11.53)	0.019
Duration of symptoms (years)	0.96 (0.84–1.10)	0.54		
Preoperative JOA score	1.01 (0.83–1.24)	0.89		
Preoperative JOACMEQ-L	0.99 (0.97–1.01)	0.32		
Signal intensity change on MRI	0.50 (0.19–1.33)	0.164	0.39 (0.13–1.18)	0.98
C2–C7 lordotic angle	1.00 (0.96–1.05)	0.92		
C7 plumb line (mm)	0.99 (0.98–1.01)	0.49		

Factors with $P < 0.20$ in the monovariant analysis were entered into the multivariable logistic model

identified: age, duration of symptoms, preoperative JOA score, signal intensity change on MRI, C2–C7 lordotic angle, and spinal cord diameter [2, 11, 12, 21, 22, 24, 25]. However, the list of factors differs according to researchers, and the prognostic significance of these factors remains controversial.

Intramedullary signal intensity changes on MRI are one of the most often used predictive factors. However, the prognostic significance of a signal intensity change on MRI remains controversial [15, 22, 23, 25]; some surgeons confirm the predictive value, whereas others deny it. Moreover, such evaluation systems are not suitable for quantitative assessment because each category covers a huge range of actual severity.

Moreover, the preoperative JOA score is often indicated as a predictive parameter for CCM [17, 22]. A disadvantage of using the JOA recovery rate as the evaluation method for neurological recovery is that the recovery rate is affected not only by treatment interference, but also by the patient's preoperative JOA score. In patients with lower preoperative JOA scores, the surgical outcomes may be

poorer than those of patients with higher preoperative JOA scores. Moreover, most of the elderly have low preoperative JOA scores, and old age is often assessed to be a factor in poor surgical outcomes.

To overcome the problems that exist with the JOA score, JOACMEQ has been used as the new evaluation method for patients with CCM. JOACMEQ, [5–7] consisting of 24 questions, was recently established as a patient-based method for evaluating CCM. The answers are evaluated based on corresponding domains according to the calculation formulas provided. Five functional areas (cervical spine function, upper limb function, lower limb function, bladder function, and quality of life) are evaluated separately. This method of evaluation is somewhat complex, but could be a more objective method than others. With this assessment method, treatment is judged to be effective based on the patient's post-treatment score; the results do not have the limitations of the JOA score.

We developed the step test as a simple physical assessment for the severity of CCM, particularly for lower limb dysfunction [16, 26]. This test does not require the use

of instruments and can be performed anywhere. The step test is the most representative and quantitative test [16] among the quantitative physical tests for CCM (other test, the 10-s grip and release test [19] and the 30-m walking test [20]). In the present study, the results of the step test were identified as independent predictors of effective lower limb function after surgery. This step test provided a quantitative assessment, after which we could clearly determine the timing of surgery using a cutoff value.

As for the reasons why gender was also identified (in addition to the step test) as an independent predictor of effectiveness as assessed by JOACMEQ-L, there are two possibilities: (1) women might have more severe forms of CCM; (2) independent of the severity of their CCM, men might have a greater aptitude for this step test than women. In our previous study on the results of the step test for 1,200 age-matched normal volunteers, men had a greater aptitude for this step test than women [26]. We need to increase the number of cases, and consider whether there are different cutoffs by gender.

Several limitations need to be considered with respect to our study. Firstly, this study was a single-center design and involved only a limited number of patients. Secondly, our follow-up term was 1 year after surgery, indicating that the relationship between the preoperative step test results and long-term prognosis of lower limb function could not be clearly established, although we could broadly predict the future condition from the trends observed [3, 18]. Thirdly, as with other physical tests, the results of this test can be altered by other locomotor diseases that were excluded from this study's population; hence, in patients with locomotor diseases such as severe hip or knee osteoarthritis, this cutoff value must not be utilized.

Overall, however, the step test has been demonstrated to be a simple quantitative test to predict surgical outcomes particularly for lower limb functional recovery after laminoplasty in patients with CCM. Quantitative neurological assessment for the severity of myelopathy contributes significantly to the determination of the most appropriate timing for surgery.

Conflict of interest None.

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