


Relationship between K-line distance and surgical outcome in cases of laminoplasty for cervical ossification of the posterior longitudinal ligament

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Abstract

Although previous studies indicate that changes in cervical alignment after laminoplasty and dynamic factors influence surgical outcomes of cervical ossification of the posterior longitudinal ligament (OPLL), the relationship between the surgical outcomes, the distance between the kyphosis-line (K-line) and OPLL, and dynamic factors have not yet been quantitatively evaluated. The purpose of the present study was to analyze the relationship between Δ K-line distance and surgical outcomes in cases of laminoplasty for OPLL of the cervical spine. We retrospectively reviewed 46 consecutive patients (33 men and 13 women) with cervical OPLL who underwent laminoplasty. "K-line distance" was measured as the minimum interval between the K-line and OPLL on lateral radiographs. The following factors were analyzed: K-line distance in neutral, flexion, and extension neck positions, Δ K-line distance, preoperative C2-7 range of motion (ROM), preoperative segmental ROM, preoperative C2-7 lordotic angle, occupying ratio of the OPLL, disease duration, preoperative and postoperative Japanese Orthopaedic Association (JOA) score, and recovery rate. Patients were divided into flexion K-line (+) and flexion K-line (–) groups. We then analyzed the influence of the K-line distance on surgical outcomes and conducted multivariate analysis to analyze the factors affecting surgical outcomes. The JOA score recovery rate in the flexion K-line (–) group was significantly lower than that in the flexion K-line (+) group ($P = .024$). The Δ K-line distance was significantly negatively correlated with the JOA score recovery rate ($r = -0.531$, $P < .001$). Additionally, multivariate analysis showed that Δ K-line distance (OR = -2.143 , $P = .015$) was negatively correlated with the JOA score recovery rate. The Δ K-line distance is considered useful for the quantitative evaluation of dynamic factors and static compression factors due to OPLL through the measurement of dynamic radiographic images.

Abbreviations: CT = computed tomography, JOA = Japanese Orthopaedic Association, K-line = kyphosis-line, LA = lordotic angle, MRI = magnetic resonance imaging, OPLL = ossification of the posterior longitudinal ligament, ROM = range of motion, SI = signal intensity, SVA = sagittal vertical axis, WI = weighted images.

Keywords: cervical laminoplasty, cervical ossification of the posterior longitudinal ligament, dynamic factor, K-line, surgical outcomes

1. Introduction

Ossification of the posterior longitudinal ligament (OPLL) is characterized by chronically progressive ectopic calcification and can sometimes cause compression myelopathy.^[1] Some patients with minimal ossification show myelopathy, whereas others with marked ossification do not. Therefore, static factors alone cannot account for the pathogenesis of OPLL-induced myelopathy. The onset of myelopathy in cervical OPLL is associated with dynamic factors.^[2–4]

Cervical laminoplasty is a widely used surgical technique for the treatment of patients with cervical OPLL. Laminoplasty

allows multilevel decompression of the spinal cord while preserving the posterior elements of the cervical spine, reducing the risk of postoperative kyphosis.^[5,6] After posterior decompression surgery, cervical alignment and OPLL thickness affect surgical outcomes.

The K-line (kyphosis-line) was proposed as a simple tool for making decisions regarding the surgical approach for patients with cervical OPLL.^[7] The K-line is defined as a line that connects the midpoints of the spinal canal at C2 and C7 on a lateral radiograph in the neutral position. The K-line has been used as a preoperative parameter to predict surgical outcomes for OPLL, and accounts for the thickness of ossification and standing

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

This study received approval from our institution's Ethical Committee. All procedures were performed in accordance with the ethical standards of this committee, as well as with the 1964 Helsinki Declaration and its later amendments.

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cervical alignment. Poor neurological improvement has been reported after cervical laminoplasty in K-line (-) patients due to insufficient postoperative spinal cord clearance from the OPLL.^[7] Additionally, the use of the K-line in the neck-flexed position (flexion K-line) has been reported in patients with OPLL, with a K-line (+) identified with the neck in the neutral position but a K-line (-) in the neck-flexed position. Previous studies have reported worse functional recovery after posterior decompression surgery in patients with OPLL with a flexion K-line (-) than those with a flexion K-line (+).^[8,9] Although these studies indicate that changes in cervical alignment after laminoplasty and dynamic factors influence surgical outcomes, the relationship between the surgical outcomes, the distance between the K-line and OPLL, and dynamic factors have not yet been quantitatively evaluated.

Herein, we proposed a “K-line distance” as the distance from the K-line to the OPLL, that simply and quantitatively evaluates the thickness of the OPLL, the cervical alignment, and dynamic factors. The “ Δ K-line distance” was calculated as the change between the K-line distance from the extension position to the flexion position in the cervical spine. The purpose of the present study was to analyze the relationship between Δ K-line distance and surgical outcomes in cases of laminoplasty for OPLL of the cervical spine.

2. Materials and methods

2.1. Patient population

The present study was a retrospective study. All assessments were performed after obtaining approval from our institution's ethics committee, and informed consent was obtained in an opt-out manner. We retrospectively reviewed 46 consecutive patients (33 men and 13 women) with cervical OPLL who underwent modified double-door laminoplasty between December 2010 and September 2020 at our hospital. In the present study, the indication for double-door laminoplasty was OPLL with the K-line (+) in the neutral neck position. The inclusion criteria of the present study were as follows: diagnosis of OPLL; no previous history of cervical spine surgery; and no cervical spinal deformity resulting from fracture, tumor, infection, or congenital abnormality. Computed tomography (CT) was performed to identify the presence of OPLL before surgery. The mean age of the sample at the time of surgery was 63.1 ± 11.4 years (age range, 30–82 years). All patients presented with symptoms and magnetic resonance imaging (MRI) findings consistent with myelopathy secondary to spinal cord compression caused by OPLL. All patients were followed up for >12 months, with a mean follow-up of 38.5 ± 23.8 months (range, 12–90 months).

2.2. Surgical technique for modified double-door laminoplasty

In the present study, double-door laminoplasty was performed according to Kurokawa's method, with some modifications to preserve the semispinalis cervicis inserted into the axis.^[10] Specifically, the laminae expanded one above and one below the OPLL level. The spinous processes were resected at the base, and the center of the laminae was cut using a threadwire saw. Bilateral gutters were created as hinges at the borders of the laminae and facets. After the halves of the laminae were elevated, hydroxyapatite spinous process spacers were tied to bridge the bilateral edges of the laminae.

2.3. Postoperative considerations

On the second postoperative day, all patients were allowed to sit and walk while wearing a soft collar, which was removed 10 days after surgery. Subsequently, early cervical

range of motion (ROM) exercises were performed during rehabilitation.

2.4. Clinical assessment

We used the modified Japanese Orthopaedic Association (JOA) score to evaluate the severity of myelopathy preoperatively and 12 months postoperatively (Table 1). Postoperative improvement was evaluated in terms of the JOA score recovery rate, calculated using the Hirabayashi method as $(\text{postoperative JOA score} - \text{preoperative JOA score}) / (17 - \text{preoperative JOA score}) \times 100\%$, with a recovery rate of 100% indicating the best postoperative improvement. The multifactorial effects of variables such as sex, duration from onset to operation, and diabetes mellitus, were also studied.

2.5. Radiological assessment

Cervical anteroposterior, lateral, flexion, and extension radiographs of the spine were obtained preoperatively. Lateral radiographs of the cervical spine in the neutral position were obtained with the patient standing in a comfortable position, with their head facing forward and maintaining a horizontal gaze. Lateral radiographs of the cervical spine in the flexion position were taken with the patient positioned with their chin angled toward their chest (40° flexion). Lateral radiographs of the cervical spine in the extension position were taken with the patient positioned with their chin angled towards the ceiling (-20° extension).

The K-line distance was measured as the minimum interval between the K-line and the OPLL on the lateral radiographs in neutral, flexion, and extension neck positions (Fig. 1). Differences in K-line distance (Δ K-line distance) were calculated using the following formula: Δ K-line distance (mm) = (extension K-line distance) - (flexion K-line distance). Patients were categorized into 2 groups based on whether the OPLL did or did not exceed the K-line on a preoperative lateral radiograph in the neck flexion position (flexion K-line [-] group and flexion K-line [+] group, respectively).

Cervical alignment was assessed in terms of the C2-C7 Cobb lordotic angle (LA), which is defined as the angle formed by the inferior end plates of C2 and C7 on standing lateral radiographs (Fig. 2A). We investigated the preoperative C2-C7 Cobb

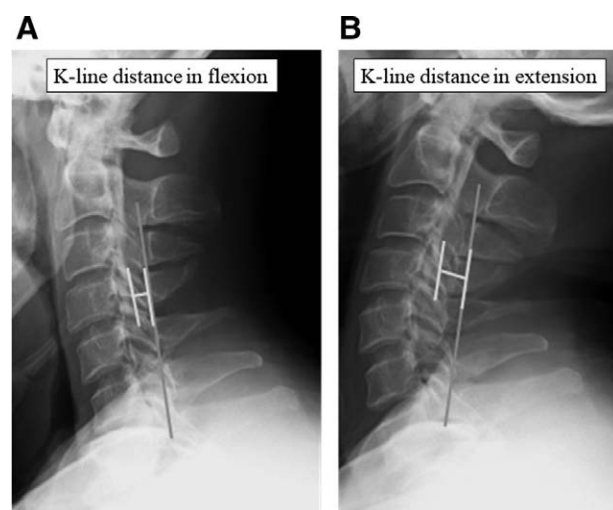


Figure 1. Measurements of radiological parameters, including K-line distance on cervical lateral radiograph. K-line distance was measured as the minimum interval between the K-line and the OPLL on the lateral radiographs. (A) K-line distance in flexion. (B) K-line distance in extension.

Table 1**The modified JOA score.**

- I. Motor function of the upper extremity
0. Impossible to eat with chopsticks or spoon
 1. Possible to eat with spoon but not with chopsticks
 2. Possible to eat with chopsticks, but inadequate
 3. Possible to eat with chopsticks, awkward
 4. Normal
- II. Motor function of the lower extremity
0. Impossible to walk
 1. Needs cane or aid on flat ground
 2. Needs cane or aid only on stairs
 3. Possible to walk without cane or aid but slowly
 4. Normal
- III. Sensory function
- A. Upper extremity
0. Apparent sensory loss
 1. Minimal sensory loss
 2. Normal
- B. Lower extremity
0. Apparent sensory loss
 1. Minimal sensory loss
 2. Normal
- C. Trunk
0. Apparent sensory loss
 1. Minimal sensory loss
 2. Normal
- IV. Bladder function
0. Complete retention
 1. Severe disturbance (sense of retention, dribbling, incomplete continence)
 2. Mild disturbance (urinary frequency, urinary hesitancy)
 3. Normal

LA, preoperative C2-C7 ROM, and the occupying ratio of the OPLL. The parameters were calculated using the following formula: C2-C7 ROM ($^{\circ}$) = (extension C2-C7 Cobb LA) – (flexion C2-C7 Cobb LA). The C2-C7 sagittal vertical axis was defined as the distance from the posterosuperior corner of C7 to the vertical line passing through the center of the C2 body (Fig. 2B).^[11,12] The T1 slope was measured as the angle between a horizontal line and the superior end plate of T1 on standing preoperative lateral radiograph (Fig. 2C).^[11,12] We also calculated the segmental ROM at the level of cervical myelopathy. The level of myelopathy was comprehensively assessed using: clinical examinations, where neuropathology was expected to be the most common cause of myelopathy; the blocked level observed on myelography; and the level of signal intensity (SI) change in the spinal cord on MRI.^[13] Segmental angles were measured between the lines drawn from the inferior margin of the upper vertebral body and the superior margin of the lower vertebral body on lateral flexion and extension radiographs (Fig. 3). Segmental ROM was calculated using the following formula: segmental ROM ($^{\circ}$) = (extension segmental angle) – (flexion segmental angle) on lateral flexion and extension radiographs. The occupying ratio of the OPLL was defined as the greatest thickness of the OPLL divided by the anteroposterior diameter of the bony spinal canal on the preoperative axial CT image. Two independent observers measured each parameter on the images generated using a Digital Imaging and Communications in Medicine viewer on a Digital Imaging and Communications in Medicine workstation; the measurements were obtained using electronic calipers. In the present study, we investigated the reliability of the measurement techniques and found good to excellent intra- and inter-observer agreement for each parameter (kappa > 0.70).

All patients underwent preoperative MRI using a 1.5-T Sigma MRI unit (Symphony; Siemens Medical Solutions, Erlangen, Germany). A modified grading system based on a protocol originally proposed by Yukawa et al^[14] was applied to assess the change in SI of the spinal cord on MRI. On sagittal T2 images,

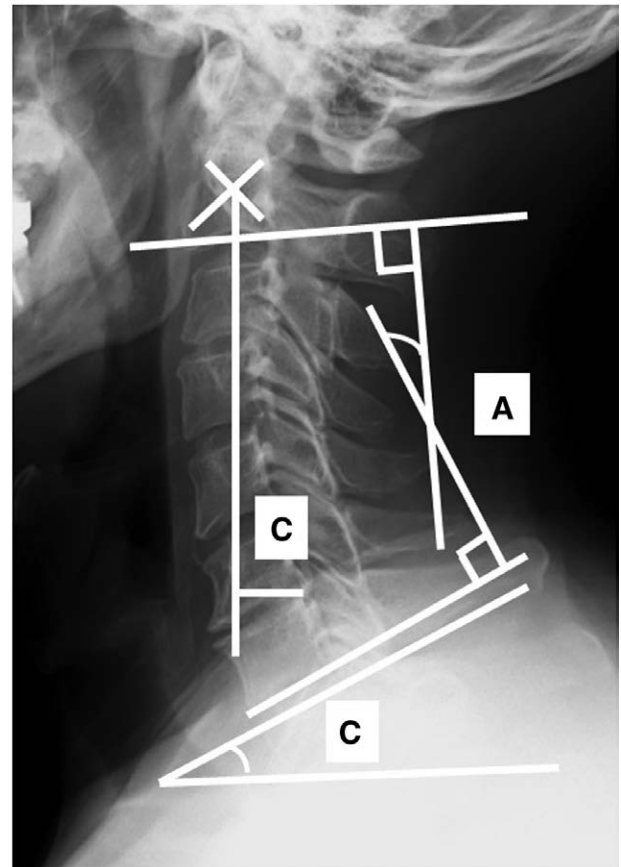


Figure 2. Measurements of radiological parameters, including C2-C7 Cobb lordotic angle (LA), T1 slope, and C2-C7 sagittal vertical axis (SVA) on cervical lateral radiograph. (A) Cervical alignment was assessed using the C2-C7 Cobb LA, which was defined as the angle formed by the inferior end plates of C2 and C7 on standing lateral radiographs. (B) T1 slope was measured as the angle between a horizontal line and the superior end plate of T1. (C) The C2-C7 SVA was defined as the distance from the posterosuperior corner of C7 to the vertical line passing through the center of the C2 body.

increased signal intensity (SI) of the spinal cord at the narrowest level was classified from grade 0 to grade 2 as follows: grade 0, no increase in SI; grade 1, lightly (obscure) increased SI; and grade 2, intense (bright) increased SI. Intensely increased SI (grade 2) was defined as an intensity similar to that of the cerebrospinal fluid signal (Fig. 4). These classifications were made by 2 independent observers. The concordance between the 2 observers in evaluating signal change on T2-weighted images (WI) was good (kappa > 0.76). Two observers established the final classification through a consensus.

2.6. Statistical analysis

Data are presented as the number of subjects in each group or the mean \pm SD. An unpaired *t* test was used to compare continuous variables, and the Mann-Whitney *U* test was used for discrete variables, as appropriate for the data distribution. Interobserver reliability was assessed by reporting both the observed agreement and computing the kappa statistic. The kappa statistic corrects the observed agreement for possible chance agreement among the observers. Spearman correlation coefficients were used to assess the correlations between the independent and dependent variables. Variables with a *P* value < .10 in univariate analysis were considered for multivariate linear analysis. Adjusted odds ratios with 95% confidence intervals are presented with their respective *P* values. Statistical significance was set at *P* < .05.



Figure 3. Measurements of radiological parameters, including segmental angles on cervical lateral radiograph. Segmental angles were measured between the lines drawn from the inferior margin of the upper vertebral body and the superior margin of the lower vertebral body.

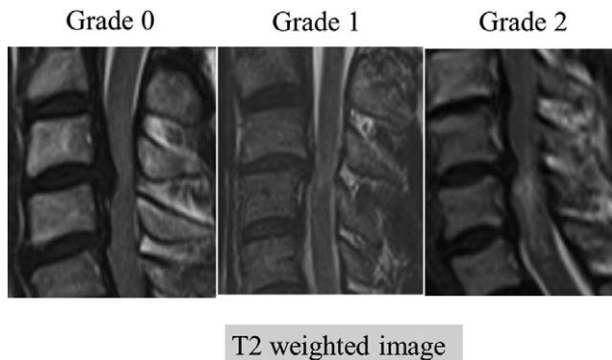


Figure 4. Representative sagittal T2 MRI scans illustrating intramedullary signal intensity loss in patients with cervical OPLL. Grade 0, no increase in signal intensity; grade 1, light (obscure) increased signal intensity; and grade 2, intense (bright) increased signal intensity. Intensely increased signal intensity (grade 2) was defined as an intensity similar to that of the CSF signal of cerebrospinal fluid.

3. Results

3.1. Comparison of clinical features and surgical outcomes in the flexion K-line (+) and flexion K-line (-) groups

Table 2 shows the comparison of clinical features and surgical outcomes between the flexion K-line (+) and flexion K-line (-) groups. The flexion K-line (+) group included 37 patients (27 men and 10 women), with an average age of 65.0 ± 9.7 years (range, 44–82 years). The flexion K-line (-) group included 9 patients (6 men and 3 women), with an average age of 61.8 ± 12.3 years (age range, 44–81 years). The duration of symptoms was 28.2 ± 41.0 months in the flexion K-line (+) group and 20.9 ± 37.7 months in the flexion K-line (-) group. In the flexion K-line (+) group, the mean JOA score was 10.9 ± 1.8 preoperatively and 14.0 ± 1.8 postoperatively, with a mean recovery rate of $52.4 \pm 9.6\%$. In the flexion K-line (-) group, the mean JOA score was 10.9 ± 1.7 preoperatively and 13.6 ± 1.2 postoperatively, with a mean recovery rate of $41.8 \pm 9.1\%$. The JOA score recovery rate in the flexion K-line (-) group was significantly lower than that in the flexion K-line (+) group ($P = .024$). There was no significant difference in the occupying ratio or number of expanded laminae.

3.2. Comparison of radiological measurements in the flexion K-line (+) and flexion K-line (-) groups

Table 3 shows a comparison of radiological measurements in the flexion K-line (+) and flexion K-line (-) groups. The Δ K-line distance was significantly larger in the flexion K-line (-) group than in the flexion K-line (+) group ($P = .037$). The K-line distance in neutral position and preoperative C2-C7 LA in neutral position were significantly larger in the flexion K-line (+) group than in the flexion K-line (-) group ($P = .034$ and $.043$, respectively). (T1 slope)-(C2-C7 LA) was significantly larger in the flexion K-line (-) group than in the flexion K-line (+) group ($P = .037$). Preoperative segmental ROM was significantly larger in the flexion K-line (-) group than in the flexion K-line (+) group ($P = .029$). However, there was no significant difference in preoperative T1 slope, preoperative C2-C7 sagittal vertical axis, preoperative C2-7 ROM, and MRI T2 SI of the spinal cord between the flexion K-line (+) and flexion K-line (-) groups.

3.3. Correlation of the JOA score recovery rate and Δ K-line distance, preoperative segmental ROM and preoperative MRI grade of SI

The Δ K-line distance was significantly negatively correlated with the JOA score recovery rate ($r = -0.531$, $P < .001$). The JOA score recovery rate was negatively correlated with preoperative segmental ROM ($r = -0.453$, $P = .020$) and negatively correlated to preoperative MRI grade of SI ($r = -0.302$, $P = .041$) with significant differences (Table 4).

3.4. Univariate and multiple linear regression analysis of the relationship between the JOA score recovery rate and preoperative measurements

Of the radiological parameters, Δ K-line distance, preoperative segmental ROM, and preoperative MRI SI grade were significant variables ($P < .10$) associated with the JOA score recovery rate, whereas other variables were not significant (Table 5). The Δ K-line distance, preoperative segmental ROM, and preoperative MRI SI grade were included in the multivariate linear regression analysis. Multivariate analysis showed that Δ K-line distance (OR = -2.143 , $P = .015$) was negatively correlated with the JOA score recovery rate (Table 6).

Table 2
Comparison of clinical features and surgical outcomes in flexion K-line (+) group and flexion K-line (-) group.

	Flexion K-line (+) (n = 37)	Flexion K-line (-) (n = 9)	P
Age at operation (yr)	65.0 ± 9.7	61.8 ± 12.3	.476
Duration from onset to operation (mo)	28.2 ± 41.0	20.9 ± 37.7	.618
Occupying ratio of OPLL (%)	44.8 ± 16.0	50.4 ± 14.4	.315
Number of expanded laminae	5.5 ± 1.5	5.5 ± 1.9	.416
Preoperative JOA score	10.9 ± 1.8	10.9 ± 1.7	.952
Postoperative JOA score	14.0 ± 1.8	13.6 ± 1.2	.301
JOA score recovery rate (%)	52.4 ± 9.6	41.8 ± 9.1	.024*

JOA = Japanese Orthopaedic Association, K-line = kyphosis-line, OPLL = ossification of the posterior longitudinal ligament.
 *P < .05.

Table 3
Comparison of radiological measurements in flexion K-line (+) group and flexion K-line (-) group.

	Flexion K-line (+) (n = 37)	Flexion K-line (-) (n = 9)	P
K-line distance in flexion (mm)	2.2 ± 1.8	-4.9 ± 2.0	<.001†
K-line distance in neutral (mm)	4.9 ± 3.3	3.3 ± 1.5	.034*
K-line distance in extension (mm)	7.7 ± 4.2	5.8 ± 5.3	.325
ΔK-line distance (mm)	5.8 ± 3.7	10.7 ± 5.8	.037*
Preoperative C2-C7 LA in neutral (°)	13.3 ± 12.9	3.3 ± 11.8	.043*
Preoperative T1 slope (°)	29.6 ± 7.5	28.2 ± 5.7	.551
(T1 slope)-(C2-C7 LA) (°)	16.2 ± 7.5	24.9 ± 9.9	.037*
Preoperative C2-C7 SVA (mm)	30.0 ± 11.0	34.4 ± 8.1	.246
Preoperative C2-C7 ROM (°)	27.5 ± 13.4	35.6 ± 18.4	.246
Preoperative segmental ROM (°)	7.1 ± 4.4	11.8 ± 5.2	.029*
MRI T2 SI of the spinal cord grade	0.9 ± 0.7	1.2 ± 0.6	.245

K-line = kyphosis-line, LA = lordotic angle, MRI = magnetic resonance imaging, ROM = range of motion, SI = signal intensity, SVA = sagittal vertical axis.
 *P < .05.
 †P < .001.

Table 4
Correlation of the JOA score recovery rate and ΔK-line distance, preoperative segmental ROM and preoperative MRI grade of SI.

Parameter	ΔK-line distance	Preoperative segmental ROM	Preoperative MRI grade of SI
The JOA score recovery rate	-0.531*	-0.453†	-0.302†

JOA = Japanese Orthopaedic Association, K-line = kyphosis-line, MRI = magnetic resonance imaging, ROM = range of motion, SI = signal intensity.
 *P < .001.
 †P < .05.

4. Discussion

The K-line is a simple and practical tool for determining the surgical strategy for patients with cervical OPLL. It reflects both cervical alignment and thickness of the OPLL in 1 radiographic parameter and predicts surgical outcomes. Studies have shown poor postoperative neurologic improvement after laminoplasty in patients with K-line (-) OPLL owing to insufficient posterior shift of the spinal cord and insufficient postoperative spinal cord clearance from the OPLL.^[7,15] Dynamic factors strongly influence the development of myelopathy and surgical outcomes in OPLL patients.^[16-18] Laminoplasty in the case of K-line (+) is often effective for neurological recovery; however, in some cases, recovery after laminoplasty may be inadequate. It is inferred that dynamic factors are involved, and that the evaluation of dynamic factors cannot be performed using only the conventional K-line. Recently, it has been reported that the K-line in the neck-flexed position is a useful indicator of surgical outcome, and flexion K-line (-) has been reported as a risk factor for poor clinical outcomes after cervical laminoplasty.^[8,9] In fact, in the present study, the mean preoperative JOA score

Table 5
Univariate analysis between JOA score recovery rate and clinical and radiological parameters.

Variable	P value
Age at operation (yr)	.140
Duration from onset to operation (mo)	.633
Occupying ratio of OPLL (%)	.239
Preoperative JOA score	.104
K-line distance in flexion (mm)	.145
K-line distance in neutral (mm)	.419
K-line distance in extension (mm)	.180
ΔK-line distance (mm)	<.001**
(T1 slope)-(C2-C7 LA) (°)	.114
Preoperative C2-C7 SVA (mm)	.875
Preoperative C2-C7 ROM (°)	.496
Preoperative segmental ROM (°)	.020*
Preoperative MRI T2 SI grade	.041*

JOA = Japanese Orthopaedic Association, K-line = kyphosis-line, LA = lordotic angle, MRI = magnetic resonance imaging, OPLL = ossification of the posterior longitudinal ligament, ROM = range of motion, SI = signal intensity, SVA = sagittal vertical axis.
 *P < .05.
 **P < .001.

in the flexion K-line (-) group was significantly lower than that in the flexion K-line (+) group (P = .024). Although the flexion K-line indicates a part of the compressive spinal lesion from the OPLL in the neck flexion position, dynamic factors in the cervical spine have not been quantitatively evaluated using 1 radiographic image. Therefore, we proposed a “K-line distance” as the distance from K-line to OPLL, that simply and quantitatively evaluates the thickness of OPLL and cervical alignment and dynamic factors. The “ΔK-line distance” was calculated as

Table 6
Multivariate analysis of factors associated with the Japanese Orthopaedic Association (JOA) score recovery rate.

	Odds ratios	95% confidence intervals	P value
ΔK-line distance	-2.143	(-3.848)–(-0.438)	.015*
Preoperative segmental ROM	-0.149	(-1.718)–(-1.419)	.849
Preoperative MRI SI grade	-6.283	(-14.113)–(-1.547)	.113

K-line = kyphosis-line, MRI = magnetic resonance imaging, ROM = range of motion, SI = signal intensity.

* $P < .05$.

the difference between the K-line distance from the extension position to the flexion position in the cervical spine.

In the present study, ΔK-line distance was significantly negatively correlated with the JOA score recovery rate ($r = -0.531$, $P < .001$). In contrast, univariate analysis showed that the K-line distance in flexion was not a significant variable ($P = .145$). Additionally, multivariate analysis showed that ΔK-line distance (OR = -2.143, $P = .015$) was negatively correlated with the JOA score recovery rate. Our findings indicate that the K-line in the flexed neck position is simple, but not sufficient to assess dynamic factors. The ΔK-line distance, which considers dynamic factors and cervical alignment, is a good indicator of surgical outcomes for patients with cervical OPLL.

Many factors have been suggested to predict surgical outcomes in patients with OPLL by previous papers.^[16–19] Specifically, the diagnostic and prognostic relevance of high-signal changes in the spinal cord on magnetic resonance imaging (MRI) has been widely studied. Several studies have reported that patients with high-signal changes on T2-WI have a poor prognosis after surgery.^[4,20,21] Sun et al also reported that signal hyperintensity on T2WI and signal hypointensity on T1WI indicated severe damage to the spinal cord in patients with OPLL.^[20] Kalb et al^[21] reported that preoperative JOA scores were lower in patients with high signal changes on MRI than in those without such changes. Our present findings are in agreement with these previous observations, namely that the JOA score recovery rate was negatively correlated with the preoperative MRI grade of SI with significant differences ($r = -0.302$, $P = .041$).

In the present study, the preoperative segmental ROM was significantly larger in the flexion K-line (-) group than in the flexion K-line (+) group ($P = .029$). Furthermore, the preoperative segmental ROM was negatively correlated with the JOA score recovery rate ($r = -0.453$, $P = .02$). Based on these results, the preoperative segmental dynamic factor is important for determining postoperative neurological recovery. The increase in cervical segmental mobility at the level of the remaining ossification mass may stimulate the maturation of ossification and aggravate the impingement of the mass on the spinal cord.^[22] Additionally, a pincer phenomenon has been described in the cervical spinal cord, in which unstable cervical segments may exhibit subluxation during flexion, extension, or both, and pinch the spinal cord.^[18] Repeated minor trauma from movement disorders may cause irreversible and severe damage to the spinal cord.^[23,24]

In the present study, patients with OPLL presenting with a flexion K-line (-) had a less lordotic cervical alignment and a greater mismatch between the T1 slope and the C2-C7 angle than patients with a flexion K-line (+). A great difference between T1 slope and C2-C7 angle is regarded as a mismatch of cervical sagittal balance.^[25] Therefore, effective compensation of the cervical alignment was not achieved in the flexion K-line (-) group after laminoplasty, and neurological recovery may have led to inadequate results.

One limitation of the present study is its relatively small sample size and retrospective study design. In addition, the postoperative follow-up period may not have been long enough to

assess potential neurological deterioration. Evaluation of OPLL type as a risk factor for the clinical outcome of laminoplasty was also attempted. A prospective randomized study with a larger sample size and longer follow-up period is required to clarify the usefulness of ΔK-line distance and elucidate the influence of these factors on the clinical outcome after laminoplasty in cases of cervical OPLL.

5. Conclusion

We analyzed the relationship between ΔK-line distance and surgical outcomes in cases of laminoplasty for OPLL of the cervical spine. The ΔK-line distance was significantly negatively correlated with the JOA score recovery rate. From these results, we suggest that the ΔK-line distance used in the present study is useful in that the dynamic and static compression factors due to OPLL can be quantitatively evaluated by measuring dynamic radiographic images.

Author contributions

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