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ARTICLE

Baseline severity of myelopathy predicts neurological outcomes after posterior decompression surgery for cervical spondylotic myelopathy: a retrospective study

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Abstract

Study design Retrospective multicenter study.

Objectives To identify the usefulness of the baseline severity of myelopathy for predicting surgical outcomes for cervical spondylotic myelopathy (CSM).

Setting Seventeen institutions in Japan.

Methods This study included 675 persons with CSM who underwent posterior decompression. According to baseline severity, the individuals were divided into the mild (Japanese Orthopaedic Association [JOA] score ≥ 14.5), moderate (JOA score = 10.5–14), and severe (JOA score ≤ 10) groups. Surgical outcomes and clinical variables were compared between the groups. Logistic regression analysis was used to develop a prediction model for unsatisfactory symptom state (postoperative JOA score ≤ 14, residual moderate or severe myelopathy).

Results The mean (±standard deviation) age was 67 ± 12 years. The participants in the severe group were older than those in the mild group. Postoperative JOA scores were higher in the mild group than in the severe group. According to multivariate logistic regression analysis, the prediction model included preoperative JOA scores (odds ratio [OR] 0.60; 95% confidence interval [CI] 0.55–0.67) and age (OR 1.06, 95% CI 1.04–1.08). On the basis of the model, a representative combination of the thresholds to maximize the value of "sensitivity − (1 − specificity)" demonstrated a preoperative JOA score of 11.5 as a predictor of postoperative unsatisfactory symptom state in people around the mean age of the study cohort (67 years).

Conclusions The combination of the baseline severity of myelopathy and age can predict postoperative symptom states after posterior decompression surgery for CSM.

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Introduction

Cervical spondylotic myelopathy (CSM) is one of the most common causes of spinal cord compression and neurological deterioration due to spondylosis and disc herniation [1]. In cases of progressive neurological deficits or severe spinal cord compression, surgical decompression is the standard treatment for CSM, which can improve neurological function and quality of life [2]. Of the various posterior decompression techniques, expansive open-door laminoplasty (ELAP), double-door laminoplasty (DD), and muscle-preserving selective laminectomy (SL) are the representative techniques that are generally considered reasonable surgical options in terms of cost-effectiveness and safety [3–6].

A recent systematic review demonstrated that one of the most important predictors of postoperative neurological outcomes in persons with CSM is the baseline severity of myelopathy [7]. Using the data from a prospective multicenter study, Tetreault et al. developed a prediction model relating a combination of clinical and imaging factors to neurological outcomes after anterior or posterior surgery in persons with CSM [8, 9]. The baseline severity of myelopathy assessed using the preoperative modified Japanese Orthopaedic Association (mJOA) scores was included in their prediction model, which showed good discrimination in the overall international population and adequate calibration [9]. Several studies have consistently reported a distinct relationship between baseline severity evaluated using the JOA scores and neurological outcomes after posterior cervical decompression [10–13]. Although previous studies pointed out the significance of baseline severity, this prognostic factor was reported as only one of the predictors of neurological outcomes. Despite its importance, none of the previous studies selected baseline severity as the main subject of analysis. Consequently, the usefulness of baseline severity as a predictor of neurological outcomes of persons with CSM after posterior decompression has not been investigated. An investigation that mainly focuses on baseline severity would be rather meaningful in providing surgeons with information about typical neurological outcomes according to the baseline severity.

In the current multicenter large cohort study, 675 individuals with CSM who underwent posterior decompression were divided into three groups based on the baseline severity of myelopathy assessed using the JOA scores (mild, moderate, and severe groups) [14]. We defined neurological outcomes as postoperative symptom state according to the JOA scores. The individual characteristics and surgical outcomes were compared among the groups. Subsequently, multivariate logistic regression analysis was performed to develop a prediction model for unsatisfactory symptom states.

Methods

Participants

Between January 2012 and December 2014, a total of 675 consecutive individuals with CSM underwent posterior cervical decompression at 17 institutions [15]. All individuals were followed up for at least 1 year after surgery. The inclusion criteria were as follows: (1) symptomatic CSM with at least one clinical sign of myelopathy, (2) cervical spinal cord compression on magnetic resonance imaging or cervical myelogram-computed tomography, and (3) no previous cervical spine surgery. The exclusion criteria were (1) radiculopathy without myelopathy; (2) ossification of the posterior longitudinal ligament; (3) history of rheumatoid arthritis, ankylosing spondylitis, or spinal tumors; (4) spinal injuries; (5) infection; or (6) concomitant lumbar stenosis. According to the preoperative severity of myelopathy, the individuals were divided into three groups according to a previous study, with slight modifications: mild (defined as JOA scores ≥ 14.5), moderate (JOA scores = 10.5–14), and severe (JOA scores ≤ 10) groups [14]. Because Fehlings et al. used the preoperative mJOA scores to define the baseline severity of myelopathy (mild, mJOA scores ≥ 15; moderate, mJOA scores = 12–14; severe, mJOA scores ≤ 11) [14], we calculated the corresponding JOA scores from the mJOA scores using a previously reported prediction formula: JOA scores = (mJOA scores − 2.4)/0.89 [16].

Surgical procedure

The surgical indication, surgical procedure, and decompression levels were decided by the spine surgeons at each institute. Three different surgical procedures of posterior cervical decompression (ELAP [3], DD [4], or SL [5, 6]) were performed in individuals in the current study. ELAP, DD, and SL were performed at 12, 7, and 9 institutions, respectively.

Data collection

We retrospectively collected the clinical information of individuals, including age, sex, follow-up period, smoking history, and medical history. Operation time and blood loss were assessed from surgical records. All surgery-related events that occurred within 30 days of the operation were considered perioperative complications. Neurological status was evaluated at the preoperative stage and final follow-up using the JOA scores for cervical myelopathy. We defined postoperative unsatisfactory symptom state as JOA scores ≤ 14 (residual moderate or severe myelopathy). This is consistent with a previous report that acceptable symptom state was calculated as a JOA score of 14.5 [17].

Statistical analysis

Each independent variable was compared among the groups (mild, moderate, and severe) using one-way analysis of variance (either the Tukey's honestly significant difference or Games-Howell post hoc tests were used) for continuous variables and the chi-square test for categorical variables. The JOA scores were compared between the preoperative and postoperative stages using a paired *t* test. Univariate and multivariate logistic regression analyses were used to detect predictors of postoperative unsatisfactory symptom state (postoperative JOA scores ≤ 14). All factors analyzed in the univariate analysis were examined using multivariate analysis. On the basis of the multivariate logistic model, receiver operating characteristic (ROC) curves were plotted to investigate the cutoff value of the preoperative JOA scores for predicting postoperative unsatisfactory symptom states. As the cutoff values of the preoperative JOA scores vary depending on the value of the covariates, we showed the preoperative JOA score cutoff values depending on the combination of values for each covariate. SPSS software (version 22.0; IBM Corporation, Armonk, NY, USA) was used for statistical analysis, and JMP 15 (SAS Institute Inc., Cary, NC, USA) was used to plot the ROC curves and to calculate the cutoff values. Means ± standard deviations were used to describe continuous variables. *P* values < 0.05 were considered statistically significant.

Results

Characteristics and comorbidities of individuals according to baseline severity

This study included 675 individuals (451 men and 224 women) with CSM who underwent posterior cervical decompression. The mean age (±standard deviation) at surgery was 67 ± 12 years, and the median (interquartile range) follow-up duration was 22 (14–26) months. The individuals were divided into three groups according to the preoperative JOA scores: mild (JOA scores ≥ 14.5, $n = 72$), moderate (JOA scores = 10.5–14, $n = 330$), and severe (JOA scores ≤ 10, $n = 273$) groups. The participants in the severe group were on average 4.7 years (95% confidence interval (CI), 2.5–6.9) older than those in the moderate group, and 12 years (95% CI, 8.6–16) older than those in the mild group (see Table 1 for details). Similarly, participants in the moderate group were on average 7.4 years (95% CI, 3.9–11) older than those in the mild group. No differences in sex ratio and smoking history were found among the three groups. A lower prevalence of cardiac disease was observed in the mild group (0%) than in the moderate (10%) and severe (9.9%) groups ($P = 0.02$). The prevalence of renal disease was higher in the severe group (5.9%) than in the moderate (1.2%) and mild (0%) groups ($P < 0.01$). No differences were noted in the comorbidity rates for hypertension, diabetes, respiratory disease, cerebrovascular disease, malignant tumor, or psychiatric disease among the three groups (Table 1).

Table 1 Individuals' characteristics and comorbidities according to baseline severity.

	Mild	Moderate	Severe	*P* value
Number of cases	72	330	273	
Age at surgery	58 ± 12	65 ± 11	70 ± 11	<0.01
Sex (male, %)	68	68	66	0.85
Smoking history (%)	30	32	32	0.97
Comorbidities (%)				
Hypertension	39	41	47	0.27
Diabetes mellitus	11	21	23	0.09
Cardiac disease	0	10	9.9	0.02
Respiratory disease	8.3	3.3	5.1	0.16
Renal disease	0	1.2	5.9	<0.01
Cerebrovascular disease	1.4	2.7	4.4	0.33
Malignant tumor	4.2	4.5	6.6	0.48
Psychiatric disease	0	3.3	2.2	0.24

Surgical factors according to baseline severity

In the moderate and severe groups, ELAP was most frequently performed (41% and 41%, respectively), whereas the frequencies of DD (30% and 30%, respectively) and SL (29% and 29%, respectively) were almost equal. Conversely, people in the mild group most frequently underwent SL (46%) and the frequency of ELAP was lower (21%). The surgical techniques performed in the mild group were different from those in the other groups ($P = 0.01$). No difference in operation time or blood loss was found among the three groups. Moreover, no difference was observed in the complication rates for C5 palsy, surgical-site infection, hematoma, dural tear, delirium, or neurological deterioration among the three groups (Table 2).

Individuals' neurological outcomes according to baseline severity

As we divided the individuals into three groups according to baseline severity, the preoperative JOA scores in the mild group were on average 3.0 (95% CI, 2.8–3.3) higher than those in the moderate group, and 6.9 (95% CI, 6.6–7.2) higher than those in the severe group (see Table 2 for details). Similarly, participants in the moderate group were on average 3.8 (95% CI, 3.5–4.1) higher preoperative JOA scores than those in the severe group. The postoperative

Table 2 Surgical factors and neurological outcomes according to baseline severity.

	Mild	Moderate	Severe	*P* value
Surgical techniques (%)				0.01
ELAP	21	41	41	
DD	33	30	30	
SL	46	29	29	
Operation time (min)	113 ± 46	102 ± 42	100 ± 45	0.07
Blood loss (g)	39 ± 72	51 ± 96	47 ± 85	0.55
Complications (%)				
C5 palsy	1.4	3.0	1.1	0.35
Surgical-site infection	1.4	0.30	0.37	0.53
Hematoma	4.2	0.91	0.73	0.12
Dural tear	1.4	0	0	0.20
Delirium	0	0.61	1.1	0.91
Neurological deterioration	1.4	3.9	1.5	0.22
JOA scores				
Preop.	15 ± 0.58	12 ± 1.1	8.3 ± 1.7	<0.01
Postop.	16 ± 0.90	14 ± 1.6	13 ± 2.2	<0.01
Postop. minus Preop.	0.92 ± 0.95	2.3 ± 1.5	4.4 ± 2.2	<0.01

ELAP expansive open-door laminoplasty, *DD* double-door laminoplasty, *SL* selective laminectomy, *JOA* Japanese Orthopaedic Association, *Preop.* preoperatively, *Postop.* postoperatively.

JOA scores at the final follow-up in the mild group were on average 1.6 (95% CI, 1.3–2.0) higher than those in the moderate group, and 3.4 (95% CI, 3.0–3.8) higher than those in the severe group (see Table 2 for details). Similarly, people in the moderate group were on average 1.8 (95% CI, 1.4–2.2) higher postoperative JOA scores than those in the severe group. The preoperative-to-postoperative changes in JOA scores in the severe group were on average 2.0 (95% CI, 1.7–2.4) higher than those in the moderate group, and 3.4 (95% CI, 3.0–3.8) higher than those in the mild group (see Table 2 for details). Similarly, people in the moderate group were on average 1.4 (95% CI, 1.1–1.7) higher preoperative-to-postoperative changes in JOA scores than those in the mild group (Table 2). All three groups showed improvement in JOA scores postoperatively compared with the preoperative status (mild group: 0.92, 95% CI 0.7–1.2; moderate group: 2.3, 95% CI 2.2–2.5; severe group: 4.4, 95% CI 4.1–4.6).

Prediction model for unsatisfactory symptom state

We determined the predictors of postoperative unsatisfactory symptom state (postoperative JOA scores ≤ 14). According to the multivariate logistic regression analysis, the prediction model for unsatisfactory symptom states included preoperative JOA scores (odds ratio (OR) 0.60, 95% CI 0.55–0.67, $P < 0.01$) and age (OR 1.06, 95% CI 1.04–1.08, $P < 0.01$) (Table 3). The area under the ROC curve was 0.82, indicating good model prediction (Fig. 1). On the basis of the model, the cutoff values of the preoperative JOA scores were established depending on the combination of the values for age at surgery (Table 4). A representative combination of the thresholds to maximize the value of "sensitivity − (1 − specificity)" demonstrated that a preoperative JOA score of 11.5 is a predictor of unsatisfactory neurological outcomes in persons aged 67 years (mean age of the study cohort).

Discussion

To our knowledge, this is the first multicenter large cohort study to mainly focus on the usefulness of the baseline severity for predicting neurological outcomes after posterior decompression for CSM. According to baseline severity, the postoperative JOA scores were higher in the mild group and lower in the severe group, whereas age was younger in the mild group and older in the severe group. On the basis of the logistic regression analysis, the prediction model for postoperative unsatisfactory symptom state included preoperative JOA scores and age. According to the prediction model, a representative combination of the thresholds showed that a preoperative JOA score of ≤11.5 is one of the indicators of postoperative unsatisfactory symptom state in persons around the mean age of the study cohort (67 years).

When focusing on postoperative neurological outcomes after posterior decompression for CSM, four studies confirmed that baseline severity is an important predictor of neurological outcomes [10–13]. Two retrospective studies reported that lower preoperative JOA scores were associated with poor recovery rate of the JOA scores [10, 11]. Tanaka et al. reported that lower preoperative JOA scores increased the risk of lower postoperative JOA scores [12]. Uchida et al. found that a preoperative JOA score of <7 was associated with a decreased postoperative JOA score in multivariate analysis [13]. Conversely, two studies found that preoperative JOA scores were not significantly associated with the recovery rate of the JOA scores [18, 19]. The results vary in previous studies owing to the small sample size ($n = 79 \pm 30$, range 45–114), collection of data from a single center, and use of a single surgical procedure [10–13, 18, 19]. In the current multicenter large cohort study, logistic regression analysis demonstrated that severe baseline myelopathy was one of the predictors of postoperative unsatisfactory symptom state. It is consistent with most of the previous studies [10–13]. Although the preoperative-to-postoperative changes in JOA scores were the greatest in the severe group, the scores did not reach the

Table 3 Logistic regression analysis for unsatisfactory neurological outcomes.

	Univariate			Multivariate		
	OR	95% CI	*P* value	OR	95% CI	*P* value
Preoperative JOA scores	0.59	0.54–0.64	<0.01	0.60	0.55–0.67	<0.01
Demographic						
Age at surgery	1.07	1.05–1.08	<0.01	1.06	1.04–1.08	<0.01
Sex, male			0.85			
Smoking history	1.4	1.0–2.0	0.05			
Comorbidities						
Hypertension	0.64	0.47–0.87	<0.01			
Diabetes mellitus	0.53	0.36–0.78	<0.01			
Cardiac disease	0.42	0.24–0.75	<0.01			
Respiratory disease			0.50			
Renal disease			1.0			
Cerebrovascular disease			0.27			
Malignant tumor			0.27			
Psychiatric disease			0.58			
Surgical factors						
Surgical techniques			0.94			
Operation time			0.38			
Blood loss			0.71			
Complications						
C5 palsy			0.62			
Surgical-site infection			0.56			
Hematoma			0.45			
Dural tear			0.37			
Delirium			0.34			
Neurological deterioration			0.34			

OR odds ratio, *CI* confidence interval, *JOA* Japanese Orthopaedic Association.

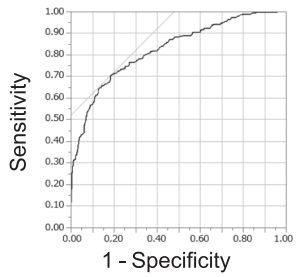

Fig. 1 ROC curve of the logistic regression prediction model for unsatisfactory neurological outcomes. The prediction model included preoperative JOA scores (OR 0.60, 95% CI 0.55–0.67, $P < 0.01$) and age (OR 1.06, 95% CI 1.01.1, $P < 0.01$). The area under the curve was 0.82.

Table 4 Combination of the thresholds based on the prediction model.

Preoperative JOA scores	Age at surgery
8	31
8.5	36
9	41
9.5	47
10	52
10.5	57
11	62
11.5	67
12	72
12.5	77
13	82

JOA Japanese Orthopaedic Association.

postoperative JOA scores seen in the mild or moderate group. The rationale behind the finding is that people with severe myelopathy may have irreversible damage due to demyelination and necrosis of the gray matter [8].

In the current study, multivariate logistic regression analysis was used to develop a prediction model for postoperative unsatisfactory symptom state (JOA scores ≤ 14). Because CSM is a progressive disease and has an insidious course, the best timing for surgery to ensure neurological recovery before the occurrence of irreversible changes in the spinal cord has been discussed [20, 21]. Based on the prediction model, a representative combination of the

thresholds demonstrated a preoperative JOA score of ≤11.5 as one of the predictors of unsatisfactory neurological outcomes in persons around the mean age of the study cohort (67 years). However, care must be taken concerning the surgical indication for nonmyelopathic individuals with evidence of cervical spinal cord compression and for persons with mild myelopathy. A recent guideline developed under the auspices of AOSpine North America and the Cervical Spine Research Society suggested that prophylactic surgery is not offered to nonmyelopathic individuals [14]. It also suggested that surgical intervention or nonoperative treatment for people with mild myelopathy (mJOA scores ≥ 15) because the desirable and undesirable surgical consequences are closely balanced or uncertain for such individuals [14]. As people with mild myelopathy may be hesitant to undergo surgery, the persons' preferences should be considered in the decision-making process for the treatment [14].

A prospective multicenter AOSpine international study that included 479 individuals with degenerative cervical myelopathy reported that older age was an independent predictor of poor surgical outcomes [22]. Consistent with the previous study, the multivariate logistic regression analysis demonstrated that both more severe baseline myelopathy and older age were the predictors of postoperative unsatisfactory symptom states in the present study. This could possibly be explained by the fact that persons who are older and have more severe disease exhibit major neuropathological alterations in the spinal cord [23].

In the current study, the prevalence of cardiac disease was lower in the mild group than in the other groups. A higher prevalence of renal disease was observed in the severe group than in the other groups. We suggest that the difference in age among the groups influenced the difference in the prevalence of these comorbidities, that is, older people generally have more cardiac or renal diseases.

We found that the surgical techniques performed in the mild group were different from those performed in the other groups. Whereas ELAP was most frequently performed in the moderate and severe groups, SL was most frequently chosen in the mild group. This may be due to the differences in surgical indications among the institute. Although a difference in the applied surgical techniques was observed among the groups, logistic regression analysis revealed that the surgical technique did not contribute to postoperative unsatisfactory symptom state.

Several limitations of the current study should be acknowledged. First, this was a retrospective study with an inherent selection bias. Second, the number of individuals in the mild group ($n = 72$) was relatively smaller than that in the moderate ($n = 330$) and severe ($n = 273$) groups. Third, the follow-up period was relatively short (at least 1 year after surgery) for a retrospective study. Fourth, the surgical indication and choice of surgical technique were left to the surgeons' discretion. Fifth, patient-based objective health-related quality-of-life outcomes were not acquired. Finally, the prediction model has not been validated on an external dataset to determine its predictive ability.

Conclusion

The current study indicates that severe baseline myelopathy and older age are predictors of postoperative unsatisfactory symptom state for CSM. Based on the prediction model, a representative combination of the thresholds showed that a preoperative JOA score of ≤11.5 is one of the predictors of postoperative unsatisfactory symptom state in people around the mean age of the study cohort (67 years).

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions SN and NN designed the research; SN, RT, and RK analyzed the data; SN, NN, and RK wrote the paper; HK, YK, NI, KN, TT, and YH performed data collection; OT, SS, EO, MY, MN, MM, KW, KI, and JY supervised the study; and all authors reviewed and approved the manuscript.

Compliance with ethical standards

Competing interests The authors declare that they have no conflict of interest.

Ethics approval This study received ethical approval from the institutional review boards of the participating institutions. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

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