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Comparison of Radiological and Functional Changes After Multi-Level Laminoplasty Between Cervical Spondylotic Myelopathy and Ossification of the Posterior Longitudinal Ligament

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ABSTRACT

AIM: To compare the radiological and functional changes after multi-level laminoplasty between patients with cervical spondylotic myelopathy (CSM) and ossification of the posterior longitudinal ligament (OPLL).

MATERIAL and METHODS: This study included 75 patients consisted with 32 of CSM (group A) and 43 of OPLL (group B) presenting a preserved cervical sagittal balance who underwent multi-level laminoplasty for cervical myelopathy. The radiological outcomes were analyzed with the following radiological parameters: C2–C7 Cobb angle in neutral (C2-7AN), flexed (C2-7AF), and extended (C2-7AE) neck postures; C2–C7 range of motion (C2-7ROM); T1 slope (T1S); and C2–C7 sagittal vertical axis (C2-7SVA). The functional outcomes were analyzed with the modified Japanese Orthopedic Association (mJOA) score, Nurick grade, and recovery rate. The radiological and functional outcomes between the two groups were evaluated at 12-month postoperatively.

RESULTS: There were statistically significance increase of C2-7SVA in group A; and decrease of C2-7AF and C2-7ROM in group A and C2-7ROM in group B postoperatively ($p<0.05$). However, C2-7AN showed no statistically significant inter-group differences and postoperative intra-group changes in both groups ($p>0.05$). There were no statistically significant differences in the postoperative functional outcomes including mJOA score ($p=0.251$), Nurick grade ($p=0.316$), and recovery rate ($p=0.435$) between the two groups.

CONCLUSION: Although there were no statistically significant differences in functional outcomes between the two groups, the group A showed a greater deterioration in sagittal balance with an increase of C2-7SVA than the group B after multi-level laminoplasty.

KEYWORDS: Cervical spondylotic myelopathy, OPLL, Laminoplasty, Cervical spine

INTRODUCTION

Laminoplasty is an effective surgical method for the treatment of degenerative cervical myelopathy. It was developed to avoid the problems associated with laminectomy, such as postoperative kyphotic change, segmental instability, and perineural adhesions (4). Nevertheless, one of the morbidities after laminoplasty is the postoperative loss of cervical lordosis and straightening of the cervical spine (12). This postoperative kyphotic change in the cervical curvature has a negative effect on the clinical outcome, and maintaining postoperative cervical lordosis is important for spinal cord decompression as a result of the posterior shift of the spinal cord (12,22).

Recently, the T1 slope (T1S) and C2–C7 sagittal vertical axis (C2-7SVA) have suggested as predictors of kyphotic cervical change after laminoplasty. Kim et al. reported that a higher preoperative T1S is associated with postoperative kyphotic cervical changes in ossification of the posterior longitudinal ligament (OPLL) (10). Lin et al. reported that a higher preoperative T1S and greater C2-7SVA indicate a higher risk of

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postoperative cervical malalignment in cervical spondylotic myelopathy (CSM) (12). Many previous studies have examined the relationship between preoperative radiological parameters and changes of sagittal alignment after laminoplasty.

Thus far, most previous studies have focused on the overall postoperative changes in patients with cervical myelopathy without distinguishing between CSM and OPLL. Few reports have compared the outcomes between CSM and OPLL after laminoplasty. In this study, we analyzed the radiological and functional outcomes after multi-level laminoplasty between patients with CSM and OPLL who had preserved preoperative sagittal balance and similar neurological status.

MATERIAL and METHODS

This study was approved by the institutional review board (No. 2020-02-039), which waved the requirement for informed consent due to retrospective design.

Study Design and Patient Population

This study included consecutive patients who underwent cervical laminoplasty for cervical myelopathy caused by CSM (group A) or OPLL (group B) under preserved lordotic cervical curvature and no dynamic instability between February 2013 and October 2018 in a single tertiary institution. Cervical myelopathy was confirmed based on the clinical symptoms, neurological examination, electrophysiological study, and magnetic resonance imaging (MRI). All patients underwent lateral radiographs including dynamic views, computed tomography (CT), and MRI preoperatively. Patients presenting with cervical myelopathy related with spinal cord tumor, infection, traumatic cervical cord injury, cervical spine deformities, myelitis, syringomyelia, and prior cervical surgeries were excluded. In addition, we also excluded patients in whom the C7 vertebral body was not observed in the preoperative imaging studies. All patients underwent open-door laminoplasty using a plate system (CENTERPIECE plate, Medtronic Sofamor Danek, Memphis, TN, USA) for treating cervical myelopathy and were followed up for 12 months. The collected demographic data included age on the day of surgery, sex, duration of symptoms, and body mass index. All clinical and radiological data of the electronic charts were obtained and reviewed retrospectively under the approval by the institutional review board.

Surgical Procedure

Patient was placed prone with the cervical spine in neutral, and the head was supported by a Mayfield head frame. Midline incision and subperiosteal dissection of posterior muscles were performed from the spinous process to the medial portion of lateral mass while preserving the muscles attached to C2 and C7. After exposing the posterior bony structures, the open side of lamina was drilled to a thin layer, which was then resected with a 1-mm Kerrison punch. On the contralateral hinge side, partial-thickness of the lamina was drilled so that it was thin enough to bend. The open side was determined by the side which was more symptomatic or showed greater cord compression. After the lamina door was elevated, the expanded spinal canal was supported and fixed using titanium miniplates and screws (CENTERPIECE plate) on the open side. All patients wore a Philadelphia neck collar for 2 months postoperatively.

Radiological Assessment

Neutral and dynamic lateral radiographs were obtained sequentially. Dynamic radiographs were taken by positioning patient's neck in complete flexion and extension. Cervical sagittal balance was evaluated with the following radiological parameters: C2-7SVA, T1S, C2–C7 Cobb angle (C2-7AN in neutral, C2-7AF in flexed, and C2-7AE in extended neck postures), and C2–C7 range of motion (C2-7ROM). C2-7SVA was measured as the horizontal distance between the C2 plumb line and the posterior-superior aspect of C7 (27). C2-7AN was measured as the sagittal Cobb angle of the lower endplate of C2 and C7 in the natural position. C2-7AF and C2-7AE were measured in the same way on dynamic radiographs. The measurement of radiological parameters is presented in Figure 1A, B. Lordosis and kyphosis were recorded as positive and negative values, respectively. C2-7ROM was measured as the difference between C2-7AE and C2-7AF, while T1S was measured as the angle between the horizontal plane and the superior T1 endplate in the preoperative sagittal view of CT. Postoperative loss of cervical lordosis was defined based on the difference between preoperative C2-7AN and postoperative C2-7AN. All measurements were performed based on the digitalized radiographic data by two independent spine surgeons, which were averaged to provide us the final measurements for the radiological parameters.

Functional Assessment

The preoperative status of cervical myelopathy and postoperative outcome were assessed using a modified Japanese Orthopedic Association (mJOA) score and Nurick grade. The mJOA score is obtained using 18-point scale wherein 5 points represent upper extremity motor function, and 7 points represent lower extremity motor function, 3 points represent sensation, and 3 points represent micturition (1). The Nurick grade is classified into six grades as follows: 0, signs or symptoms of root involvement but with no evidence of spinal cord disease; 1, signs of spinal cord disease but no difficulty in walking; 2, slight difficulty in walking that does not prevent full-time employment; 3, difficulty in walking that prevents full-time employment or the ability to perform housework but is not severe enough to require assistance when walking; 4, able to walk with assistance; and 5, chair bound or bedridden (13). The recovery rate was calculated using the formula established by Hirabayashi et al. [postoperative - preoperative mJOA score/18 - preoperative mJOA score × 100 (%)] (3).

Statistical Analysis

Student's *t*-test for parametric continuous variables and Mann–Whitney U test for non-parametric continuous variables were used to compare the two population means. The chi-square test was used to assess the relationship between categorical variables, and repeated-measures analysis of variances (ANOVA) was used for parametric continuous variables changing over time to compare the two population means.

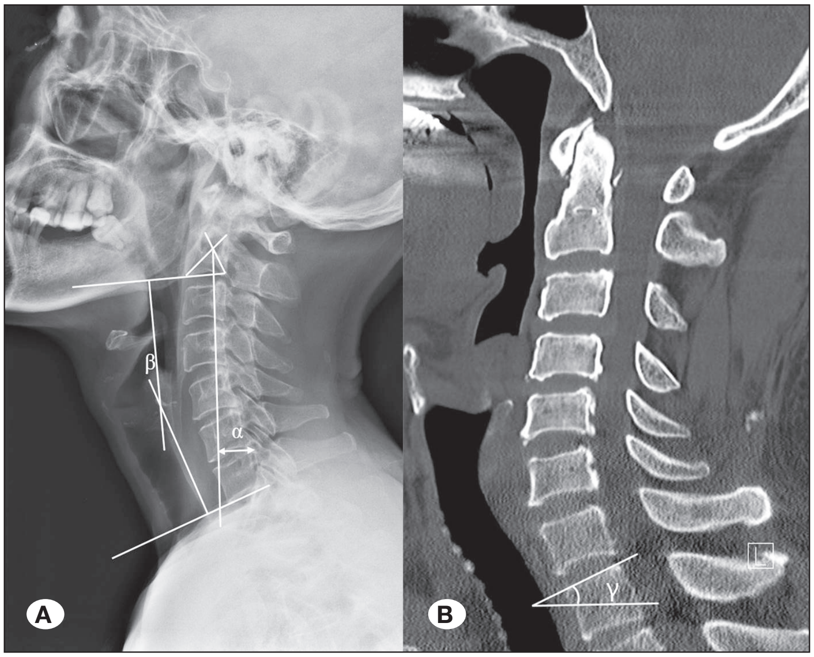

Figure 1: Measurement of C2–C7 sagittal vertical axis (α) and C2–C7 Cobb angle (β) on lateral radiograph **(A)**, and T1 slope (γ) on sagittal view of computed tomography **(B)**.

The Pearson correlation coefficient (*r*) was used to assess the relationship between the parametric continuous variable. The value of *r* ranged from +1 to -1, with a value between ± 0.50 and ± 1.00 indicating a strong correlation, between ± 0.30 and ± 0.49 indicating a moderate correlation, and below ± 0.29 indicating a weak correlation. The inter-observer reliabilities for radiological parameters were measured using intra-class correlations (ICC; two-way mixed model with consistency agreement; 95% confidence interval). ICC values of 0.00–0.20 indicated for poor agreement, 0.21–0.40 for fair agreement, 0.41–0.60 for moderate agreement, 0.61–0.80 for good agreement, and 0.81–1.0 for very good agreement. Statistical analysis was conducted using SPSS version 25.0 software (SPSS Inc., Chicago, Illinois), and p<0.05 was considered statistically significant.

RESULTS

Demographic and Clinical Data

Among the 95 patients with cervical myelopathy, 20 patients were excluded owing to traumatic cervical cord injury (n=10), prior cervical surgery (n=4), follow-up loss (n=4), and inappropriate radiographs (n=2). The final analysis included 75 patients consisted with 32 of group A and 43 of group B. There were no statistically significant differences in age (64.5 ± 11.7 vs. 63.6 ± 10.4 years, p=0.727), sexual distribution (25 men and 7 women vs. 29 men and 14 women, p=0.308), and duration of symptom (11.9 ± 16.2 vs. 10.8 ± 13.3 months, p=0.737) between the two groups. However, group B showed significantly higher BMI (23.8 ± 3.4 vs. 25.3±3.2, p=0.046) and larger extent of lesion (3.0 ± 0.6 vs. 3.6 ± 1.4 levels, p=0.020). There were no statistically significant differences in the extent (2.6 ± 0.6 vs. 2.7 ± 0.6 levels, p=0.305), sites (p=0.206), and involvement of C3 (p=0.283) and C7 (p=0.056) in laminoplasty between the two groups. Detailed data are presented in Table I.

Radiological Outcomes

1. Preoperative radiological parameters

Preoperative radiological parameters were analyzed between the groups A and B. There was a statistically significant difference in preoperative C2-7ROM (46.5 ± 15.2° vs. 37.9 ± 13.2°, p=0.010). However, there were no statistically significant differences in C2-7AN (17.2 ± 10.4° vs. 15.2 ± 10.6°, p=0.423), C2-7AF (16.9 ± 8.5° vs. 12.9 ± 9.2°, p=0.059), C2-7AE (29.5 ± 11.5° vs. 24.9 ± 12.8°, p=0.109), T1S (23.4 ± 7.3° vs. 23.9 ± 8.3°, p=0.744), and preoperative C2-7SVA (17.9 ± 10.6 vs. 22.7 ± 13.4 mm, p=0.104). Preoperative radiological data are presented in Table II.

2. Postoperative radiological parameters

Postoperative radiological parameters were analyzed between groups A and B. There were no statistically significant differences in postoperative radiological parameters including C2-7AN (13.1 ± 13.9° vs. 11.3 ± 11.5°, p=0.547), C2-7AF (10.8 ± 9.9° vs. 12.3 ± 9.4°, p=0.499), C2-7AE (23.4 ± 14.7° vs. 19.8 ± 11.4°, p=0.240), C2-7ROM (32.2 ± 12.9° vs. 31.8 ± 10.8°, p=0.313), T1S (25.5 ± 5.3° vs. 23.2 ± 5.1°, p=0.058), and C2-7SVA (27.3 ± 15.3 vs. 23.8 ± 12.5 mm, p=0.268). There were statistically significant differences in C2-7AF, C2-7ROM, and C2-7SVA of group A and in C2-7ROM of group B between the pre- and postoperative data (p<0.05). Postoperative radiological data are presented in Table II.

3. Comparison of the changes (Δ) in radiological parameters for 12 months between the two groups

There was a statistically significant difference in ΔC2-7SVA (9.4 ± 17.1 vs. 1.1 ± 17.2 mm, p=0.041) between groups A and

Table I: Demographic and Clinical Data

	Group A	Group B	Group A+B	p value⁺
Patients	32	43	75	
Age (years)	64.5 ± 11.7 (47-82)	63.6 ± 10.4 (45-84)	63.9 ± 10.7 (45-84)	0.727
Sex (men:women)	25:7	29:14	54:21	0.308
BMI	23.8 ± 3.4 (18.7-32.1)	25.3 ± 3.2 (17.1-34.1)	24.7 ± 3.4 (17.1-34.1)	**0.046**
Duration of symptom (month)	11.9 ± 16.2 (1-60)	10.8 ± 13.3 (1-36)	11.3 ± 14.5 (1-60)	0.737
Extent of lesion (level)	3.0 ± 0.6	3.6 ± 1.4	3.3 ± 1.1	**0.020**
OPLL type	-	Continuous 5	-	
	-	Segmental 7	-	-
	-	Mixed 27	-	
	-	Localized 4	-	
Extent of laminoplasty (level)	2.6 ± 0.6 (2-3)	2.7 ± 0.6 (2-4)	2.6 ± 0.6 (2-4)	0.305
Site of laminoplasty				
C3/4/5	6 (18.8%)	3 (7.0%)	9 (12.0%)	
C4/5/6	9 (28.1%)	13 (30.2%)	22 (29.3%)	
C3/4/5/6	17 (53.1%)	22 (51.2%)	39 (52.0%)	0.206
C4/5/6/7	0 (0%)	3 (7.0%)	3 (4.0%)	
C3/4/5/6/7	0 (0%)	2 (4.7%)	2 (2.7%)	
Involvement of C3	23 (71.9%)	27 (62.8%)	50 (66.7%)	0.283
Involvement of C7	0 (0%)	5 (11.6%)	5 (6.7%)	0.056

***CSM:** Cervical spondylotic myelopathy, **OPLL:** Ossification of posterior longitudinal ligament, Group A patients with CSM, Group B patients with **OPLL:** BMI body mass index, ⁺ between the groups A and B.*

Table II: Pre- and Postoperative Radiological Parameters in the Groups A and B

	Group A	Group B	Group A+B	p value⁺
Preoperative				
C2-7AN (º)	17.2 ± 10.4	15.2 ± 10.6	16.1 ± 10.5	0.423
C2-7AF (º)	16.9 ± 8.5	12.9 ± 9.2	14.7 ± 9.1	0.059
C2-7AE (º)	29.5 ± 11.5	24.9 ± 12.8	26.9 ± 12.4	0.109
C2-7ROM (º)	46.5 ± 15.2	37.9 ± 13.2	41.6 ± 14.6	**0.010**
T1S (º)	23.4 ± 7.3	23.9 ± 8.3	23.7 ± 7.9	0.744
C2-7SVA (mm)	17.9 ± 10.6	22.7 ± 13.4	20.6 ± 12.4	0.104
Postoperative (12 months)				
C2-7AN (º)	13.1 ± 13.9	11.3 ± 11.5	*12.1 ± 12.6	0.547
C2-7AF (º)	*10.8 ± 9.9	12.3 ± 9.4	11.6 ± 9.6	0.499
C2-7AE (º)	23.4 ± 14.7	19.8 ± 11.4	*21.3 ± 12.9	0.240
C2-7ROM (º)	*32.2 ± 12.9	*31.8 ± 10.8	*32.8 ± 11.8	0.313
T1S (º)	25.5 ± 5.3	23.2 ± 5.1	24.1 ± 5.3	0.058
C2-7SVA (mm)	*27.3 ± 15.3	23.8 ± 12.5	*25.3 ± 13.8	0.268

CSM:** Cervical spondylotic myelopathy, **OPLL:** Ossification of posterior longitudinal ligament, Group A patients with CSM, Group B patients with OPLL, C2-7AN C2-7 Cobb angle in neutral, C2-7AF C2-7 Cobb angle in flexion, C2-7AE C2-7 Cobb angle in extension, C2-7ROM C2-7 range of motion, T1S T1 slope, C2-7SVA C2-7 sagittal vertical axis, ⁺ between the groups A and B, ** Significant difference compared to preoperative data (p<0.05).*

Table III: Comparison of the Changes (Δ) of Radiological Parameters for 12 Months Between the Groups A and B

	Group A	Group B	Group A+B	p value⁺
Δ C2-7AN (º)	-4.1 ± 17.2	-3.9 ± 15.2	-4.0 ± 15.9	0.959
Δ C2-7AF (º)	-6.2 ± 15.2	-0.7 ± 12.4	-3.1 ± 13.9	0.088
Δ C2-7AE (º)	-6.2 ± 17.9	-5.1 ± 17.1	-5.5 ± 17.3	0.787
Δ C2-7ROM (º)	-12.3 ± 19.9	-6.1 ± 16.8	-8.7 ± 18.3	0.150
Δ T1S (º)	2.1 ± 7.1	-0.9 ± 8.1	0.4 ± 7.8	0.106
Δ C2-7SVA (mm)	9.4 ± 17.1	1.1 ± 17.2	4.6 ± 17.5	**0.041**

***CSM:** Cervical spondylotic myelopathy, **OPLL:** Ossification of posterior longitudinal ligament, Group A patients with CSM, Group B patients with OPLL, C2-7AN C2-7 Cobb angle in neutral, C2-7AF C2-7 Cobb angle in flexion, C2-7AE C2-7 Cobb angle in extension, C2-7ROM C2-7 range of motion, T1S T1 slope, C2-7SVA C2-7 sagittal vertical axis, ⁺ between the groups A and B.*

B; however, there were no statistically significant differences in radiological parameters including ΔC27AN (p=0.959), ΔC2-7AF (p=0.088), ΔC2-7AE (p=0.787), ΔC2-7ROM (p=0.150), and T1S (p=0.106) between the two groups. Comparison of radiological changes (Δ) for 12 months between the two groups is presented in Table III.

4. Relationships between preoperative factors (age, C2-7ROM, and T1S) and changes (Δ) in radiological parameters during the postoperative 12 months

Preoperative age was statistically significantly correlated with ΔC2-7AF in group A (r=0.39); and ΔC2-7AF (r=0.29) and ΔC2-7SVA (r=-0.24) in total patients (group A+B), respectively. Preoperative C2-7ROM was statistically significantly correlated with ΔC2-7AF (r=-0.47) and ΔC2-7AE (r=-0.37) in group A; ΔC2-7AN (r=-0.31), ΔC2-7AF (r=-0.31), and ΔC2-7AE (r=-0.55) in group B; and ΔC2-7AN (r=-0.27), ΔC27AF (r=-0.43), ΔC2-7AE (r=-0.45), and ΔC2-7SVA (r=0.31) in group A+B, respectively. Preoperative T1S was statistically significantly correlated with ΔC2-7AN (r=-0.43) and ΔC2-7AE (r=-0.45) in group B; and ΔC2-7AN (r=-0.28) and ΔC2-7AE (r=-0.27) in group A+B, respectively. Detailed data are presented in Table IV.

5. Inter-observer reliability

Regarding radiological parameters, inter-observer reliability presented as ICC showed very good agreement, ranging from 0.80 to 0.99. The final radiological parameter measurements used were the average of the two investigators' measurements.

Functional Outcomes

There were no statistically significant differences in the preoperative mJOA score (10.9 ± 2.1 vs. 11.3 ± 1.9, p=0.487) and Nurick grade (3.1 ± 0.9 vs. 2.9 ± 0.8, p=0.507) between the two groups. Postoperatively, there were also no statistically significant differences in postoperative mJOA score (14.1 ± 1.3 vs. 14.5 ± 1.4, p=0.251), Nurick grade (1.9 ± 0.7 vs. 1.8 ± 0.7, p=0.316), and recovery rate (41.2 ± 27.7 vs. 45.5±20.3%, p = 0.435) between the two groups. Detailed data are presented in Table V.

DISCUSSION

Studies about the differences in radiological and functional outcomes between patients with OPLL and CSM after laminoplasty are scarce. Herein, we primarily focused on the changes in cervical curvature, ROM, and SVA in terms of radiological outcomes. Sakai et al. (16) and Lee et al. (11) reported that both cervical lordosis and SVA worsened following laminoplasty in both CSM and OPLL groups, while Sakaura et al. (18) and Kato et al. (7) reported no significant differences in cervical lordosis and SVA after laminoplasty in both CSM and OPLL groups. Our results were not consistent with the results of these previous studies. Unlike the OPLL group, the CSM group showed a significant increase of C2-7SVA at the 12-month follow-up. Additionally, there was a marginal loss of cervical lordosis, with no statistical significance, in both groups. Considering the changes in radiological parameters, there was a deterioration of the sagittal balance with increase of C27SVA in the CSM group compared to the OPLL group after multi-level laminoplasty.

There was a significant reduction in ROM at 12 months after laminoplasty in both groups, and the CSM group showed a greater reduction in ROM than the OPLL group. Some previous studies have reported a reduction in ROM as well as a progression of sagittal imbalance after laminoplasty, but the etiology of these problems remains debatable (15,19). The damage and atrophy of the posterior deep muscles including the semispinalis cervicis muscle, the injury of the nuchal ligament, and bony fusion of facet joints after laminoplasty are considered the main reasons for these postoperative changes (20,23,25). The reduction in ROM following laminoplasty is reported to range from 30% to 70% of the preoperative ROM (2,5,8). Seichi et al. reported a reduction of 13°-47° in the ROM of CSM patients (20). Our study showed a postoperative reduction of approximately 30% in the CSM group and 20% in the OPLL group. The lesser preoperative ROM of the OPLL group compared to the CSM group may have originated from the stiff segments with calcification of the posterior longitudinal ligaments. Consequently, we expect the postoperative deterioration of sagittal balance to be lesser in the OPLL group than in the CSM group after laminoplasty. In addition, Hyun et al. reported a smaller postoperative ROM in

Table IV: Relationships Between Preoperative Factors (age, C2-7ROM, and T1S) and Changes of Radiological Parameters During Postoperative 12 Months

	Preoperative factors		
	Age (years)	**C2-7ROM (°)**	**T1S (°)**
Group A			
Δ C2-7AN (°)	-0.32	-0.25	-0.10
Δ C2-7AF (°)	*0.39	**-0.47	-0.10
Δ C2-7AE (°)	-0.27	*-0.37	-0.01
Δ C2-7ROM (°)	0.15	-	-0.04
Δ T1S (°)	0.02	-0.02	-
Δ C2-7SVA (mm)	-0.24	*0.35	-0.05
Group B			
Δ C2-7AN (°)	-0.06	*-0.31	**-0.43
Δ C2-7AF (°)	0.22	*-0.31	0.29
Δ C2-7AE (°)	0.06	**-0.55	**-0.45
Δ C2-7ROM (°)	0.22	-	-0.24
Δ T1S (°)	-0.17	-0.27	-
Δ C2-7SVA (mm)	-0.27	0.17	-0.20
Group A+B			
Δ C2-7AN (°)	-0.19	*-0.27	*-0.28
Δ C2-7AF (°)	*0.29	**-0.43	0.12
Δ C2-7AE (°)	-0.10	**-0.45	*-0.27
Δ C2-7ROM (°)	0.17	-	-0.14
Δ T1S (°)	-0.08	-0.09	-
Δ C2-7SVA (mm)	*-0.24	*0.31	-0.15

Pearson correlation coefficient (r) was used to assess the relationship. ***CSM:*** *Cervical spondylotic myelopathy;* ***OPLL:*** *Ossification of posterior longitudinal ligament, Group A patients with CSM, Group B patients with OPLL, C2-7AN C2-7 Cobb angle in neutral;, C2-7AF C2-7 Cobb angle in flexion, C2-7AE C2-7 Cobb angle in extension, C2-7ROM C2-7 range of motion, T1S T1 slope, C2-7SVA C2-7 sagittal vertical axis, *p<0.05, **p<0.01.*

Table V: Functional Outcomes

	Group A	**Group B**	**Group A+B**	**p value+**
Preoperative				
mJOA score	10.9 ± 2.1	11.3 ± 1.9	11.1 ± 1.9	0.487
Nurick grade	3.1 ± 0.9	2.9 ± 0.8	3.0 ± 0.9	0.507
Postoperative (12 months)				
mJOA score	*14.1 ± 1.3	*14.5 ± 1.4	*14.3 ± 1.4	0.251
Nurick grade	*1.9 ± 0.7	*1.8 ± 0.7	*1.9 ± 0.7	0.316
Recovery rate (%)	41.2 ± 27.7	45.5 ± 20.3	43.7 ± 23.7	0.435

CSM: *Cervical spondylotic myelopathy,* ***OPLL:*** *Ossification of posterior longitudinal ligament, Group A patients with CSM, Group B patients with OPLL, mJOA modified Japanese Orthopedic Association, + between the groups A and B, * Significant difference compared to preoperative data (p<0.05).*

the OPLL group than in the CSM group because of the higher frequency of postoperative laminar auto-fusion in OPLL group than in CSM group (6).

It is necessary to consider the effect of age on the development of sagittal imbalance with kyphotic change. Sakai et al. reported that advanced age was a risk factor for kyphotic deformity after laminoplasty in CSM patients with normal preoperative sagittal alignment (17). In the thoracolumbar spine, a decrease of lumbar lordosis and an increase of thoracic kyphosis are associated with increasing age, which results in increased SVA being an indicator of the sagittal global balance (14,21,26). However, unlike the thoracolumbar spine, the sagittal balance of the cervical spine is relatively well maintained in elderly patients because of increased cervical lordosis as a compensatory mechanism (9). To maintain the lordotic curvature of the cervical spine in a condition with sagittal imbalance, it is necessary to preserve and enhance the strength of the cervical extensor muscles. There are several less-invasive methods for saving cervical posterior structures to maintain cervical lordosis after laminoplasty (17). Tumturk et al. reported that *en block* laminoplasty is useful for preserving posterior structure and preventing postoperative sagittal malalignment (24). However, it is generally assumed that extensor muscles already show age-related degradation in elderly patients, which will worsen the deterioration of the cervical extension mechanism postoperatively.

The age-related cervical ROM and curvature should also be evaluated in asymptomatic individuals. Yukawa et al. reported that the cervical motions (flexion, extension, and total range) and the curvature of the neutral neck posture were 25.5 ± 9.5°, 16.2 ± 9.4°, 41.8 ± 12.7°, and 18.4 ± 11.6° in male patients and 26.3 ± 98.4°, 26.7 ± 8.8°, 53.0 ± 10.9°, and 16.9 ± 10.8° in female patients in their 60s, respectively, which was the average age of our patients (28). When compared with preoperative parameters of our patients, these results show a similar cervical lordosis but a greater range of flexion. With increasing age, there was decreased ROM and increased cervical lordosis, and the range of extension decreased more than that of the flexion. These results show that cervical lordosis naturally increases and the range of extension decreases with aging because of a compensatory mechanism in asymptomatic individuals. This phenomenon was different from our postoperative radiological findings including the reduction of both ROM and cervical lordosis. In particular, the effects of age on ΔC2-7AF (positive correlation) and ΔC2-7SVA (negative correlation) were limited, and the final result at 12-month postoperatively showed a significant decrease of cervical flexion and increase of SVA but no significant difference in cervical extension.

Few studies have focused on restriction of each cervical flexion or extension after laminoplasty, although many studies have reported a reduction in the overall ROM with loss of cervical lordosis. Suk et al. reported significant restriction in both flexion and extension, while Hyun et al. showed restriction in flexion but not in extension (5,22). However, these results did not highlight any differences between the CSM and OPLL groups. Our results showed significantly more restriction of cervical flexion in the CSM group than in the OPLL group after laminoplasty. With a reduction in the overall ROM, the composition of ROM, comprising flexion and extension, changed from 1:2 to 1:3 postoperatively in the CSM group; however, there was no change in the OPLL group. We believe that the reason for restriction of cervical flexion being primarily observed in the CSM group after laminoplasty is the compensatory mechanism against the progression of sagittal imbalance caused by a postoperative dysfunction of cervical posterior structures. In other words, a reduction of ROM with distinct restriction of cervical flexion has occurred to correct the sagittal imbalance in which the center of gravity of the head leans forward with loss of cervical lordosis and increase of SVA (Figure 2A-D).

In addition to age, the effect of preoperative T1S should be also considered to evaluate the radiological outcomes after laminoplasty between the CSM and OPLL groups. The preoperative high T1S is already known to be an important factor related to the development and deterioration of sagittal imbalance after laminoplasty (10,12). In our study, T1S did not significantly differ between the two groups pre- and postoperatively. There were no significant correlations between T1S and the changes in radiological parameters in the CSM group. However, higher preoperative T1S was related to restricted cervical extension and loss of cervical lordosis postoperatively in the OPLL group. In a comprehensive review of the effects of age, ROM, and T1S, we expect C2-7ROM, unlike age and T1S, to be affected mainly by the dysfunction of posterior cervical structures. The effect of posterior surgery with the damages to posterior extensor muscles and ligaments are bigger in the CSM group presenting with greater preoperative ROM, thus leading to the increase of SVA. The reduction of ROM is also thought to be involved in the compensatory mechanism as mentioned above. Unfortunately, the compensatory mechanism associated with the reduction of ROM in the CSM group was insufficient to prevent the deterioration of sagittal balance with increasing SVA, even though it minimized the loss of cervical lordosis. However, the stiff and less-flexible segments with the formation of ossification of the posterior longitudinal ligaments combined with a compensatory mechanism of ROM preserved SVA and maintained cervical lordosis in the OPLL group.

Unfortunately, long-term changes in ROM and cervical curvature could not be determined from the 12-month follow-up study; thus, these can be predicted indirectly by referring to the results of previous studies. Kawaguchi et al. reported a rapid decrease in ROM within the first year following surgery and no further decreases thereafter without distinction between the CSM and OPLL groups (8). Hyun et al. reported the differences in the reduction of ROM between the CSM and OPLL groups (6). The OPLL group showed a continuous reduction of ROM for 5 years; however, in the CSM group, there was a recovery after initial reduction for 2 years. However, there were no significant differences in functional outcomes according to the radiological changes. In our results, we found significant improvements in functional outcomes in the CSM and OPLL groups with no significant differences 12 months postoperatively. Considering these favorable functional

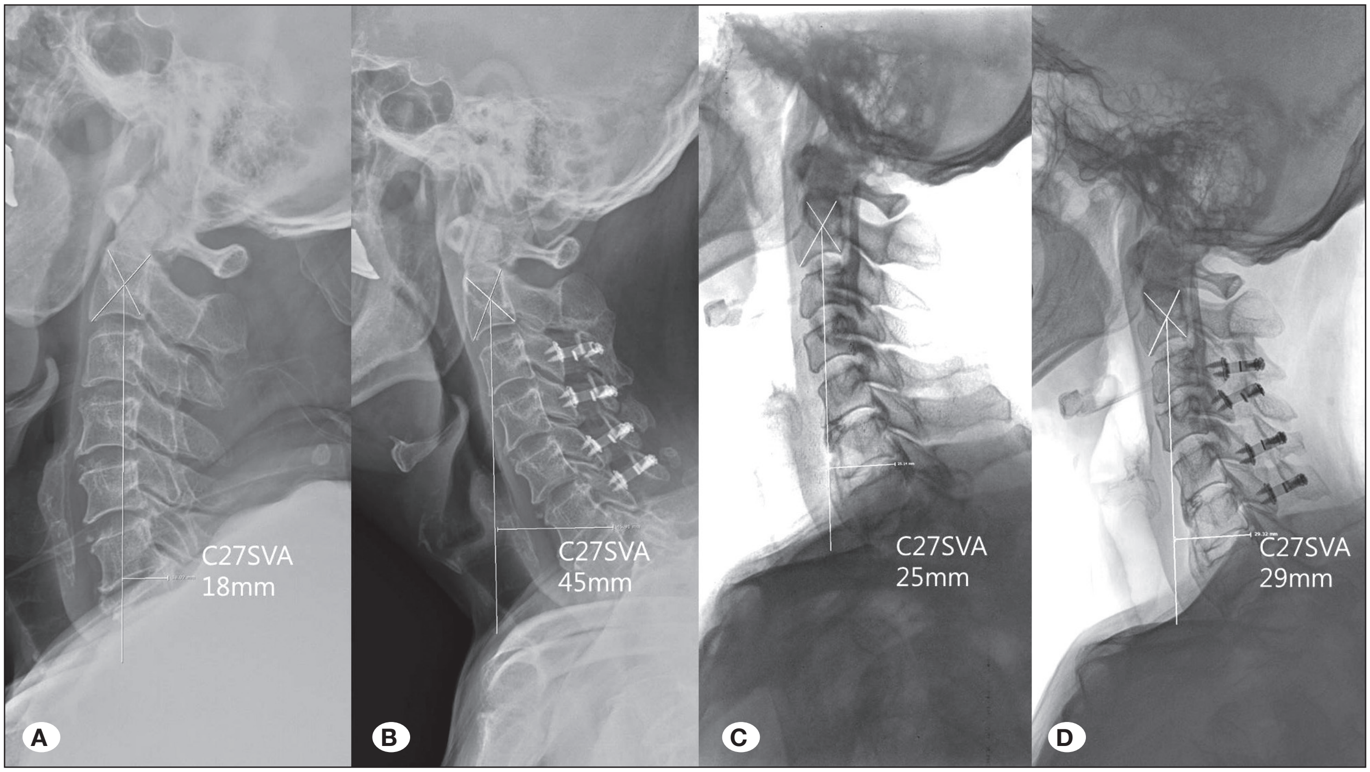

Figure 2: Changes in cervical lordosis and sagittal balance pre- and postoperatively. In the CSM patient, the preoperative lateral radiograph showed preserved cervical lordosis and sagittal balance **(A)**. There was increased C2-7SVA despite maintained cervical lordosis on the postoperative lateral radiograph **(B)**. In OPLL patients, there were no statistically significant differences between pre- **(C)** and post- **(D)** operative lateral radiographs. Both the cervical lordosis and sagittal balance were maintained.

outcomes, the radiological changes including the reduction of ROM and increase of SVA in the CSM group can be regarded as meaningless. However, we think that careful observation is required even after 12 months when considering the greater deterioration of sagittal balance in the CSM group than in the OPLL group unlike the results of previous studies.

Our study has several limitations. First, it was a retrospective study with relatively small number of participants. Second, the 12-month follow-up period was quite short to expect to observe overall changes in postoperative sagittal balance. Third, there was no consideration of whole-spine sagittal balance, which can influence cervical sagittal balance. Further studies with a larger number of participants during the long-term follow-up period are required to demonstrate the exact radiological and clinical differences between the CSM and OPLL groups.

CONCLUSION

Although there were no statistically significant differences in the functional outcomes, the CSM group showed a greater deterioration of sagittal balance with a significant increase of C2-7SVA after multi-level laminoplasty than the OPLL group. We consider that the stiffness and less-flexible segments of OPLL with the reduction of ROM as a compensatory mechanism prevented the deterioration of sagittal balance while preserving SVA and maintaining cervical lordosis. Additional careful observations are required considering these radiological and structural differences between the CSM and OPLL groups.

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