Cervical Lordosis Ratio as a Novel Predictor for the Loss of Cervical Lordosis After Laminoplasty

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Objective: Maintaining cervical lordosis (CL) after laminoplasty is important for indirect decompression of the spinal cord. This study aimed to identify preoperative dynamic radiographic predictors for the loss of CL after laminoplasty.

Methods: We retrospectively analyzed 141 consecutive patients who underwent cervical laminoplasty for cervical myelopathy. The following radiographic parameters were measured before surgery and at 1 year of follow-up: CL, C7 slope, C2–7 sagittal vertical axis (SVA), C2–7 range of motion (ROM), CL in flexion, CL in extension, ROM of flexion (Flex ROM), and ROM of extension. The CL ratio (CLR) was defined as 100 × Flex ROM/C2–7 ROM. ΔCL was defined as postoperative CL minus preoperative CL. Patients were classified into 2 groups: group K (kyphotic change group, ΔCL ≤ -10) and group C (control group, ΔCL > -10).

Results: The patient population comprised 94 men and 47 women (mean age, 70.9 ± 9.4 years), with 24 patients (17.0%) classified into group K. CL, C7 slope, and CLR were significantly higher in group K than in group C. The groups did not significantly differ in age, sex, C2–7 SVA, and C2–7 ROM. On multivariable analysis, the CLR was significantly associated with postoperative kyphotic changes. On receiver-operating characteristic curve analysis (area under the curve = 0.717, p < 0.001), the cutoff value for CLR was 68.9%, with sensitivity and specificity of 87.5% and 57.3%, respectively.

Conclusion: The CLR, reflecting the balance between flexion and extension mobility, was identified as a novel predictor for CL loss after laminoplasty, with a cutoff value of 68.9%.

Keywords: Cervical lordosis ratio, T1 slope, Cervical spondylotic myelopathy, Ossification posterior longitudinal ligament, Laminoplasty, Loss of cervical lordosis

INTRODUCTION

Cervical laminoplasty is used to treat cervical myelopathy caused by cervical spondylotic myelopathy (CSM) or ossification of the posterior longitudinal ligament (OPLL). Cervical laminoplasty is an effective posterior surgical method for spinal cord decompression, preserving the motion segments and relatively good long-term results reported.1-3 The decompression effects of this procedure comprise direct posterior decompression and indirect anterior decompression by a posterior shift of the spinal cord.4,5 The cervical spine alignment should be lordotic to obtain the indirect decompression effect; thus, maintaining postoperative cervical lordosis (CL) is important. Kyphotic cervical alignment may lead to poor postoperative clinical outcomes.6 However, cervical laminoplasty, as posterior decompression surgery, can cause injury to the posterior neck muscle-ligament complex; therefore, preoperative CL is not maintained postoperatively in some cases.7,8

Several reports have described preoperative predictors of the loss of CL after laminoplasty.9-17 Recently, the T1 slope has been reported to be an important factor for predicting postoperative kyphosis as the kyphotic alignment change was greater in patients with a high T1 slope.9,10,12 Other studies have focused on whole-spine alignment parameters for predicting postoperative
kyphotic changes. However, studies evaluating dynamic radiographic parameters are limited.

Therefore, the purpose of this study was to evaluate preoperative dynamic cervical sagittal alignment parameters as potential risk factors for the loss of CL after laminoplasty and determine the cutoff value for the identified risk factor(s). We focused on preoperative radiographic parameters in neutral, extension, and flexion positions.

MATERIALS AND METHODS

1. Patient Enrollment
This study was approved by the Institutional Review Board of Clinical Research Center Kurashiki Central Hospital (No. 3449). We retrospectively reviewed 383 consecutive patients who underwent cervical laminoplasty at our institution between December 2012 and May 2019. Patients diagnosed with CSM or OPLL who underwent cervical laminoplasty from C3 to C6 and completed a 1-year follow-up visit were included. The exclusion criteria were as follows: a history of previous cervical surgery (N = 10), combined with instrumentation (N = 36) and foraminotomy (N = 25), decompression levels including C1 or thoracic spine levels, or use of more selective methods (e.g., C4 to C6) (N = 95), inappropriate radiographic data (N = 33), and follow-up period < 1 year (N = 43). Finally, 141 patients were enrolled in the study. Data regarding demographic variables, including age, sex, body mass index (BMI), and diagnosis (CSM or OPLL), were collected.

2. Surgical Procedures
The muscles attached to the C2 and C7 spinous processes were preserved, while the C3 to C6 laminae were exposed. Double-door laminoplasty was performed from C3 to C6. Hydroxyapatite spacers were placed in the laminar spread from C4 to C6. A spacer could not be placed at C3 because the C2 spinous process was obstructed; however, the C3 lamina was passively maintained spread apart along the C4 lamina. Partial laminectomy was performed at the lower edge of the C2 lamina and the upper edge of the C7 lamina, avoiding damage to the muscle attached to the C2 and C7 spinous processes. Local bone was grafted into the gutter. Postoperatively, patients wore a soft neck collar for several days.

3. Radiographic Parameters
Cervical lateral radiographs were taken in neutral, flexion, and extension positions before surgery and at the 1-year follow-up visit. For radiographs in the neutral position, patients were instructed to stand comfortably and look forward, and CL, C7 slope, and the C2–7 sagittal vertical axis (SVA) were measured (Fig. 1). CL was defined as the angle formed by the inferior end-plates of C2 and C7. The C7 slope was defined as the angle formed by the inferior end-plate of C7 and the horizontal line. C2–7 SVA was defined as the distance between the vertical line from the center of the C2 body and the posterosuperior corner of the C7 body.

For radiographs in the flexion and extension positions, patients either flexed or extended the cervical spine as much as possible, and CL in flexion (Flex CL) and extension (Ext CL)

Fig. 1. CL (A), C7 slope (B), and C2–7 SVA (C) were measured in the neutral position. Flex CL (D) and Ext CL (E) were measured with the patients in maximal flexion and extension, respectively. CL, cervical lordosis; SVA, sagittal vertical axis; Flex CL, CL in flexion; Ext CL, CL in extension.
was measured (Fig. 1). The C2–7 range of motion (ROM) was calculated as Ext CL – Flex CL. ROM of flexion (Flex ROM) was calculated as CL – Flex CL, whereas ROM of extension (Ext ROM) was calculated as Ext CL – CL. The CL ratio (CLR) was defined as 100 × Flex ROM/C2–7 ROM (Fig. 2).

ΔCL was defined as postoperative CL – preoperative CL. Patients were classified into the following 2 groups based on the ΔCL: group K (kyphotic change group, ΔCL ≤ -10) and group C (control group, ΔCL > -10).

4. Clinical Parameters

Clinical outcomes were evaluated using the Japanese Orthopedic Association (JOA) score before surgery and at the 1-year follow-up visit. The recovery rate was calculated based on the Hirabayashi method as follows: JOA recovery rate = 100 × (postoperative JOA – preoperative JOA)/(17 – preoperative JOA).19

5. Statistical Analysis

Data are presented as the mean ± standard deviation unless otherwise specified. Spearman rank-order correlation analysis was used to evaluate the relationships between the CLR, ΔCL, and other preoperative parameters. Differences between groups K and C were evaluated using the chi-square test and Mann-Whitney U-test for categorical and continuous variables, respectively. To identify the risk factors for postoperative kyphotic change, a multivariable logistic regression analysis was performed. Receiver-operating characteristic (ROC) curve analysis was used to determine the optimal cutoff value, defined as the point corresponding to the maximum sum of the sensitivity and specificity. Values of p < 0.05 were considered statistically significant, and JMP Pro 14 (SAS Institute Inc., Cary, NC, USA) was used for all analyses.

RESULTS

1. Demographic, Radiographic, and Clinical Data

In total, 141 patients (mean age, 70.9 ± 9.4 years; 94 males, 47 females) were enrolled in this study. The overall demographic, radiographic, and clinical data are summarized in Table 1.

2. Correlations Between the CLR, ΔCL, and Other Preoperative Radiographic Parameters

The correlations between the CLR, ΔCL, and other preoperative radiographic parameters are shown in Table 2. ΔCL was correlated with the CLR (r = -0.499, p < 0.001), CL (r = -0.282, p < 0.001), Flex ROM (r = -0.330, p < 0.001), and Ext ROM (r = 0.390, p < 0.001). In patients with a higher preoperative CL or CLR, greater kyphotic alignment change was observed postoperatively. Similarly, the CLR was correlated with CL (r = 0.341, p < 0.001), C2-7 SV A (r = -0.222, p = 0.008), Flex ROM (r = 0.509, p < 0.001).

Table 1. Demographic, radiographic, and clinical data (n = 141)

| Variable                           | Value       |
|------------------------------------|-------------|
| Age (yr)                           | 70.9 ± 9.4  |
| Sex, male:female                   | 94:47       |
| Body mass index (kg/m²)            | 23.8 ± 3.7  |
| Diagnosis, CSM:OPLL                | 118:23      |
| Radiographic data                  |             |
| Preoperative CL (°)                | 15.5 ± 12.7 |
| C7 Slope (°)                       | 28.1 ± 9.3  |
| C2–7 SV A (mm)                     | 26.5 ± 13.6 |
| Flex CL (°)                        | -9.3 ± 13.9 |
| Ext CL (°)                         | 27.2 ± 13.1 |
| C2–7 ROM (°)                       | 36.5 ± 13.6 |
| Flex ROM (°)                       | 24.9 ± 11.4 |
| Ext ROM (°)                        | 11.6 ± 8.0  |
| CLR (%)                            | 67.7 ± 19.3 |
| Postoperative CL (°)               | 13.1 ± 12.7 |
| ΔCL (°)                            | -2.5 ± 7.8  |
| Clinical data                      |             |
| Preoperative JOA score             | 10.3 ± 2.8  |
| Postoperative JOA score            | 13.0 ± 2.3  |
| JOA recovery rate (%)              | 37.1 ± 36.2 |

Values are presented as mean ± standard deviation or number. CSM, cervical spondylotic myelopathy; OPLL, ossified posterior longitudinal ligament; CL, cervical lordosis; SV A, sagittal vertical axis; Flex CL, CL in flexion; Ext CL, CL in extension; ROM, range of motion; Flex ROM, ROM of flexion; Ext ROM, ROM of extension; CLR, CL ratio; ΔCL, postoperative CL – preoperative CL; JOA, Japanese Orthopedic Association.
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Table 2. Spearman rank-order correlations between CLR, ΔCL, and other preoperative radiographic parameters

| Variable       | CLR   | ΔCL  | CL  | Flex CL | Ext CL | C7 slope | C2–7 SVA | C2–7 ROM | Flex ROM | Ext ROM |
|----------------|-------|------|-----|---------|--------|----------|----------|----------|----------|---------|
| CLR            | -     | -0.499 | 0.341 | -       | -      | -0.222   | -        | -0.509   | -0.807   |
| p-value        | -     | < 0.001* | < 0.001* | 0.215   | 0.142  | 0.125    | 0.008*   | 0.846    | < 0.001* | < 0.001* |
| ΔCL            | -0.499 | -     | -0.282 | -       | -      | -0.704   | 0.738    | 0.100    | 0.188    | 0.368   |
| p-value        | < 0.001* | -     | < 0.001* | 0.704   | 0.538  | 0.100    | 0.188    | 0.368    | < 0.001* | < 0.001* |

CL, cervical lordosis; CLR, CL ratio; ΔCL, postoperative CL – preoperative CL; Flex CL, CL in flexion; Ext CL, CL in extension; SVA, sagittal vertical axis; ROM, range of motion; Flex ROM, ROM of flexion; Ext ROM, ROM of extension.

*p < 0.05, statistically significant difference.

Table 3. Comparison of each variable according to the postoperative loss of CL

| Variable                  | Group K (n = 24) | Group C (n = 117) | p-value |
|---------------------------|------------------|-------------------|---------|
| Age (yr)                  | 72.4 ± 7.8       | 70.6 ± 9.7        | 0.651   |
| Sex, male:female          | 13:11            | 81:36             | 0.154   |
| Body mass index (kg/m²)   | 23.9 ± 3.3       | 23.8 ± 3.8        | 0.958   |
| Diagnosis, CSM:OPLL       | 22.2             | 96:21             | 0.246   |
| Preoperative CL (°)       | 21.5 ± 12.4      | 14.3 ± 12.5       | 0.016*  |
| C7 Slop (°)               | 31.6 ± 9.0       | 27.4 ± 9.2        | 0.043*  |
| C2–7 SVA (mm)             | 25.3 ± 16.8      | 26.8 ± 12.9       | 0.777   |
| Flex CL (°)               | -9.4 ± 12.8      | -9.3 ± 14.2       | 0.945   |
| Ext CL (°)                | 30.0 ± 13.0      | 26.6 ± 13.1       | 0.163   |
| C2–7 ROM (°)              | 39.3 ± 14.2      | 35.9 ± 13.5       | 0.330   |
| Flex ROM (°)              | 30.9 ± 13.2      | 23.6 ± 10.6       | 0.014*  |
| Ext ROM (°)               | 8.4 ± 5.2        | 12.3 ± 8.3        | 0.037*  |
| CLR (%)                   | 78.1 ± 13.5      | 65.5 ± 19.7       | < 0.001*|
| Postoperative CL (°)      | 7.5 ± 11.0       | 14.2 ± 12.8       | 0.027*  |
| ΔCL (°)                   | -14.0 ± 4.1      | -0.1 ± 6.2        | < 0.001*|

Clinical data

| Preoperative JOA score    | 9.5 ± 2.9        | 10.4 ± 2.7        | 0.159   |
| Postoperative JOA score   | 12.6 ± 2.4       | 13.1 ± 2.3        | 0.321   |
| JOA recovery rate (%)     | 39.6 ± 29.3      | 36.6 ± 37.6       | 0.993   |

Values are presented as mean ± standard deviation or number. Group K, kyphotic change group (ΔCL ≤ -10); Group C, control group (ΔCL > -10).

CSM, cervical spondylotic myelopathy; OPLL, ossified posterior longitudinal ligament; CL, cervical lordosis; SVA, sagittal vertical axis; Flex CL, CL in flexion; Ext CL, CL in extension; ROM, range of motion; Flex ROM, ROM of flexion; Ext ROM, ROM of extension; CLR, CL ratio; ΔCL, postoperative CL – preoperative CL; JOA, Japanese Orthopedic Association.

*p < 0.05, statistically significant difference.

Table 4. Risk factors for the postoperative loss of CL (ΔCL ≤ -10)

| Variable       | p-value | OR     | 95% CI             |
|----------------|---------|--------|-------------------|
| CL             | 0.474   | -      | -                 |
| C7 slope       | 0.275   | -      | -                 |
| CLR (%)        | 0.012*  | 42.402 | 1.906–943.054     |

CL, cervical lordosis; ΔCL, postoperative CL – preoperative CL; OR, odds ratio; 95% CI, 95% confidence interval; CLR, CL ratio.

*p < 0.05, statistically significant difference.

p < 0.001), and Ext ROM (r = -0.807, p < 0.001). Patients with a higher preoperative CLR had higher CL and lower C2–7 SVA. No significant correlations were observed between the other evaluated parameters.

3. Comparison of Each Variable According to the Postoperative Loss of CL

Postoperative loss of CL (ΔCL ≤ -10) occurred in 24 patients (17.0%; i.e., group K). The differences between groups K and C are summarized in Table 3. The groups did not significantly differ in age, sex, BMI, and diagnosis. The preoperative CL was higher (21.5 ± 12.4 vs. 14.3 ± 12.5, p = 0.016) and the postoperative CL was lower (7.5 ± 11.0 vs. 14.2 ± 12.8, p = 0.016) in group K than in group C. Accordingly, ΔCL was lower in group C than in group K (-14.0 ± 4.1 vs. -0.1 ± 6.2, p < 0.001).

The C7 slope, CLR, Flex ROM, and Ext ROM significantly differed between groups K and C. The C7 slope (31.6 ± 9.0 vs. 27.4 ± 9.2, p = 0.043), CLR (78.1 ± 13.5 vs. 65.5 ± 19.7, p < 0.001), and Flex ROM (30.9 ± 13.2 vs. 23.6 ± 10.6, p = 0.014) were higher and Ext ROM (8.4 ± 5.2 vs. 12.3 ± 8.3, p = 0.037) was lower in group K than in group C. No significant differences were observed in the other radiographic parameters. Preoperative JOA, postoperative JOA, and JOA recovery rates did not significantly differ between groups K and C.
4. Risk Factors for Postoperative Kyphotic Change

Multivariable logistic regression analysis was performed to estimate the odds ratio for the postoperative loss of CL ($\Delta$CL $\leq$ -10) according to 3 preoperative radiographic parameters: CL, C7 slope, and CLR (Table 4). Among the dynamic radiographic factors (CLR, Flex CL, Ext CL, C2–7 ROM, Flex ROM, and Ext ROM), the CLR with the most significant correlation with $\Delta$CL and the smallest p-value on comparison of group K with group C were applied in the multivariable analysis. The CLR was observed to be an independent risk factor for the postoperative loss of CL (p = 0.012; odds ratio, 42.402; 95% confidence interval, 1.906–943.054). The scatterplot in Fig. 3 shows the relationship between $\Delta$CL and CLR. Patients with a higher CLR tended to lose their preoperative CL after surgery considerably. In the ROC curve analysis for the prediction of $\Delta$CL $\leq$ -10 (area under the curve [AUC] = 0.717, p < 0.001), the cutoff value for CLR was 68.9%, with a sensitivity of 87.5% and a specificity of 57.3% (Fig. 4).

CLR (AUC = 0.717) was more useful as a predictor than CL (AUC = 0.657), C7 slope (AUC = 0.631), Flex ROM (AUC = 0.659), and Ext ROM (AUC = 0.635). CLR was nonnormally distributed, and it did not show significant correlations with age (p = 0.572), sex (p = 0.962), BMI (p = 0.374), and diagnosis (p = 0.744).

Fig. 4. ROC curve analysis for the prediction of $\Delta$CL $\leq$ -10 (area under the curve = 0.717, p < 0.001). The cutoff value for the CLR was 68.9%, with a sensitivity of 87.5% and a specificity of 57.3%. CL, cervical lordosis; $\Delta$CL, postoperative CL – preoperative CL; CLR, CL ratio; ROC, receiver-operating characteristic.

DISCUSSION

Cervical laminoplasty is an effective surgical procedure for cervical myelopathy. In this surgical method, posterior com-
pression factors are directly removed and the posterior spinal cord shifts, thus providing indirect decompression effects. To obtain this indirect decompression effect, cervical lordotic alignment is important. Therefore, cervical alignment, before and after laminoplasty, is considered to affect clinical outcomes. However, the alignment and ROM of the cervical spine have been reported to change with laminoplasty. For example, Machino et al. reported that the C2–7 Cobb angle became 1.8° more lordotic in the neutral position, 5.9° more lordotic in the flexion position, and 0.6° more kyphotic in the extension position, and the ROM was reduced to 87.9% after surgery. In some cases, the cervical alignment became kyphotic after laminoplasty despite preoperatively maintaining CL. Thus, the preoperative prediction of the loss of CL after surgery would be useful for obtaining good clinical outcomes by laminoplasty.

Various risk factors have been reported for kyphotic alignment change after laminoplasty. For example, Machino et al. reported that the cutoff value of the preoperative C2–7 lordosis angle for the prediction of postlaminoplasty kyphosis was 7° in patients with CSM without a preoperative kyphotic angle. Additionally, Sakai et al. reported that a greater center of gravity of the head – C7 SVA (cutoff value, 42 mm) and advanced age (cutoff value, 75 years) were risk factors for kyphotic deformities after laminoplasty in patients without preoperative cervical kyphotic alignment. In contrast, Matsuoka et al. focused on the global spinal alignment and reported that in patients without preoperative cervical and global spinal sagittal imbalance, a small C7 SVA accompanied by lumbar hyperlordosis was the characteristic alignment leading to postoperative cervical kyphosis after laminoplasty. Recently, the T1 slope has been discussed as a predictor of postoperative kyphotic alignment change. Kim et al. reported that patients with a high T1 slope had greater kyphotic alignment change after cervical laminoplasty at the 2-year follow-up; the authors hypothesized that kyphotic alignment change by posterior structural injury after laminoplasty was more marked in patients with a high T1 slope. In another study, Kim et al. reported that patients with OPLL and a higher T1 slope had more lordotic curvature before surgery and demonstrated a greater loss of CL at the 2-year follow-up. However, Cho et al. reported that the degree of aggravation did not correlate with the preoperative T1 slope and that most clinical parameters improved regardless of the preoperative T1 slope.

We evaluated both static alignment and dynamic image parameters to identify useful predictors for postoperative kyphotic alignment change. Lee et al. reported extension function (EF; Ext ROM) as a new predictor of the loss of CL; no significant kyphotic changes occurred after laminoplasty when the EF was greater than or equal to 14°. The authors hypothesized that the function of the posterior neck muscle-ligament complex was represented by the EF. Suk et al. reported that one of the preoperative factors affecting postoperative kyphosis is a kyphotic angle during flexion that is larger than the lordotic angle during extension. We proposed a new factor, the CLR, as an index reflecting the location of the neutral cervical position within the range of the extension and flexion motion. This implies that patients with a higher CLR have a large flexion ROM and small extension ROM because the neutral position is closer to the maximum extension. The degree of extension mobility indicates the function of the posterior neck muscle-ligament complex and is considered an inhibiting factor of kyphotic alignment change.

Additionally, poor flexion mobility is also considered to indicate that cervical kyphosis is inhibited by structural factors, such as bone, ligament, or muscle. Therefore, both Flex ROM and Ext ROM are important factors. This new factor, the CLR, is a useful and simple index for expressing the balance between flexion and extension mobility.

For cases wherein cervical kyphotic change after laminoplasty is predicted, the indications for laminectomy and fusion or anterior cervical discectomy and fusion (ACDF) should be considered. However, in this study, no significant differences were observed in clinical outcomes between the kyphotic change and control groups. One reason for this may be that the postoperative CL angle in the kyphotic change group was +7.5° on average, and lordotic alignment was maintained in most cases. Alignment changes were considered insufficient to worsen the clinical outcomes, even in the kyphotic change group. As reflected in the cervical laminoplasty procedures of our institution, we consider that preservation of the posterior neck muscle-ligament complex is important; therefore, the paravertebral muscles attached to the C2 and C7 spinous processes are preserved, even with multilevel stenosis, including C2/3 or C6/7. Supposedly, this minimally invasive surgical procedure contributed to the noninferior clinical outcomes in the kyphotic change group. Takeshita et al. reported that subaxial laminoplasty maintained the cervical alignment; however, if laminoplasty included C2, the alignment worsened. Iizuka et al. reported that preservation of the muscles attached to the C2 spinous process prevented significant changes in cervical alignment after laminoplasty.

This study has several limitations. First, because our study was retrospective, a selection bias may exist. Second, a total of 43 cases were lost to follow-up at 1 year. Third, as the follow-up period was 1 year, the long-term prognosis is unknown. Fourth,
CONCLUSION

We identified a new factor, the CLR, for predicting the loss of CL after laminoplasty. The CLR is a useful and simple index for expressing the balance between flexion and extension mobility. The cutoff value for the CLR was 68.9%.

CONFLICT OF INTEREST

The authors have nothing to disclose.

REFERENCES

1. Chiba K, Ogawa Y, Ishii K, et al. Long-term results of expansive open-door laminoplasty for cervical myelopathy: average 14-year follow-up study. Spine (Phila Pa 1976) 2006;31:2998-3005.
2. Seichi A, Takeshita K, Ohishi I, et al. Long-term results of double-door laminoplasty for cervical stenotic myelopathy. Spine (Phila Pa 1976) 2001;26:479-87.
3. Kawaguchi Y, Kanamori M, Ishihara H, et al. Minimum 10-year followup after en bloc cervical laminoplasty. Clin Orthop Relat Res 2003;411:129-39.
4. Sodeyama T, Goto S, Mochizuki M, et al. Effect of decompression enlargement laminoplasty for posterior shifting of the spinal cord. Spine (Phila Pa 1976) 1999;24:1527-31.
5. Baba H, Uchida K, Maezawa Y, et al. Lordotic alignment and posterior migration of the spinal cord following en bloc open-door laminoplasty for cervical myelopathy: a magnetic resonance imaging study. J Neurol 1996;85:626-32.
6. Suda K, Abumi K, Ito M, et al. Local kyphosis reduces surgical outcomes of expansive open-door laminoplasty for cervical spondylotic myelopathy. Spine (Phila Pa 1976) 2003;28:1258-62.
7. Iizuka H, Shimizu H, Tateno K, et al. Extensor musculature of the cervical spine after laminoplasty: morphologic evaluation by coronal view of the magnetic resonance image. Spine (Phila Pa 1976) 2001;26:2220-6.
8. Lin S, Zhou F, Sun Y, et al. The severity of operative invasion to the posterior muscular-ligament complex influences cervical sagittal balance after open-door laminoplasty. Eur Spine J 2015;24:127-35.
9. Kim TH, Lee SY, Kim YC, et al. T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy. Spine (Phila Pa 1976) 2013;38:E992-7.
10. Kim B, Yoon DH, Ha Y, et al. Relationship between T1 slope and loss of lordosis after laminoplasty in patients with cervical ossification of the posterior longitudinal ligament. Spine J 2016;16:219-25.
11. Cho JH, Ha JK, Kim DG, et al. Does preoperative T1 slope affect radiological and functional outcomes after cervical laminoplasty? Spine (Phila Pa 1976) 2014;39:E1575-81.
12. Zhang JT, Li JQ, Niu RJ, et al. Predictors of cervical lordosis loss after laminoplasty in patients with cervical spondylotic myelopathy. Eur Spine J 2017;26:1205-10.
13. Sakai K, Yoshii T, Hirai T, et al. Cervical sagittal imbalance is a predictor of kyphotic deformity after laminoplasty in cervical spondylotic myelopathy patients without preoperative kyphotic alignment. Spine (Phila Pa 1976) 2016;41:299-305.
14. Suk KS, Kim KT, Lee JH, et al. Sagittal alignment of the cervical spine after the laminoplasty. Spine (Phila Pa 1976) 2007;32:E656-60.
15. Machino M, Ando K, Kobayashi K, et al. Postoperative kyphosis in cervical spondylotic myelopathy: cut-off preoperative angle for predicting the postlaminoplasty kyphosis. Spine (Phila Pa 1976) 2020;45:641-8.
16. Matsuoka Y, Suzuki H, Endo K, et al. Small sagittal vertical axis accompanied with lumbar hyperlordosis as a risk factor for developing postoperative cervical kyphosis after expansive open-door laminoplasty. J Neurosurg Spine 2018;29:176-81.
17. Lee SH, Son DW, Lee JS, et al. Does extension dysfunction affect postoperative loss of cervical lordosis in patients who undergo laminoplasty? Spine (Phila Pa 1976) 2018;44:E456-64.
18. Kurokawa T, Tsuyama N, Tanaka H, et al. Enlargement of spinal canal by sagittal splitting of the spinal process. Bessatsu Seikeigeka 1984;2:234-40. (Japanese).
19. Hirabayashi K, Miyakawa J, Satomi K, et al. Operative re-
sults and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976) 1981;6:354-64.

20. Machino M, Yukawa Y, Hida T, et al. Cervical alignment and range of motion after laminoplasty: radiographical data from more than 500 cases with cervical spondylotic myelopathy and a review of the literature. Spine (Phila Pa 1976) 2012;37: E1243-50.

21. Takeshita K, Seichi A, Akune T, et al. Can laminoplasty maintain the cervical alignment even when the C2 lamina is contained? Spine (Phila Pa 1976) 2005;30:1294-8.

22. Iizuka H, Nakajima T, Iizuka Y, et al. Cervical malalignment after laminoplasty: relationship to deep extensor musculature of the cervical spine and neurological outcome. J Neurosurg Spine 2007;7:610-4.