Relationship between Enlargement of the Cross-Sectional Area of the Dural Sac and Neurological Improvements after Cervical Laminoplasty: Differences between Cervical Spondylotic Myelopathy and Ossification of the Posterior Longitudinal Ligament

Kazunari Takeuchi[1], Toru Yokoyama[1], Kan-ichiro Wada[2] and Hitoshi Kudo[2]

1) Department of Orthopedic Surgery, Odate Municipal General Hospital, Akita, Japan
2) Department of Orthopaedic Surgery, Hirosaki University School of Medicine, Aomori, Japan

Abstract:

Introduction: The purpose of this study was to investigate the relationship between postoperative enlargement of the dural sac cross-sectional area at the symptomatic level and neurological improvements after laminoplasty.

Methods: The cross-sectional areas of the dural sac at the symptomatic level before and after laminoplasty and the expansion ratio (post-/preoperative cross-sectional area) were measured using magnetic resonance imaging in patients with ossification of the posterior longitudinal ligament (OPLL) (n = 25) and patients with cervical spondylotic myelopathy (CSM) (n = 49). The relationships between the expansion ratio and the Japanese Orthopedic Association (JOA) score, JOA Cervical Myelopathy Evaluation Questionnaire (JOACMEQ), and postoperative laminae morphology were investigated.

Results: In the OPLL group, the expansion ratio was significantly positively correlated with the postoperative JOA score ($P = 0.025$), recovery rate of the JOA score ($P = 0.026$), and postoperative change in lower extremity sensory function according to the JOA score ($P = 0.0375$); furthermore, patients whose JOACMEQ responses indicated positive outcomes for lower extremity function had a significantly larger expansion ratio than patients with negative results ($P = 0.027$). In the CSM group, the expansion ratio showed no correlation with the JOA and JOACMEQ scores. The expansion ratio was significantly positively correlated with the width between bilateral gutters in both CSM ($P = 0.025$) and OPLL ($P = 0.0451$). In the OPLL group, the expansion ratio in those with a gutter position of less than 0.8 was significantly smaller than that those with a gutter position of more than 0.8 ($P = 0.0156$). However, there was no correlation between the gutter position and the recovery rate of the JOA score.

Conclusions: In OPLL, insufficient enlargement of the cross-sectional area of the dural sac at the symptomatic level leads to poor neurological improvements after laminoplasty.

Keywords:

cervical laminoplasty, surgical outcome, ossification of the posterior longitudinal ligament, cervical spondylotic myelopathy, Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire, magnetic resonance images, cross-sectional area, dural sac

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Introduction

Cervical laminoplasty is one of the standard treatments for cervical spondylotic myelopathy (CSM) or ossification of the posterior longitudinal ligament (OPLL), and reportedly produces stable long-term neurological improvement for cervical myelopathy[1-3]. Poor neurological improvements after laminoplasty can result from many patient-associated risk factors, including malalignment of the cervical spine[4-6], signal change of the spinal cord on magnetic resonance images (MRI)[6,7], anterior compressive factors in CSM[8], K-line (−) OPLL[9,10], or thick OPLL[11]. However, few reports have investigated the influence of variations in operative technique on neurological improvements after laminoplasty[12].

Corresponding author: Kazunari Takeuchi, t11161968@yahoo.co.jp
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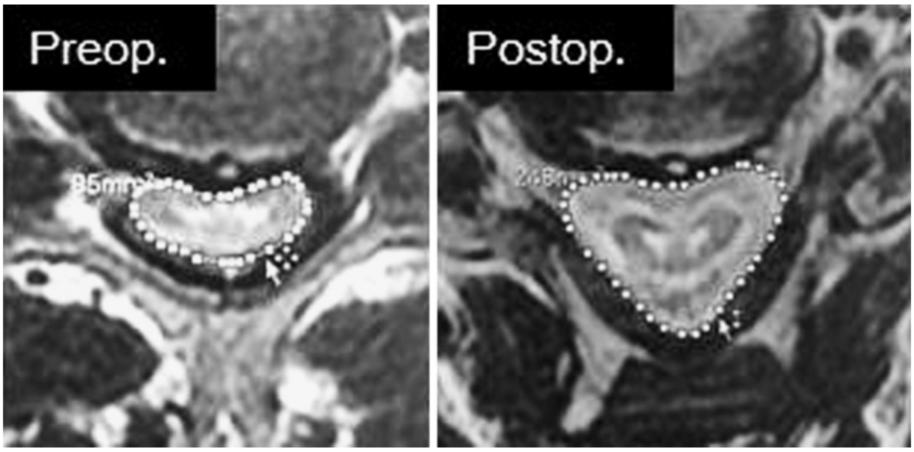

Figure 1. The cross-sectional area of the dural sac was measured on axial T2-weighted magnetic resonance images. Preop., preoperative; postop., postoperative

The concept of the laminoplasty procedure is to expand the spinal canal at consecutive multilevel segments of the cervical spine, and the degree of postoperative expansion of the dural sac is commonly evaluated by MRI. However, it is unknown how much influence the expansion of the dural sac at the neurologically symptomatic level actually has on the neurological improvements after laminoplasty.

This retrospective study investigated the relationship between postoperative expansion of the dural sac at the neurologically symptomatic level and neurological improvements after cervical laminoplasty in patients with CSM or OPLL.

Materials and Methods

Patients

The present study included 74 patients with cervical compressive myelopathy who underwent cervical laminoplasty at our institution from 2009 to 2015. All patients who completed 2 years of follow-up were included (follow-up rate: 85%). The patients with CSM were classified as the CSM group, comprising 28 males and 21 females with an average age at the time of surgery of 72 years (range, 50-88 years). The patients with OPLL were classified as the OPLL group, comprising 13 males and 12 females with an average age at the time of surgery of 66.2 years (range, 27-81 years). All the patients in the OPLL group had K-line (+) OPLL. All the procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration.

Operative technique and postoperative treatment

All the patients underwent C3 laminectomy with complete preservation of the semispinalis cervicis insertion at C2[13]. Laminoplasties of C4 to C7 were performed. The laminoplasty procedure was an adaptation of the spinous process-splitting laminoplasty using hydroxyapatite (HA) spinous process spacers (double-door type)[14]. We aimed to create gutters on the inside 1/3 of the facet joint, and used a micro-spatula to touch and confirm the inside of the facet joint from the spinal canal intraoperatively. Postoperatively, immobilization with a collar was not performed in any patient.

Cross-sectional area of the dural sac

The pre- and postoperative cross-sectional areas of the dural sac at all vertebrae and disk levels from C3 to C7/T1 were measured on T2-weighted axial MRI (Fig. 1) using XTREX VIEW (J-MAC System, Sapporo, Japan). The ratio of the postoperative cross-sectional area to the preoperative cross-sectional area (the "expansion ratio") was calculated as expansion ratio = postoperative cross-sectional area of the dural sac / preoperative cross-sectional area of the dural sac. The neurologically symptomatic level was diagnosed by evaluating the preoperative spinal cord evoked potential (SCEP). The SCEP was measured after electrical stimulation to the spinal cord, as described by Tani *et al*.[15] After local anesthesia was applied, a stimulating electrode and a recording electrode with platinum tips were introduced into the dorsal epidural space at the lower thoracic level and the C3 level, respectively. Recordings were obtained simultaneously at the C3, C3/4, C4, C4/5, C5, C5/6, C6, C6/7, C7, and C7/T1 levels. Each test set comprised an adding frequency of 50 times, with a stimulation frequency of 30 Hz and a stimulus intensity of 7-10 mA. A level was defined as neurologically symptomatic when the negative peak increased at the immediately caudal level, and the negative peak decreased at the immediately cranial level. Table 1 shows the distributions of the neurologically symptomatic level. The cross-sectional area of the dural sac was measured by the same author (K.T.) twice on different days, and SPSS software was used to calculate intraobserver reliability. The intraclass correlation coefficient for measurement of the cross-sectional area of the dural sac was 0.933, indicating a good intraobserver reliability.

The correlations between the SCEP findings and the smallest cross-sectional area of the dural sac on the preop-

Table 1. Distributions of the Neurologically Symptomatic Level.

	C3/4	C4/5	C5/6	C6/7	C7/T1
Number in the CSM group (%) (n=49)	10 (20)	17 (35)	16 (33)	4 (8)	2 (4)
Number in the OPLL group (%) (n=25)	4 (16)	6 (24)	13 (52)	2 (8)	0

CSM: cervical spondylotic myelopathy; OPLL: ossification of the posterior longitudinal ligament

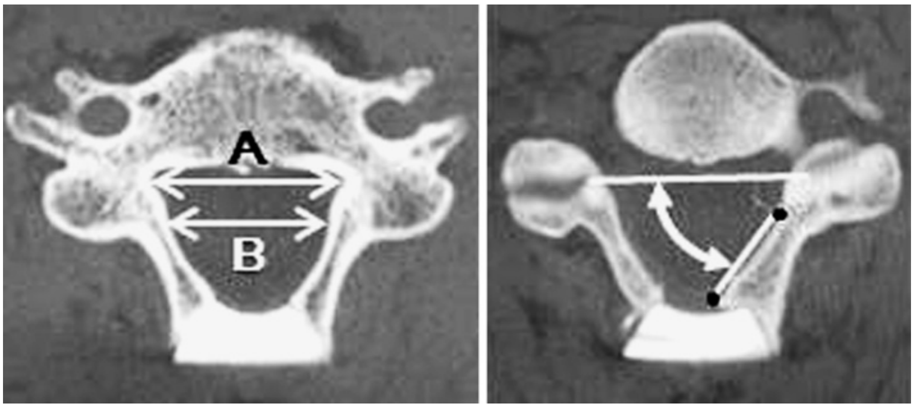

Figure 2. The width between bilateral gutters (left) and the inclination angle of the lamina (right) were measured on axial computed tomography images. A indicates the transverse diameter of the spinal canal, while B indicates the inside distance between bilateral gutters.

erative MRI, and between the SCEP findings and the spinal cord high-signal intensity changes on T2-weighted MRI were also investigated.

Neurological evaluations

The pre- and postoperative Japanese Orthopedic Association (JOA) scores and the recovery rate of the JOA score were investigated in all the patients. The recovery rate of the JOA score was calculated as: recovery rate (%) = (postoperative JOA score-preoperative JOA score) / (17-preoperative JOA score) × 100. In addition, improvements in the six individual JOA-score items (motor functions of the upper and lower extremities, sensory functions of the upper and lower extremities and the trunk, and bladder function) were investigated.

Pre- and postoperative JOA Cervical Myelopathy Evaluation Questionnaire (JOACMEQ)[16] findings were investigated in all the patients. Improvements in the five individual JOACMEQ domains (cervical spine function, upper extremity function, lower extremity function, bladder function, and quality of life) were investigated. According to the JOACMEQ exclusion criteria, patients whose pre- and postoperative scores were both ≥ 90 points were excluded from the analysis. The software provided by the JOA was used to calculate the functional score of each domain. The treatment was defined as "effective" if either 1) the postoperative score increased by more than 20 points compared with the preoperative score, or 2) the preoperative score was < 90 and the postoperative score was ≥ 90 points; the treatment was defined as "ineffective" if neither of these two conditions were satisfied. The relationship between postlaminoplasty neurological improvements and the cross-sectional areas of the dural sac at the symptomatic level was investigated.

The relationships between the expansion ratio at the asymptomatic levels and the gutter position, and between the expansion ratio at the asymptomatic levels and the recovery rate of the JOA score were investigated.

Gutter position and laminar inclination angle

Postoperative computed tomography (CT) was used to measure the width between bilateral gutters and the inclination angle of the lamina. The gutter position was defined as the inside distance between bilateral gutters / the transverse diameter of the spinal canal (Fig. 2). The inclination angle of the lamina was measured as the angle created by the line between bilateral facet joints and the line between the rising point of the inside of the lamina and the inside corner of the lamina of the spacer side (Fig. 2). The intraclass correlation coefficients for measurements of the gutter position and the inclination angle of the lamina were calculated via the same method as for the cross-sectional of the dural sac. The intraclass correlation coefficients for measurements of the gutter position and the inclination angle of the lamina were 0.989 and 0.971, respectively, indicating good intraobserver reliabilities.

The relationships between postoperative C5 palsy and the gutter position (C4 or C5), and between C5 palsy and the inclination angle of the lamina (C4 or C5) were investigated. C5 palsy was defined as new deterioration of muscle strength of the deltoid and/or the biceps brachii[17].

Table 2. Pre- and Postoperative Cross-Sectional Areas of the Dural Sac and the Expansion Ratio.

	CSM group (n=49)	OPLL group (n=25)	*P* value
Preoperative cross-sectional area (mm^2)	97.0±32.0	106.2±24.2	0.2111
Postoperative cross-sectional area (mm^2)	170.1±48.2	178.5±40.3	0.4572
Expansion ratio	1.87±0.65	1.73±0.38	0.3165

CSM: cervical spondylotic myelopathy; OPLL: ossification of the posterior longitudinal ligament

Postoperative anterior compression of the spinal cord

The MRI in both of the groups was used to evaluate the presence of postoperative anterior compression of the spinal cord (ACS) at the neurologically symptomatic level. The relationships between ACS and the disease (CSM or OPLL), and between ACS and the gutter position (< 0.8 or ≥ 0.8) were investigated.

Postoperative neurological improvement

Factors related to postoperative neurological improvement were investigated, including pre- and postoperative C2-C7 lordotic angle, postoperative change in C2-C7 lordotic angle, intervertebral range of motion (ROM) or instability at the symptomatic level, K-line (−) in the neck-flexed position[10], and occupying ratio of the OPLL[11]. The C2-C7 lordotic angle was measured on lateral radiography of a neutral view of the cervical spine using the posterior tangents of the C2 and C7 vertebral bodies. Postoperative intervertebral ROM and instability were measured on the lateral flexion and the extension radiographs of the cervical spine using the posterior tangents of the vertebral bodies at the symptomatic level; instability was measured as the anteroposterior distance between the two posterior tangents. In the OPLL group, the differentiation between K-line (+) OPLL or K-line (−) OPLL was determined in the neck-flexed position on lateral radiography[10]. The occupying ratio of the OPLL[11] relative to the anteroposterior diameter of the spinal canal was calculated as: occupying ratio (%) = thickness of the OPLL (mm) / anteroposterior diameter of the spinal canal (mm); measurements were made on sagittal plane preoperative CT. XTREX VIEW (J-MAC System) was used to make all the assessments of factors related to postoperative neurological improvement. The relationships between these factors and the postoperative recovery rate of the JOA score were investigated.

Statistical analysis

The Student's *t*-test, χ^2 test and Spearman rank-order correlation were used to conduct the statistical analyses. Differences with a *P* value of < 0.05 were considered statistically significant.

Results

Pre- and postoperative cross-sectional area of the dural sac and the expansion ratio

Table 2 shows the mean pre- and postoperative cross-sectional areas of the dural sac, and the mean expansion ratio at the symptomatic level in both of the groups. None of these values differed significantly between the two groups.

Relationship between SCEP findings and MRI findings

The intervertebral level of the smallest preoperative cross-sectional area of the dural sac (i.e., the maximum compression level) was recognized as the symptomatic level using SCEP in 67% (33 of 49 patients) in the CSM group, and 60% (15 of 25) in the OPLL group. Putting both of the groups together, the intervertebral level with the smallest preoperative cross-sectional area of the dural sac was judged as the symptomatic level by SCEP examination in 48 (65%) of 74 patients. In the CSM group, 26 (53%) of 49 patients had a spinal cord signal change, this occurred at the SCEP level in 24 patients (92%), but not in two (8%). In the OPLL group, 11 (44%) of 25 patients had a spinal cord signal change, this occurred at the SCEP level in all patients. Putting both of the groups together, the intervertebral level of the spinal cord signal change was judged as the symptomatic level by SCEP examination in 35 (95%) of 37 patients.

Relationship between the cross-sectional area of the dural sac and neurological improvements

The mean pre- and postoperative JOA scores in the CSM group were 9.4 and 12.6 points, respectively, and the mean recovery rate of the JOA score was 41.4%. The mean pre- and postoperative JOA scores in the OPLL group were 11.4 and 13.4 points, respectively, and the mean recovery rate of the JOA score was 35.3%. There was no significant difference between groups in the mean JOA score recovery rate. In the CSM group, there were no significant correlations between the expansion ratio at the symptomatic level and the postoperative JOA score or the recovery rate of the JOA score (Fig. 3) or any the six individual JOA-score items. In the OPLL group, the expansion ratio at the symptomatic level was significantly positively correlated with the postoperative JOA score (*P* = 0.025), the recovery rate of the JOA score (*P* = 0.026), and the postoperative change in lower ex-

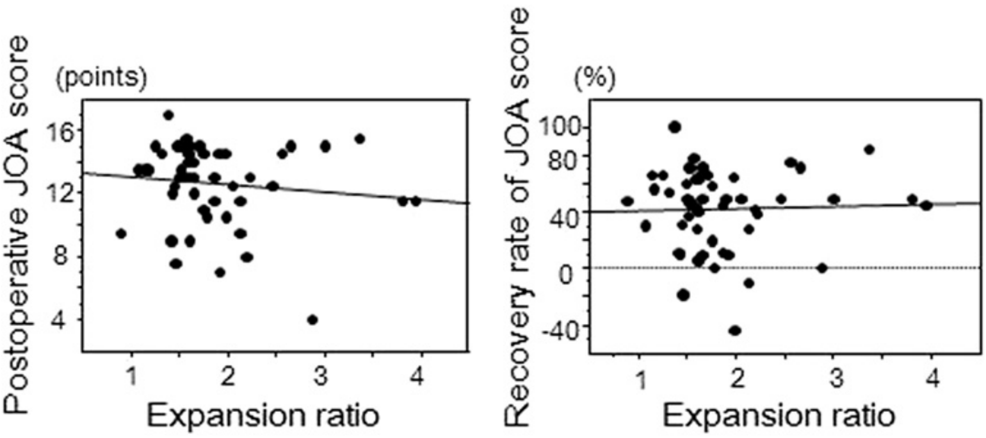

Figure 3. Relationships of the expansion ratio with the postoperative JOA score and the recovery rate of the JOA score in the CSM group. JOA, Japanese Orthopedic Association; CSM, cervical spondylotic myelopathy

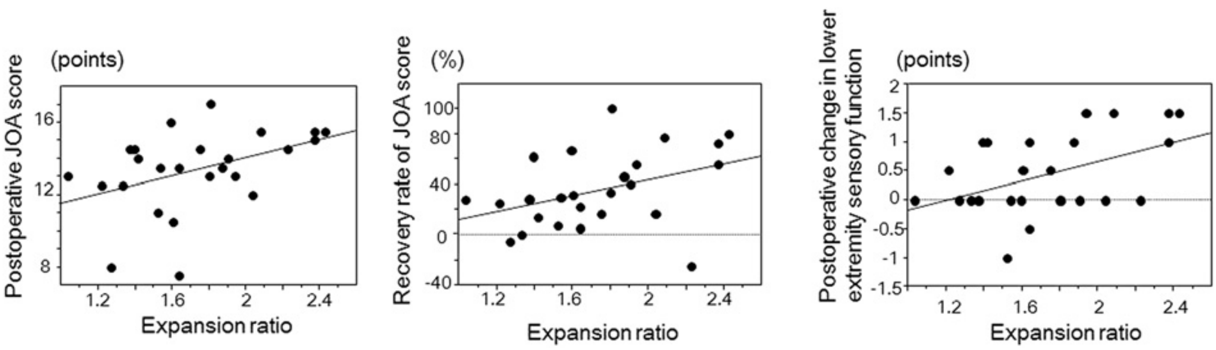

Figure 4. Relationships of the expansion ratio with the postoperative JOA score, the recovery rate of the JOA score, and the postoperative change in lower extremity sensory function in the OPLL group. JOA, Japanese Orthopedic Association; OPLL, ossification of the posterior longitudinal ligament

Table 3. Relationships between the Mean Expansion Ratio and the JOACMEQ Outcomes.

		Cervical spine function	Upper extremity function	Lower extremity function	Bladder function	Quality of life
Expansion ratio of the CSM group (number)	Excluded	(12)	(10)	(6)	(6)	(0)
	Effective	1.79 (14)	1.80 (15)	2.03 (9)	1.79 (16)	1.57 (7)
	Ineffective	1.91 (23)	1.98 (24)	1.89 (34)	1.93 (27)	1.92 (42)
	P value	0.5305	0.4479	0.5937	0.4427	0.1948
Expansion ratio of the OPLL group (number)	Excluded	(5)	(4)	(7)	(4)	(0)
	Effective	1.72 (7)	1.83 (4)	1.96 (5)	1.68 (5)	1.80 (7)
	Ineffective	1.67 (13)	1.66 (17)	1.54 (13)	1.69 (16)	1.70 (18)
	P value	0.7852	0.4509	0.0270	0.9756	0.5714

JOACMEQ: Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire; CSM: cervical spondylotic myelopathy; OPLL: ossification of the posterior longitudinal ligament

tremity sensory function (P = 0.0375) (Fig. 4). Table 3 shows the relationships between the expansion ratio and the JOACMEQ findings in both of the groups. In the CSM group, there were no significant relationships between the pre- or postoperative cross-sectional areas of the dural sac or the expansion ratio at the symptomatic level and all five domains of the JOACMEQ. In the OPLL group, patients whose JOACMEQ responses indicated effective treatments for lower extremity function had a significantly larger mean expansion ratio at the symptomatic level (1.96) than patients with ineffective treatments (1.54; P = 0.027). These results indicate that a smaller expansion ratio resulted in poorer postoperative improvement of lower extremity function. Of the 13 patients whose JOACMEQ responses indicated ineffective treatments for lower extremity function, six were insufficiently improved (postoperative score was less than 20

Table 4. Mean Gutter Position and Inclination Angle of the Laminae at the Symptomatic Level.

	CSM group	OPLL group	*P* value
Gutter position	0.79±0.85	0.78±0.69	0.9106
Inclination angle of the smaller side (degrees)	52.1±7.2	51.9±6.0	0.9517
Inclination angle of the larger side (degrees)	60.8±7.6	61.2±36.7	0.8509
Mean inclination angle of both sides (degrees)	56.4±6.2	56.6±4.5	0.9356

CSM: cervical spondylotic myelopathy; OPLL: ossification of the posterior longitudinal ligament

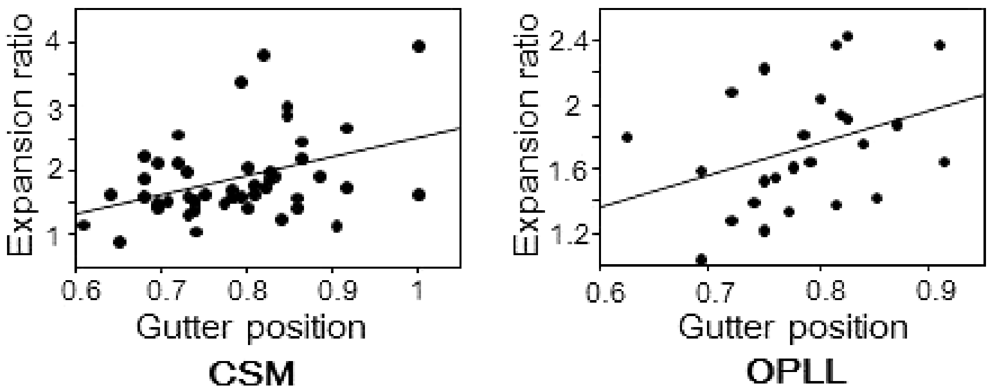

Figure 5. Relationship between the expansion ratio and the gutter position in the CSM and OPLL groups. CSM, cervical spondylotic myelopathy; OPLL, ossification of the posterior longitudinal ligament

points higher than the preoperative score), and seven were deteriorated postoperatively.

In both of the groups, the expansion ratio was not correlated with the recovery rate of the JOA score at the asymptomatic levels (196 levels in the CSM group, 100 levels in the OPLL group).

Relationship between the expansion ratio and the gutter position or laminar inclination angle

The mean gutter position, inclination angle of the smaller side or larger side, and mean inclination angle of both sides at the symptomatic level did not differ between the groups (Table 4). In both of the groups, the gutter position was significantly positively correlated with the expansion ratio at the symptomatic level (P = 0.025 in the CSM group, and P = 0.0451 in the OPLL group) (Fig. 5). In both of the groups, there was no correlation between any measurement of the inclination angle of the lamina and the expansion ratio at the symptomatic level. In the OPLL group, the expansion ratio in those with a gutter position of less than 0.8 was significantly smaller than that those with a gutter position of more than 0.8 (1.58 versus 1.94; P = 0.0156) (Fig. 6). However, there was no correlation between gutter position and the recovery rate of the JOA score at the symptomatic level in either of the two groups (Fig. 7).

At the asymptomatic levels, the gutter position was significantly positively correlated with the expansion ratio in both the CSM group (P < 0.0001) and the OPLL group (P = 0.0179).

Relationship between postoperative C5 palsy and postoperative laminae morphology

Six of the total 74 cases (8.1%) had postoperative C5 palsy. The incidence of postoperative C5 palsy did not significantly differ between the CSM group (five of 49; 10.2%) and the OPLL group (one of 25; 4%). Postoperative C5 palsy was not significantly correlate with the gutter position (C4 or C5) or the inclination angle of the lamina (C4 or C5) in either group.

Relationships between postoperative anterior compression of the spinal cord and the diseases, or the gutter positions

The incidence of postoperative ACS was significantly larger in the OPLL group (13 patients; 52%) than in the CSM group (seven patients; 14%) (P = 0.0015). Postoperative ACS was present in nine patients (27%) with a gutter position ≥ 0.8, and in 11 patients (31%) with a gutter position < 0.8; there was no significant relationship between ACS and gutter position.

Relationships between neurological improvement and the recovery rate of the JOA score

Table 5 summarizes the factors related to postoperative neurological improvement. Pre- and postoperative C2-C7 lordotic angle, postoperative decrease in C2-C7 lordotic angle, and postoperative intervertebral instability did not differ significantly between the two groups, and these factors were not correlated with the recovery rate of the JOA score in

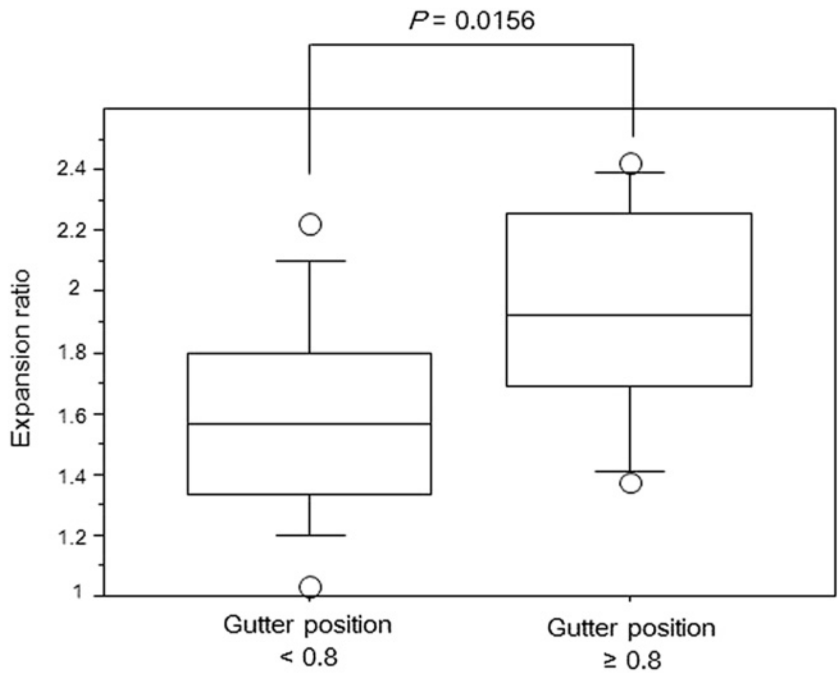

Figure 6. Relationship between the expansion ratio and the gutter position in the OPLL group. OPLL, ossification of the posterior longitudinal ligament

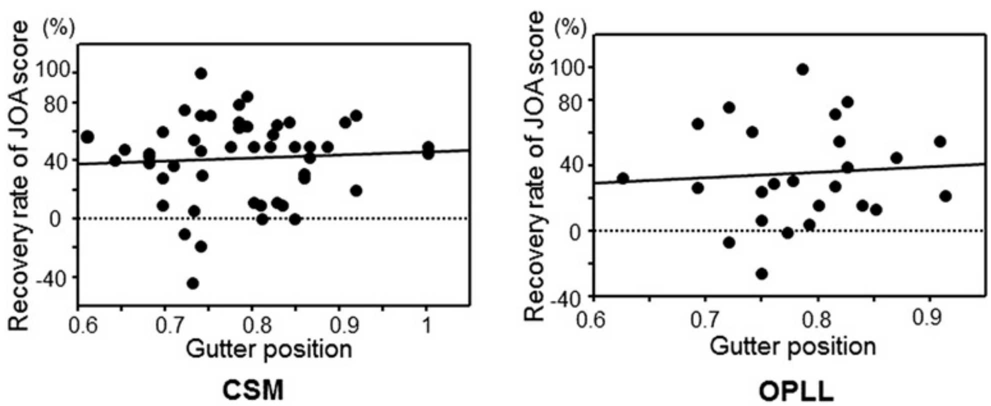

Figure 7. Relationship between the gutter position and the recovery rate of the JOA score in the CSM and OPLL groups. JOA, Japanese Orthopedic Association; CSM, cervical spondylotic myelopathy; OPLL, ossification of the posterior longitudinal ligament

Table 5. Related Factors for Neurological Outcomes.

	CSM group	OPLL group	*P* value
Preoperative C2-C7 lordotic angle (degrees)	17.6±14.3	13.2±7.6	0.1523
Postoperative C2-C7 lordotic angle (degrees)	20.8±14.3	16.9±10.7	0.2301
Postoperative change in C2-C7 lordotic angle (degrees)	−3.21±9.5	−3.7±9.7	0.8277
Postoperative intervertebral ROM (degrees)	5.8±4.4	3.3±3.6	0.0157
Postoperative intervertebral instability (mm)	0.8±1.1	0.7±0.9	0.8305
K-line in the neck-flexed position (number)	-	plus: (9), minus: (16)	-
Occupying ratio of OPLL (%)	-	33.3±12.1	-

CSM: cervical spondylotic myelopathy; OPLL: ossification of the posterior longitudinal ligament; ROM: range of motion

either group. The mean postoperative intervertebral ROM at the symptomatic level in the CSM group was significantly larger than that in the OPLL group (P = 0.0157). The CSM group showed no correlation between the postoperative in-

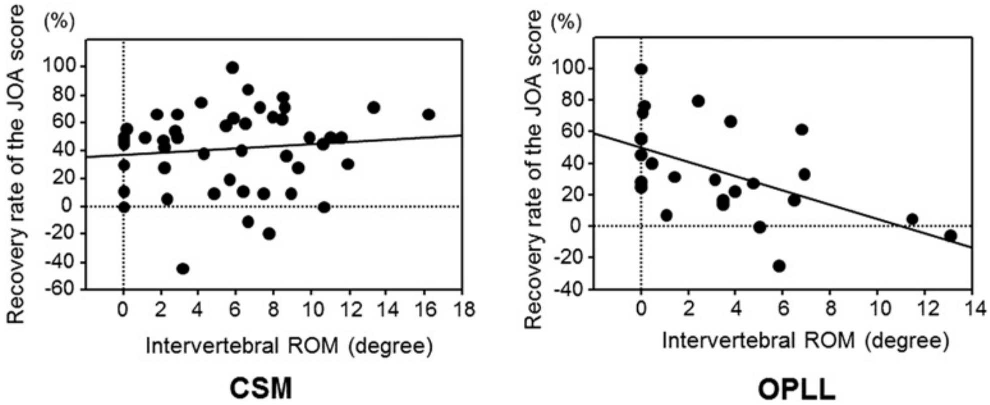

Figure 8. Relationship between the postoperative intervertebral ROM at the neurologically symptomatic level and the recovery rate of the JOA score in the CSM and OPLL groups. ROM, range of motion; JOA, Japanese Orthopedic Association; CSM, cervical spondylotic myelopathy; OPLL, ossification of the posterior longitudinal ligament

tervertebral ROM at the symptomatic level and the recovery rate of the JOA score; however, the postoperative intervertebral ROM at the symptomatic level was significantly negatively correlated with the recovery rate of the JOA score in the OPLL group (P = 0.0098) (Fig. 8). The K-line in the neck-flexed position and the occupying ratio of the OPLL were not correlated with the recovery rate of the JOA score in the OPLL group.

Discussion

The postoperative enlargement of the spinal cord at the maximum compression level measured on CT myelography is reportedly related to neurological improvements[18-20]. However, recently, many studies have reported no correlation between the cross-sectional area of the spinal cord on MRI and neurological outcomes after laminoplasty[21,22]. Therefore, the prognostic significance of the transverse area of the spinal cord after laminoplasty remains controversial. In the present study, the smallest preoperative cross-sectional area (i.e., the maximum compression level) was recognized as the neurologically symptomatic level by SCEP examinations in 65% only of patients, while the intervertebral level with high-intensity spinal cord change were recognized as the symptomatic level by SCEP examination in 95% of patients. This suggests that the previous reports that adopted the maximum compression level as the neurologically symptomatic level might not have assessed the neurologically symptomatic level accurately. Regarding the dural sac, satisfactory decompressions were previously demonstrated by a significantly increased sagittal diameter and cross-sectional area of the dural sac together with a significant drift-back distance of the spinal cord in 116 CSM[23] patients after laminectomy and laminoplasty hybrid decompression, and in 82 OPLL[24] patients after extensive laminectomy. This suggests that the postoperative cross-sectional area of the dural sac at the symptomatic level can be a predictor of postoperative neurological outcome.

The present study aimed to examine the relationship between insufficient enlargement of the cervical spinal canal after laminoplasty (which was caused by poor surgical technique) and postoperative poor neurological improvement. The insufficient enlargement of the cervical spinal canal is suggested by bony spinal canal parameters including the narrower gutter position, the smaller inclination angle of the laminae, and the smaller HA spinous process spacers, which surgeons can control artificially intraoperatively. However, we could not accurately measure the cross-sectional area of the bony spinal canal after double-door laminoplasty, as the lifted laminae and HA spinous process spacers cannot be accurately viewed together on an axial slice of the relevant intervertebral disc due to the drooping form of the laminae. Therefore, we considered that the cross-sectional area of the dural sac would reflect the postoperative morphology of the bony spinal canal after laminoplasty, and we assessed the enlargement of the dural sac at the neurologically symptomatic level after laminoplasty. To the authors' knowledge, no report has described the relationship between the postoperative enlargement of the dural sac at the symptomatic level (recognized by SCEP) measured on MRI and postoperative outcomes assessed via the JOACMEQ.

In the present study, the postoperative dural sac enlargement was significantly related to the postoperative JOA score, recovery rate of the JOA score, lower extremity sensory function item in the JOA score, and JOACMEQ outcomes in the OPLL group. The incidence of postoperative ACS was significantly larger in the OPLL group than in the CSM group. Although the mean postoperative intervertebral ROM at the symptomatic level in the OPLL group was significantly smaller than that in the CSM group, the postoperative intervertebral ROM at the symptomatic level was significantly negatively correlated with the recovery rate of the JOA score only in the OPLL group. The dural sac was evaluated on MRI only with the neck in neutral position; hence, the postoperative ACS and postoperative intervertebral ROM might have influenced the postoperative outcomes in the OPLL group in the present study. The longitudinal distance of the cervical spine in patients with OPLL is also reportedly longer than that in patients with CSM.[25] The tense spinal cord might be easily stimulated by the postoperative anterior compression of the OPLL and the smaller intervertebral ROM in the OPLL group. Furthermore, postoperative ACS might newly appear in the neck flexion and/or extension position in patients with small enlargement of the dural sac in the OPLL group because the OPLL in many cases actually made contact with the spinal cord without compression at the symptomatic level. In contrast, the postoperative enlargement of the dural sac at the symptomatic level in the CSM group did not correlate with the postoperative neurological outcome in the present study. The CSM group had a significantly larger postoperative intervertebral ROM at the symptomatic level than the OPLL group; hence, postoperative dural sac enlargement might not influence the postoperative neurological outcomes, as the incidence of postoperative ACS in the CSM group was originally less than that in the OPLL group. Furthermore, the redundant spinal cord in multiple cervical spondylosis[25] might not be stimulated by the larger postoperative intervertebral ROM in the CSM group. Further study is required using MRI in the neck flexion or extension position in patients in both of the groups.

In the present study, a smaller enlargement of the dural sac was significantly correlated with poorer lower extremity sensory function, but not with lower extremity motor function in the OPLL group. Furthermore, the outcome of the lower extremity function JOACMEQ domain correlated with the enlargement of the dural sac. Although the JOA scores clearly divide the lower extremity functions into motor or sensory, the JOACMEQ lower extremity function domain does not. If the persistence of ACS is correlated with the intervertebral ROM as mentioned above, the lack of improvement in lower extremity function in the JOACMEQ after laminoplasty in the OPLL group in the present study may be due to poorer lower extremity sensory improvements caused by disruption of the anterior funiculus (including the anterior spinothalamic tract of the spinal cord) after laminoplasty due to insufficient postoperative enlargement of the dural sac at the neurologically symptomatic level.

The current study has several limitations. The biggest limitation was the small study population. Furthermore, the follow-up duration was short. As OPLL reportedly elongates[26] and thickens[27] after laminoplasty, longer-term investigations are necessary. Additionally, the cross-sectional area or morphology of the spinal cord were not evaluated; the transverse area of the spinal cord at the maximum compression level on CT myelography reportedly related to postoperative neurological outcomes[18-20]. Postoperative movement of the spinal cord in the neck flexion or extension position was also not examined; postoperative ACS might newly appear on MRI in the neck flexion or extension position, even if ACS was not confirmed on MRI in the neck neutral position. In addition, the morphology of the lamina was measured only at 2 years postoperatively; as the opening angle of the lamina after Hirabayashi open-door laminoplasty reportedly decreases by 10.2% at 6 months postoperatively[28], the morphology of the lamina immediately after surgery should be evaluated.

Conclusions

Insufficient enlargement of the cross-sectional area of the dural sac at the neurologically symptomatic level in the OPLL group led to poor neurological improvements, as evaluated using postoperative JOA score, recovery rate of JOA score, and postoperative change in lower extremity sensory function in the JOA scoring system and the JOACMEQ. Poor JOACMEQ outcome for lower extremity function was related to a small expansion ratio at the symptomatic level. The width between bilateral gutters was related to the expansion ratio.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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