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Original Article

Corresponding Author
Sun Joon Yoo
https://orcid.org/0000-0002-6161-1847

Department of Neurosurgery, Yongin Severance Hospital, Yonsei University College of Medicine, 363 Dongbaekjukjeon-daero, Giheung-gu, Yongin 16995, Korea
Email: nsysj@yuhs.ac

Co-corresponding Author
Chang Kyu Lee
https://orcid.org/0000-0002-1366-3677

Department of Neurosurgery, Severance Hospital, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea
Email: NSCKLEE@yuhs.ac

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Flexion K-Line Status Predicts Surgical Strategy in Multilevel Cervical Ossification of the Posterior Longitudinal Ligament: A Multicenter Comparison of Laminoplasty and Laminectomy With Fusion

Jun Jae Shin[1], Sun Joon Yoo[1], Se Jun Park[1], Dong Kyu Kim[2], Hyun Jun Jang[2], Bong Ju Moon[2], Kyung Hyun Kim[2], Jeong Yoon Park[2], Sung Uk Kuh[2], Dong Kyu Chin[2], Keun Su Kim[2], Yong Eun Cho[2], Chang Kyu Lee[3], Dong Ah Shin[3], Seong Yi[3], Keung Nyun Kim[3], Joongkyum Shin[4], Yoon Ha[3]

[1]Department of Neurosurgery, Yongin Severance Hospital, Yonsei University College of Medicine, Yongin, Korea
[2]Department of Neurosurgery, Gangnam Severance Hospital, Yonsei University School of Medicine, Seoul, Korea
[3]Department of Neurosurgery, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea
[4]University of Pacific, Stockton, CA, USA

Objective: To evaluate the clinical significance of a negative K-line in the neck flexion position (FK-line [-]), which indicates that cervical ossification of the posterior longitudinal ligament (OPLL) crosses the K-line during flexion, and to compare surgical outcomes between laminoplasty (LP) and laminectomy with fusion (LF) for multilevel FK-line (-) cervical OPLL.
Methods: A total of 349 patients with multiple cervical OPLL who underwent posterior decompression surgery (LP or LF) with a minimum of 2 years of follow-up were stratified by FK-line status. Clinical and radiological parameters were compared between the FK-line (+) and FK-line (-) groups. Subgroup analysis of FK-line (-) patients evaluated the efficacy of LP versus LF. Multivariate regression identified predictors of neurological recovery.
Results: Patients with FK-line (-) OPLL exhibited a smaller FK-line distance, more kyphotic alignment, greater cervical flexion, and lower recovery ratios compared to those with FK-line (+). In the FK-line (-) subgroup, LF achieved a significantly greater increase in FK-line distance, better correction of the flexion angle, and more neurological recovery than LP. Multivariate analyses identified postoperative FK-line distance, C2–7 flexion angle, and preoperative dynamic extension reserve as independent predictors of neurological outcomes.
Conclusion: FK-line status reflects the sagittal cord position and predicts surgical outcomes in cervical OPLL. In FK-line (-) patients, LF provides better neurological recovery and more effective posterior cord shift and kyphotic alignment correction than LP. Incorporating FK-line assessment to guide surgical planning could improve individualized treatment outcomes for multilevel OPLL.

Keywords: K-line, Flexion K-line, Ossification of the posterior longitudinal ligament, Sagittal alignment, Laminectomy with fusion, Laminoplasty

INTRODUCTION

The K-line is a useful measure for evaluating cervical curvature and informing surgical strategy in patients with cervical ossification of the posterior longitudinal ligament (OPLL).[1] Cervical laminoplasty (LP) generally results in favorable neurological outcomes in patients with K-line (+) and multilevel OPLL involving more than 3 levels, whereas poor outcomes have been reported in K-line (-) patients.[1] However, even when LP is performed in patients with preoperative K-line (+) in a neutral position, some patients still experience suboptimal recovery.

Dynamic mechanical factors are significant contributors to the development and progression of the cervical myelopathy associated with OPLL.[2,3] Although the importance of static assessments of the K-line has been reported, this does not fully reflect dynamic cord compression during neck movement. In particular, K-line status changes according to neck flexion position and has been shown to correlate with clinical outcomes.[4] Patients who are K-line (+) in the neutral position but become K-line (-) during flexion (FK-line [-]) exhibit poor outcomes after LP.[4,5] This discrepancy indicates that flexed radiographs provide additional clinical value in surgical planning by identifying dynamic cord compression that is not apparent in the neutral position.

Although a few studies have proposed that laminectomy with fusion (LF), which restricts cervical flexion and stabilizes sagittal alignment in FK-line (-) OPLL patients,[6] has potential benefits, no study has examined how instrumentation fixation affects the surgical outcomes of FK-line (-) OPLL patients. Furthermore, no comparison of surgical outcomes between LP and LF in patients with preoperative FK-line (-) has been conducted.

Among patients with cervical myelopathy caused by multilevel OPLL, this retrospective study compares clinical and radiological outcomes after LP and LF according to FK-line status. The aim was to analyze the relationship between changes in cervical parameters and neurological outcomes, especially focusing on preoperative FK-line (-) patients. Additionally, the study examines how changes in cervical parameters after surgery predict neurological recovery in FK-line (-) OPLL patients.

MATERIALS AND METHODS

1. Patient Demographics

This study was approved by the Institutional Review Board (IRB No. 2-2024-0541).

This retrospective multicenter study analyzed patients with OPLL from 3 university-affiliated hospitals. Between January 2017 and December 2023, 426 patients with multilevel OPLL (involving more than 3 vertebral levels) underwent posterior decompression surgery, either LP or LF. Among them, 69 patients were excluded due to insufficient follow-up (39 patients), the absence of initial dynamic radiographs (5 patients), or other confirmed neurological disorders (25 patients), such as Parkinson disease, cerebral infarction, or hemorrhage. Additionally, 8 patients who underwent combined anterior-posterior decompression were excluded due to small sample size. Ultimately, data for 349 patients with a minimum follow-up of 2 years were analyzed (Fig. 1). OPLL was confirmed by plain radiographs and computed tomography (CT). Cervical myelopathy was diagnosed based on radiographic evidence of cord compression and upper motor neuron signs on neurological examination. Exclusion criteria included trauma, infection, tumor, prior cervical surgery, circumferential fusion, and other neurological disorders.

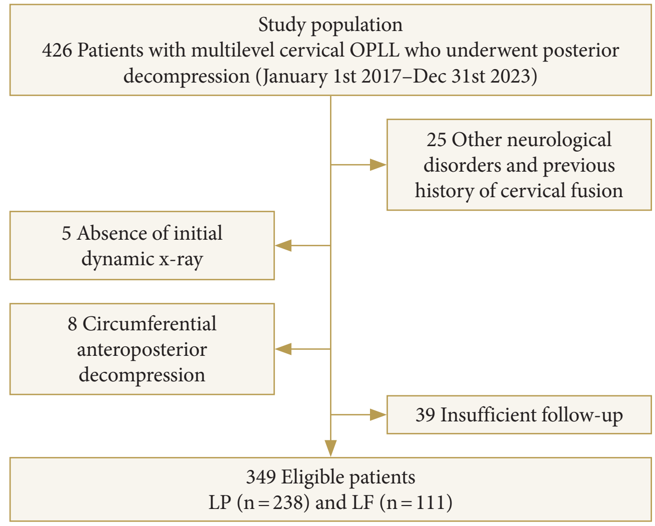

Fig. 1. Patient selection flow chart. OPLL, ossification of the posterior longitudinal ligament.

2. Radiologic Assessments

The radiologic assessments were the C2 slope (C2S), C2–7 Cobb angle (CA), C2–7 sagittal vertical axis (SVA), T1 slope (T1S), C2–7 range of motion (ROM), canal occupying ratio (COR), and OPLL type. The radiographic measurements were defined as follows: C2S, the angle between the lower endplate of C2 and the horizontal plane; CA, the Cobb angle between the lower endplates of C2 and C7; SVA, the distance from the centroid of C2 to the posterior-superior corner of C7; and T1S, the angle between the upper endplate of T1 and the horizontal plane in a standing lateral view radiograph (Fig. 2A).[7] ROM was de-

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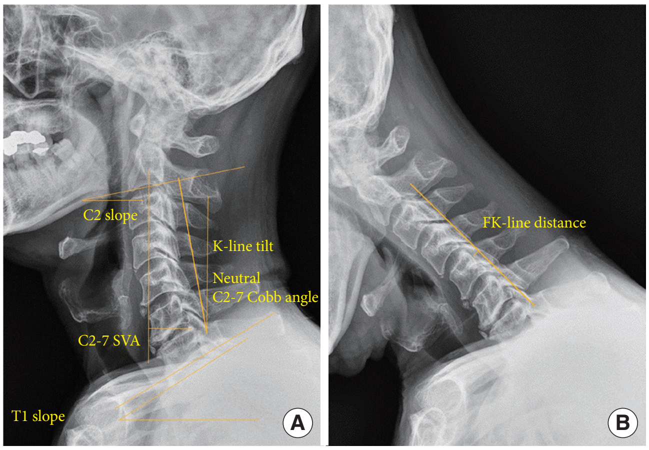

Fig. 2. Measurement of radiologic parameters. (A) Sagittal alignment parameters: C2 slope (angle between the inferior endplate of C2 and the horizontal plane), T1 slope (angle between the superior endplate of T1 and the horizontal plane), C2–7 Cobb angle (angle between the inferior endplates of C2 and C7), C2–7 sagittal vertical axis (SVA; horizontal distance from the centroid of C2 to the posterior-superior corner of C7), and K-line tilt (angle between the K-line and a line perpendicular to the horizontal plane). (B) FK-line distance, defined as the shortest distance between the flexion K-line and the posterior border of the nearest vertebral body on a lateral flexion radiograph in patients with ossification of the posterior longitudinal ligament.

fined as the difference between the extension CA and flexion CA. Dynamic extension reserve (DER) was calculated as the difference between the extension and neutral C2–7 CA, representing extension function.[7] OPLL was classified preoperatively on CT into segmental, continuous, mixed, or localized types.[8] COR was calculated as the maximum thickness of the OPLL divided by the anteroposterior diameter of the spinal canal at the most affected level. The K-line was drawn by connecting the midpoints of the spinal canal at C2 and C7 on lateral radiographs to determine whether the OPLL crossed (K-line [-]) or did not cross (K-line [+]) that line. We assessed the K-line in the neck-flexed position (FK-line) and indicated that the OPLL mass never crossed the K-line posteriorly (FK-line [+]) or crossed it (FK-line [-]). FK-line tilt was defined as the angle between the FK-line and a perpendicular line to the horizon during flexion. The FK-line distance was defined as the shortest distance between the FK-line and the posterior border of the vertebral body line, as shown on an OPLL lateral neck flexion radiograph in Fig. 2B. Spinal cord signal intensity was graded on T2-weighted magnetic resonance imaging (MRI) at the site of maximal compression as follows: grade 0, none; grade 1, faint and indistinct; and grade 2, intense and well-defined.[2,9] The radiological parameters in the cervical neutral and flexion states were measured and analyzed using software (ZeTTA PACS, TaeYoung Soft Co., Ltd., Korea). Radiographic measurements were collected from the database and independently reviewed by 2 surgeons (CKL and JJS). Discrepancies were resolved through consensus discussion. The representative radiographic figure demonstrates the FK-line measurement technique using annotated lines and arrows to enhance reproducibility and clarity (Fig. 3).

3. Assessment of Clinical Outcomes

Clinical outcomes were evaluated using a patient-reported visual analogue scale (VAS) for neck pain and the Japanese Orthopaedic Association (JOA) score.[10] Data were assessed preoperatively and at least 24 months postoperatively. The JOA recovery ratio was calculated as: JOA recovery ratio (%) = (postoperative JOA score – preoperative JOA score)/(17 [total score] – preoperative JOA score).

4. Surgical Procedures

The surgical policy involved assessing the patient's comorbidities.[11] LP was preferred in patients with preserved preoperative lordosis, whereas LF was performed in patients with kyphotic alignment greater than 10° to minimize further loss of lordosis. When OPLL extended to C7 or T1, fusion was extended to the lower levels across the cervicothoracic junction. LP was performed through a midline approach with bilateral muscle detachment, removal of the spinous process, creation of unilateral gutters, and fixation using posterior cervical titanium miniplates (Centerpiece, Medtronic Sofamor Danek, USA), which maintained the "door" in the open position. LF involved laminectomy with posterior fusion using lateral mass screws (C1 and C3–6) and pedicle screws (C2 and C7), with autologous bone grafting. Postoperatively, all patients wore either a Miami collar or a Philadelphia brace for approximately 3 months. Follow-up included clinical and radiographic evaluations 1, 3, and 6 months postoperatively and every 6 months thereafter.

5. Statistical Analysis

Continuous variables are reported as the mean ± standard deviation or percentage. Normally distributed data were compared using Student t-test or analysis of variance, while non-normally distributed data were compared using the Mann-Whitney U-test or Kruskal-Wallis test. For categorical variables, cross-tabulation analysis was conducted to compare distributions between groups. The chi-square test was used to assess statistical

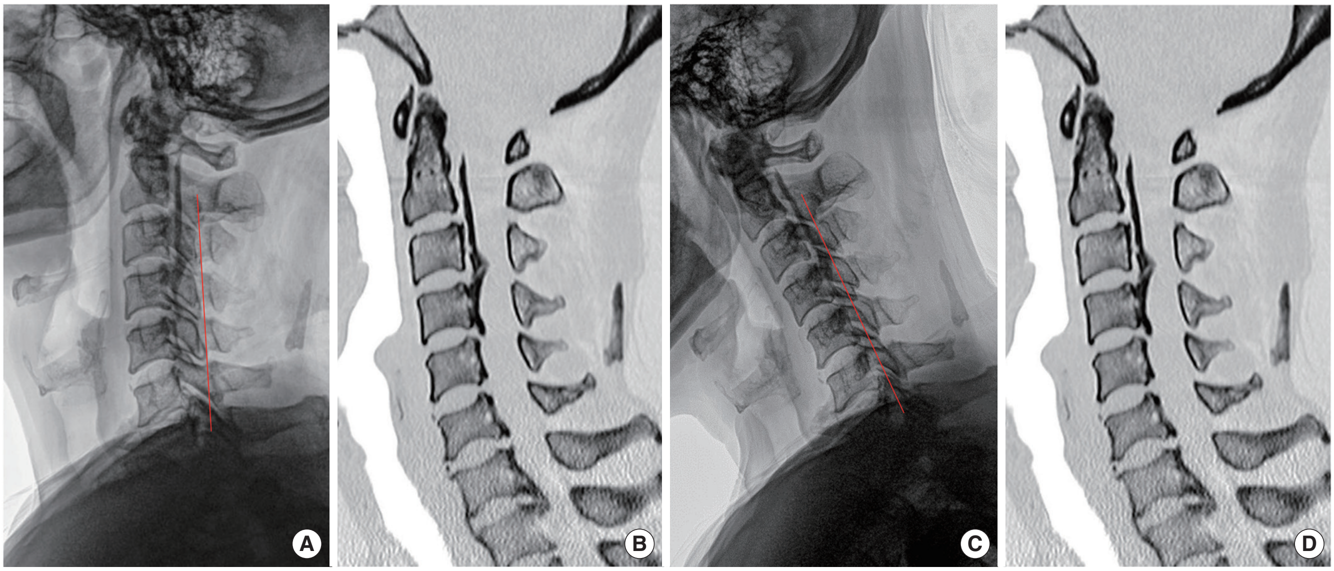

Fig. 3. FK-line measurement technique. (A) The plain lateral radiograph is inverted to enhance visualization of the OPLL mass. The K-line is drawn to assess its relationship to the lesion. (B) An inverted computed tomography (CT) sagittal image is used to confirm OPLL boundaries, correlating with the radiographic image. (C) On flexion lateral radiographs, the FK-line is evaluated for positive or negative status. (D) When the interpretation of the FK-line is ambiguous on radiographs, the inverted CT image is rotated to simulate the neck flexion posture, improving the consistency and reproducibility of the assessment. FK-line, flexion K-line; OPLL, ossification of the posterior longitudinal ligament.

significance, and Fisher exact test was applied when the expected frequency for any category was less than 5. Correlations between the recovery ratio and radiologic or clinical factors were assessed using Pearson's correlation and analysis of variance, as appropriate. Multivariate stepwise regressions were performed to identify independent predictors of neurological recovery. Statistical significance was set at $p < 0.05$. All analyses were conducted using MedCalc ver. 23.2.8 (MedCalc Software Ltd., Belgium).

RESULTS

A total of 349 patients (257 males and 92 females) underwent posterior cervical decompression, with 238 treated by LP and 111 by LF, for multilevel cervical OPLL. There were 226 patients with neutral K-line (+) and 123 with neutral K-line (-). Among the 226 patients classified as neutral K-line (+), 107 (47.35%) were FK-line (-) on flexion radiographs (Supplementary Fig. 1). Ultimately, 119 patients were in the FK-line (+) group, and 230 were in the FK-line (-) group. The mean follow-up period was 43.2 ± 18.7 (range, 25–64) months, and the average age at surgery was 57.32 ± 10.17 (range, 34–82) years. Baseline demographic and clinical characteristics stratified by FK-line status are summarized in Table 1.

1. Clinical and Radiographic Characteristics According to FK-Line Status

Age did not differ significantly between the FK-line (+) and FK-line (-) groups; however, the FK-line (-) group had a significantly higher proportion of male patients ($p = 0.014$) and a higher number of operated levels ($p = 0.037$). FK-line (-) patients exhibited a smaller FK-line distance, larger C2S, lower T1S, and reduced C2–7 CA, indicating a more kyphotic alignment than FK-line (+) patients. The FK-line (-) group demonstrated a significantly higher COR ($p = 0.009$), suggesting more severe spinal cord compression. Additionally, those with FK-line (-) showed greater cervical flexion; however, C2–7 SVA, FK-line tilt angle, ROM, and DER did not differ significantly between groups. Preoperative JOA scores were similar, but postoperative recovery ratios were significantly higher in the FK-line (+) group ($p = 0.011$). The distribution of OPLL subtypes did not differ significantly between the groups (Table 1).

2. Comparison of LP and LF in FK-Line (-) Patients

In the FK-line (-) subgroup, 133 patients underwent LP, and 97 underwent LF. Patients who underwent LF were significantly older ($p < 0.001$), more often male ($p = 0.007$), and had more operative levels ($p < 0.001$) than those in the LP group. The LF group demonstrated significantly greater posterior cord shift,

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Table 1. Clinical and radiological characteristics according to FK-line status

Characteristic	FK-line (+) (n = 119)	FK-line (-) (n = 230)	p-value
Age (yr)	58.98 ± 8.80	58.39 ± 9.59	0.575
Sex, male:female	78:41	179:51	0.014*
FK-line distance (mm) pre	4.15 ± 1.61	0.51 ± 3.33	< 0.001*
C2S (°) pre	12.38 ± 8.72	15.43 ± 8.14	0.006*
T1S (°) pre	26.93 ± 5.98	24.09 ± 6.49	0.001*
C2–7 SVA (mm) pre	26.20 ± 12.36	23.06 ± 12.05	0.161
C2–7 CA (°) pre	13.17 ± 8.87	7.56 ± 9.68	< 0.001*
C2–7 flex CA (°) pre	-11.62 ± 10.29	-18.03 ± 11.04	< 0.001*
DER pre	9.61 ± 8.71	9.01 ± 11.28	0.845
K-line tilt (°) pre	8.82 ± 7.50	9.23 ± 7.31	0.608
FK-line tilt (°) pre	26.94 ± 9.01	28.04 ± 9.24	0.493
ROM (°) pre	35.09 ± 12.62	36.72 ± 13.43	0.189
COR (%) pre	44.92 ± 13.02	48.51 ± 13.91	0.009*
No. of operated levels	3.53 ± 0.96	3.76 ± 1.02	0.037*
OPLL type			0.140
Segmental	36 (30.25)	54 (23.48)	
Continued	37 (31.09)	65 (28.26)	
Mixed	43 (36.14)	98 (42.61)	
Other	3 (2.52)	13 (5.65)	
JOA score			
Pre	12.66 ± 2.89	12.48 ± 2.24	0.056
Final	14.89 ± 2.90	14.71 ± 1.91	0.004*
Recovery ratio (%)	58.91 ± 36.47	49.18 ± 36.19	0.011*

Values are presented as mean ± standard deviation or number (%).
FK-line, flexion K-line; FK-line distance, the distance from the flexion K-line to the posterior vertebral body line; C2S, C2 slope; T1S, T1 slope; SVA, sagittal vertical axis; CA, Cobb angle; C2–7 flex CA, C2–7 flexion Cobb angle; DER, dynamic extension reserve; ROM, range of motion; COR, canal occupying ratio; OPLL, ossification of the posterior longitudinal ligament; JOA, Japanese Orthopaedic Association; Pre, preoperative.
*p < 0.05, statistically significant differences.

reflected by a larger increase in the FK-line distance (p = 0.021), and more effective correction of the C2–7 flexion angle (p = 0.001). These radiologic improvements corresponded with better neurological recovery in the LF group, evidenced by a greater JOA score improvement (p < 0.001) and a higher recovery ratio (p = 0.023), despite a lower preoperative functional baseline. ROM reduction was more pronounced in the LF group. Operative time and intraoperative blood loss were significantly higher in the LF group than in the LP group. However, the incidence of postoperative complications (C5 palsy, hematoma, du-

Table 2. Comparison of clinical and radiological outcomes between LP and LF in FK-line (-) patients

Variable	LP (n = 133)	LF (n = 97)	p-value
Age (yr)	56.37 ± 8.74	61.90 ± 10.05	< 0.001*
Sex, male:female	106:27	73:24	0.424
FK-line distance (mm)			
Preoperative	0.28 ± 2.49	0.33 ± 3.46	0.928
Final	3.96 ± 4.08	5.71 ± 3.08	0.021*
C2S (°)			
Preoperative	13.37 ± 7.39	16.67 ± 8.83	0.015*
Final	18.17 ± 27.35	21.06 ± 8.56	0.050
T1S (°)			
Preoperative	24.72 ± 6.14	26.71 ± 6.30	0.051
Final	24.04 ± 6.11	27.28 ± 6.89	0.003*
C2–7 SVA (mm)			
Preoperative	22.65 ± 12.78	25.32 ± 12.21	0.294
Final	28.43 ± 12.79	31.27 ± 11.93	0.146
C2–7 CA (°)			
Preoperative	8.66 ± 10.00	9.03 ± 9.09	0.313
Final	5.97 ± 9.45	4.53 ± 8.87	0.317
C2–7 flex CA (°)			
Preoperative	-16.85 ± 11.12	-14.68 ± 10.90	0.184
Final	-11.20 ± 11.61	-7.01 ± 9.78	0.001*
DER pre	6.89 ± 10.77	5.99 ± 12.67	0.913
K-line tilt (°)			
Preoperative	7.36 ± 6.37	12.07 ± 8.95	0.008*
Final	10.26 ± 7.53	14.65 ± 7.36	0.011*
FK-line tilt (°)			
Preoperative	25.94 ± 9.35	27.76 ± 7.93	0.311
Final	25.13 ± 15.23	25.32 ± 9.46	0.572
ROM (°)			
Preoperative	35.06 ± 13.08	33.44 ± 13.49	0.411
Final	24.02 ± 12.83	15.48 ± 9.58	< 0.001*
COR (%)	47.17 ± 14.32	48.32 ± 13.12	0.707
JOA score			
Preoperative	13.07 ± 1.73	11.68 ± 2.59	< 0.001*
Final	14.86 ± 1.61	14.51 ± 2.25	0.595
Change	1.83 ± 1.52	2.83 ± 2.09	< 0.001*
Recovery ratio (%)	44.85 ± 37.88	55.13 ± 32.98	0.023*
Neck VAS score			
Preoperative	4.00 ± 2.57	4.23 ± 2.94	0.4712
Final	2.34 ± 1.74	2.51 ± 1.79	0.4951
Change	-1.66 ± 2.27	-1.74 ± 2.95	0.5227

(*Continued*)

Table 2. Comparison of clinical and radiological outcomes between LP and LF in FK-line (-) patients (Continued)

Variable	LP (n = 133)	LF (n = 97)	p-value
No. of operated levels	3.47 ± 0.85	4.26 ± 1.09	< 0.001*
Operation time (min)	157.00 ± 44.38	212.29 ± 75.97	< 0.001*
Blood loss (mL)	432.03 ± 307.46	763.66 ± 596.77	< 0.001*
OPLL type			0.5430
Segmental	32 (24.06)	22 (22.68)	
Continued	36 (27.07)	30 (30.93)	
Mixed	58 (43.61)	41 (42.27)	
Other	7 (5.26)	4 (4.12)	
Complications	6	8	0.8871
C5 palsy	2	3	
Hematoma	1	1	
Revision	1	1	
Dura tear	2	3	

Values are presented as mean ± standard deviation or number (%).
LP, laminoplasty; LF, laminectomy with fusion; FK-line, flexion K-line; FK-line distance, the distance from the flexion K-line to the posterior vertebral body line; C2S, C2 slope; T1S, T1 slope; SVA, sagittal vertical axis; CA, Cobb angle; C2–7 flex CA, C2-7 flexion Cobb angle; DER, dynamic extension reserve; ROM, range of motion; COR, canal occupying ratio; JOA, Japanese Orthopaedic Association; VAS, visual analogue scale; OPLL, ossification of the posterior longitudinal ligament.
*p < 0.05, statistically significant differences.

ral tear, and revision) did not differ significantly between groups (Table 2). Additionally, among the 123 patients with neutral K-line (-), 74 underwent LP, often due to comorbidities or surgical preference. These patients had a lower mean JOA recovery rate compared to those who underwent LF, as shown in Supplementary Table 1.

3. Multivariate Regression Analysis of Cervical Parameters for Neurologic Improvement

The stepwise multivariate regression analyses identified postoperative FK-line distance, postoperative C2–7 flexion Cobb angle, and preoperative DER as independent predictors of neurological recovery (Table 3). Increased postoperative FK-line distance was positively associated with the JOA recovery ratio (β = 3.06, p = 0.001), indicating that greater posterior cord shift contributed to better outcomes. Higher DER was positively associated with recovery (β = 0.68, p = 0.039), and increased postoperative C2–7 kyphosis during flexion was negatively associated with recovery (β = -0.89, p = 0.011).

Table 3. Stepwise multivariate regression analyses of cervical parameters predicting JOA neurological recovery

Variable	Multivariate analysis	
	Model: (R^2 = 0.205, p < 0.001)	
	β-coefficient	p-value
FK-line distance postoperative	3.056	0.001*
C2–7 flex CA postoperative	-0.887	0.011*
DER	0.683	0.039*

JOA, Japanese Orthopaedic Association; FK-line, flexion K-line; CA, Cobb angle; DER, dynamic extension reserve.
*p < 0.05, statistically significant differences.

4. Changes in Cervical Parameters After LP and LF in FK-Line (-) Patients

In FK-line (-) patients, LF resulted in a significantly greater increase in FK-line distance than LP (p = 0.003), indicating a more pronounced posterior cord shift. Although changes in C2S, C2–7 CA, and T1S tended to favor LF over LP, suggesting a potential advantage of LF in improving sagittal alignment, those differences did not reach statistical significance. Representative cases are illustrated in Figs. 4 and 5.

DISCUSSION

This study investigated the clinical significance of FK-line status and compared the surgical outcomes of LP and LF in patients with multilevel cervical OPLL, focusing on those with FK-line (-). FK-line (-) patients exhibited a smaller FK-line distance, lower C2–7 CA, higher COR, larger C2S, and lower T1S, indicating a more kyphotic alignment and greater cervical flexion angle than FK-line (+) patients. Neurological recovery and sagittal alignment were poorer in FK-line (-) patients following posterior decompression. Among FK-line (-) patients, LF achieved better correction of kyphotic alignment, greater posterior cord shift, and superior neurological outcomes compared with LP. Additionally, multivariate analysis identified postoperative FK-line distance, postoperative C2–7 flexion angle, and preoperative DER as independent predictors of neurological recovery.

Dynamic factors, such as neck flexion and extension, influence the progression of myelopathy in OPLL by altering the sagittal diameter of the spinal canal and increasing anterior cord compression.[2,3,12] Takeuchi et al.[4] reported poor clinical outcomes after LP in OPLL patients with K-line (+) in the neutral position and K-line (-) in the neck flexion position. Nori et al.[6] also observed higher incidences of residual spinal cord compression and poorer outcomes in FK-line (-) patients after LP. Unlike

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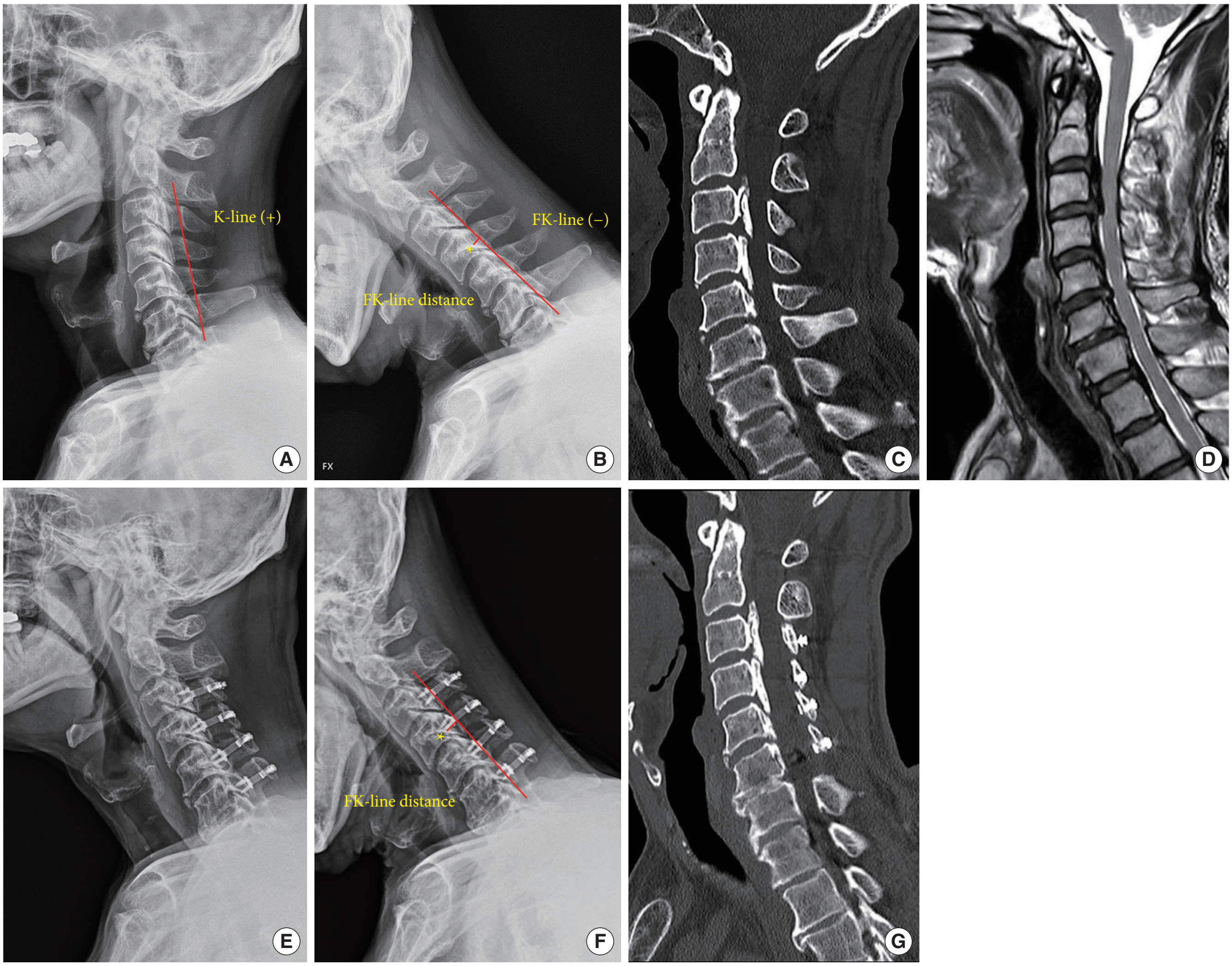

Fig. 4. Representative case of LP in a patient with FK-line (-). A 59-year-old man with cervical OPLL involving C3–T1 presented with bilateral numbness, weakness, and gait ataxia. (A) Preoperative radiograph showed lordotic alignment and a positive K-line. (B) Flexion radiograph revealed a negative K-line (FK-line [-]) with an FK-line distance of 4.7 mm (asterisk). (C) Sagittal computed tomography (CT) showed mixed-type OPLL from C3 to T1. (D) T2-weighted magnetic resonance imaging demonstrated significant spinal cord compression. (E) Postoperative radiograph after LP at C3–6 showed loss of cervical lordosis. (F) Postoperative flexion radiograph showed a kyphotic C2–7 angle and an FK-line distance of 5.0 mm (asterisk). (G) Postoperative CT scan confirmed widening of the spinal canal. The JOA score improved from 12 to 13 (recovery rate: 20%) at 2-year follow-up. LP, laminoplasty; FK-line, flexion K-line; OPLL, ossification of the posterior longitudinal ligament; JOA, Japanese Orthopaedic Association.

prior reports,[4,6] our study directly compared LP and LF in the FK-line (-) subgroup and identified specific radiologic predictors of recovery, reinforcing the clinical relevance of FK-line status in surgical planning.

During flexion, the cervical spinal cord moves more anteriorly and elongates longitudinally, resulting in increased ventral compression and mechanical stress.[13] An anterior shift of the spinal cord during flexion places pressure on the ventral gray matter, including the anterior horn laminae and adjacent corticospinal tracts near the anterior median fissure. This compression may disrupt axonal integrity and compromise microvascular perfusion in the anterior spinal artery territory, resulting in ischemia and motor pathway injury, which likely contributes to poor postoperative neurological recovery.[3] These pathophysiological changes are supported by MRI signal alterations and diffusion tensor imaging evidence of microstructural damage.[14] Specifically, in cervical kyphotic alignment, the ventral OPLL mass exacerbates anterior spinal cord compression, leading to

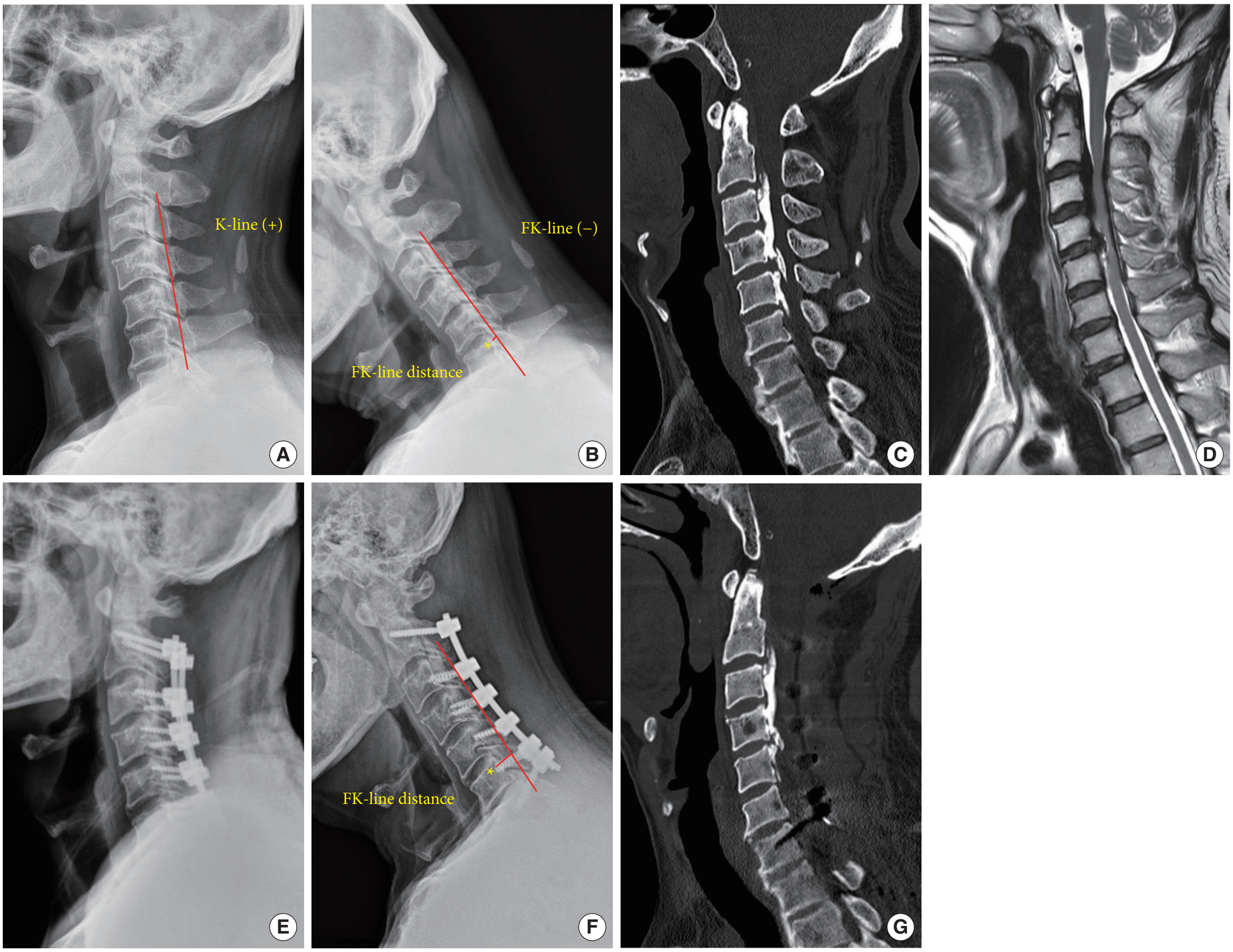

Fig. 5. Representative case of LF in a patient with FK-line (-). A 64-year-old man with cervical OPLL involving C2–6 presented with bilateral numbness and weakness in all extremities. (A) Preoperative radiograph revealed a slightly kyphotic alignment and a positive K-line. (B) Flexion radiograph revealed a negative K-line (FK-line [-]) with an FK-line distance of 3.1 mm (asterisk). (C) Sagittal computed tomography (CT) demonstrated mixed-type OPLL from C2 to C6. (D) T2-weighted magnetic resonance imaging confirmed severe spinal cord compression. (E) Postoperative radiograph following LF at C2–7 showed improved alignment. (F) Postoperative flexion radiograph demonstrated correction of the kyphotic C2–7 angle and an increased FK-line distance of 13.0 mm (asterisk). (G) Postoperative CT confirmed effective decompression of the spinal canal. The JOA score improved from 12 to 16 (recovery rate: 80%) at 2-year follow-up. LF, laminectomy with fusion; FK-line, flexion K-line; OPLL, ossification of the posterior longitudinal ligament; JOA, Japanese Orthopaedic Association.

insufficient decompression and affecting neurological recovery after posterior decompression.[12,13] Our findings suggest that FK-line (-) patients exhibited lower T1S, lower C2–7 CA, and a larger C2S than FK-line (+) patients. FK-line (-) patients exhibited increased cervical kyphosis during flexion and diminished lordosis during extension, indicating a flexion-dominant cervical alignment. Postoperative JOA scores and recovery ratios were lower in FK-line (-) patients than FK-line (+) patients, consistent with previous findings.[4-6] Furthermore, FK-line (-) patients exhibited a greater cervical flexion angle, smaller FK-line distance, and higher COR than FK-line (+) patients. Based on those observations, it is reasonable to predict that neurological recovery in FK-line (-) patients might be improved by increasing cervical lordosis, decreasing the cervical flexion angle, and expanding the FK-line distance.

Both LP and LF are effective posterior surgical procedures for multilevel cervical OPLL, but they produce significantly different outcomes in patients with FK-line (-). Our findings indi-

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cate that LF leads to superior neurological improvement compared with LP in FK-line (-) patients. Posterior decompression procedures, such as LP and LF, indirectly achieve ventral decompression by allowing posterior cord shift.[15,16] Baba et al.[17] reported that, as measured by the posterior shift score of the cord, significant neurological improvement is associated with posterior cord migration after LP. The extent of spinal cord shift influences spinal cord biomechanics, with LF resulting in lower stress and strain on the spinal cord than LP.[18] Additionally, the greater spinal cord drift achieved with LF compared to LP suggests its superior ability to maximize decompression in severe degenerative cervical myelopathy.[19] However, other studies reported that the extent of the cord shift does not consistently predict clinical outcomes.[20,21] Itoh and Tsuji emphasized that a 4-mm expansion of the spinal canal is optimal for achieving favorable outcomes following LP, and a 3-mm posterior shift of the spinal cord is required to attain a recovery rate exceeding 50%.[19,22,23] In the literature, the posterior shift of the cervical cord after LF averaged around 2.7 mm, compared with 1.7–2.2 mm after LP.[19,24] In this study, the increase in FK-line distance was greater in the LF group (mean, 5.37 mm) than the LP group (3.32 mm), which likely explains the superior neurological recovery observed in the LF group.

One complication following posterior decompression surgery is C5 nerve palsy, attributed to spinal cord shifting and the resultant traction on the spinal cord and/or nerve roots. The incidence has been reported to range from 0% to 13.6%.[25,26] In this study, 5 patients who underwent LP (n = 2) and LF (n = 3) developed C5 palsy, which resolved within 7 months of rehabilitation. Radcliff et al.[27] reported that patients who developed C5 palsy after LF had significantly greater spinal cord drift at the C5 level (5.1 mm) compared to those without palsy (2.4 mm). Other studies noted that although LF resulted in a greater degree of cord shift than LP (2.65 mm vs. 2.20 mm), the difference in C5 palsy incidence was not statistically significant.[19] Our findings are consistent with prior literature, suggesting that while increased cord shift may contribute to C5 palsy, most cases are transient and recover with rehabilitation.

When the C2–7 kyphotic angle exceeds 20°, biomechanical studies have shown a rapid increase in intraspinal pressure.[12] Local kyphosis exceeding 13° on preoperative alignment has been associated with the highest risk of poor recovery after LP.[28] Funaba et al. reported that the postoperative C2–7 kyphotic angle in neck flexion is associated with poor outcomes.[29,30] Our study demonstrates that the preoperative cervical flexion angle is associated with FK-line status and that the postoperative C2–7 flexion angle correlates significantly with neurological recovery, differentiating outcomes between LP and LF. LF achieved more effective correction of the C2–7 flexion angle, resulting in improved posterior cord shift and sagittal alignment, thereby enhancing neurological recovery. These findings provide radiological and clinical evidence explaining the differences in outcomes between LP and LF in patients with high COR and FK-line (-), a relationship previously reported but not mechanistically elucidated.[31] Additionally, we found that, among patients with neutral K-line (-), those who underwent LF showed greater neurological improvement than those who underwent LP. All patients with neutral K-line (-) maintained FK-line (-) on flexion. These findings suggest that fusion surgery may be more appropriate to achieve decompression and stabilization, especially when kyphosis is present.

This study suggests that LF should be considered over LP in patients with FK-line (-) status, a high COR, and preoperative kyphotic alignment—particularly when posterior decompression without stabilization may be insufficient to achieve ventral cord decompression or correct sagittal imbalance. Patients with a greater cervical flexion angle and limited extension function may be at increased risk of inadequate decompression and postoperative sagittal malalignment if managed with LP.[7] In such cases, LF provides superior correction of flexion kyphosis, greater posterior cord shift, and better restoration of alignment, contributing to improved neurological recovery.

Postoperative loss of cervical lordosis is associated with poor outcomes, possibly as a result of injury to the posterior musculoligamentous complex.[32,33] Recently, DER, which indicates the functional reserve of posterior structures, has attracted attention as a potential risk factor for decreased cervical lordosis.[7,34] Lower DER has been shown to correlate with greater loss of cervical lordosis and poorer outcomes after LP.[35] However, some researchers have argued that DER is not a significant predictor of postoperative loss of lordosis, suggesting instead that parameters such as higher C2–7 SVA and preoperative lordosis are more influential.[36] Our findings support that DER serves as an independent predictor of postoperative neurological outcomes by reflecting cervical extension function.

Assessing the FK-line status provides a practical evaluation of dynamic anterior cord compression and kyphotic alignment. Our findings underscore the importance of both dynamic and structural sagittal parameters in predicting surgical outcomes. In FK-line (-) patients, the greater increase in FK-line distance following LF suggests more effective spinal cord decompression and sagittal correction, potentially contributing to improved neurological recovery, in patients with preoperative kyphosis and high COR. However, LF was associated with longer operative times, increased blood loss, and a more pronounced reduction in neck ROM compared to LP.

This study has several limitations. First, its retrospective design carries inherent risk of selection bias, particularly due to differing surgical indications for LP and LF. Second, surgeon preference might have influenced the surgical methods. However, unlike previous studies,[4,6] we directly compared LP and LF in FK-line (-) patients in a large multicenter cohort, providing stronger evidence for surgical decision-making in this challenging population. Third, radiological assessments were limited to standard static and flexion-extension radiographs, without MRI-based confirmation of cord shift. Fourth, the mean follow-up period was 43.2 months, so longer-term studies are needed to assess the durability of the outcomes. Further prospective studies with long-term follow-up are warranted to validate our findings and to establish standardized criteria for surgical selection based on FK-line status.

CONCLUSION

FK-line status is a clinically significant radiological parameter that reflects dynamic sagittal alignment during neck flexion and serves as a valuable predictor of neurological recovery following posterior decompression in patients with cervical OPLL. FK-line (-) patients exhibited more kyphotic alignment, greater cervical flexion, and poorer neurological recovery than FK-line (+) patients. Among FK-line (-) patients, LF was more effective than LP in promoting posterior cord shift, improving sagittal alignment, and enhancing neurological recovery. Postoperative FK-line distance, C2–7 flexion angle, and preoperative extension reserve independently predicted recovery. These findings highlight the importance of incorporating FK-line status and dynamic sagittal parameters into surgical planning to optimize outcomes in cervical OPLL.

NOTES

Supplementary Materials: Supplementary Table 1 and Supplementary Fig. 1 are available at https://doi.org/10.14245/ns.2551108.554.

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ORCID

Jun Jae Shin: 0000-0002-1503-6343
Sun Joon Yoo: 0000-0002-6161-1847
Se Jun Park: 0009-0004-1570-9116
Dong Kyu Kim: 0000-0001-6509-1167
Hyun Jun Jang: 0000-0001-6063-3510
Bong Ju Moon: 0000-0003-1681-9734
Kyung Hyun Kim: 0000-0002-1338-5523
Jeong Yoon Park: 0000-0002-3728-7784
Sung Uk Kuh: 0000-0003-2566-3209
Dong Kyu Chin: 0000-0002-9835-9294
Keun Su Kim: 0000-0002-3384-5638
Yong Eun Cho: 0000-0001-9815-2720
Chang Kyu Lee: 0000-0002-1366-3677
Dong Ah Shin: 0000-0002-5225-4083
Seong Yi: 0000-0003-0700-4744
Keung Nyun Kim: 0000-0003-2248-9188
Joongkyum Shin: 0000-0002-1907-3766
Yoon Ha: 0000-0002-3775-2324

REFERENCES

1. Fujiyoshi T, Yamazaki M, Kawabe J, et al. A new concept for making decisions regarding the surgical approach for cervical ossification of the posterior longitudinal ligament: the K-line. Spine (Phila Pa 1976) 2008;33:E990-3.
2. Shin JJ, Yoo SJ, Kim TW, et al. Radiological and clinical significance of cervical dynamic magnetic resonance imaging for cervical spondylotic myelopathy. Neurospine 2024;21:443-54.
3. Joaquim AF, Baum GR, Tan LA, et al. Dynamic cord compression causing cervical myelopathy. Neurospine 2019;16:448-53.
4. Takeuchi K, Yokoyama T, Numasawa T, et al. K-line (-) in

the neck-flexed position in patients with ossification of the posterior longitudinal ligament is a risk factor for poor clinical outcome after cervical laminoplasty. Spine (Phila Pa 1976) 2016;41:1891-5.
5. Nori S, Aoyama R, Ninomiya K, et al. K-line (-) in the neck-flexed position affects surgical outcomes in patients with ossification of the posterior longitudinal ligament after muscle-preserving selective laminectomy. J Orthop Sci 2020;25:770-5.
6. Nori S, Nagoshi N, Suzuki S, et al. K-line (-) in the neck-flexed position negatively affects surgical outcome of expansive open-door laminoplasty for cervical spondylotic myelopathy. J Orthop Sci 2022;27:551-7.
7. Mun HW, Lee JJ, Shin HC, et al. Comparative analysis of outcomes and kyphotic risk factors after cervical laminoplasty in 2 different ossification of the posterior longitudinal ligament groups and cervical spondylotic myelopathy. Neurosurgery 2024;97:320-31.
8. Sun N, Jiang C, Liu Y. Surgical options for ossification of the posterior longitudinal ligament of the cervical spine: a narrative review. J Orthop Surg Res 2024;19:707.
9. Shin JJ, Jin BH, Kim KS, et al. Intramedullary high signal intensity and neurological status as prognostic factors in cervical spondylotic myelopathy. Acta Neurochir (Wien) 2010; 152:1687-94.
10. Hirabayashi K, Miyakawa J, Satomi K, et al. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976) 1981;6:354-64.
11. Shin JJ, Yoo SJ, Kim DK, et al. The role of K-line and canal-occupying ratio in surgical outcomes for multilevel cervical ossification of the posterior longitudinal ligament: a retrospective multicenter study. Neurospine 2025;22:337-48.
12. Chavanne A, Pettigrew DB, Holtz JR, et al. Spinal cord intramedullary pressure in cervical kyphotic deformity: a cadaveric study. Spine (Phila Pa 1976) 2011;36:1619-26.
13. Breig A, Turnbull I, Hassler O. Effects of mechanical stresses on the spinal cord in cervical spondylosis. A study on fresh cadaver material. J Neurosurg 1966;25:45-56.
14. Wang K, Chen Z, Zhang F, et al. Evaluation of DTI parameter ratios and diffusion tensor tractography grading in the diagnosis and prognosis prediction of cervical spondylotic myelopathy. Spine (Phila Pa 1976) 2017;42:E202-10.
15. Shimokawa N, Sato H, Matsumoto H, et al. Review of radiological parameters, imaging characteristics, and their effect on optimal treatment approaches and surgical outcomes for cervical ossification of the posterior longitudinal ligament. Neurospine 2019;16:506-16.
16. Nagoshi N, Nori S, Tsuji O, et al. Surgical and functional outcomes of expansive open-door laminoplasty for patients with mild kyphotic cervical alignment. Neurospine 2021;18:749-57.
17. 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;243:626-32.
18. Vedantam A, Harinathan B, Warraich A, et al. Differences in spinal cord biomechanics after laminectomy, laminoplasty, and laminectomy with fusion for degenerative cervical myelopathy. J Neurosurg Spine 2023;39:28-39.
19. Basu S, Gohil K. Comparing spinal cord drift, clinical outcomes and C5 palsy in degenerative cervical myelopathy: a study of cervical laminoplasty versus laminectomy/fusion. Global Spine J 2025;15:1277-87.
20. Hatta Y, Shiraishi T, Hase H, et al. Is posterior spinal cord shifting by extensive posterior decompression clinically significant for multisegmental cervical spondylotic myelopathy? Spine (Phila Pa 1976) 2005;30:2414-9.
21. Nori S, Shiraishi T, Aoyama R, et al. Posterior spinal cord shift does not affect surgical outcomes after muscle-preserving selective laminectomy. J Clin Neurosci 2018;50:226-31.
22. Itoh T, Tsuji H. Technical improvements and results of laminoplasty for compressive myelopathy in the cervical spine. Spine (Phila Pa 1976) 1985;10:729-36.
23. 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; discussion 1531-2.
24. Ashana AO, Ajiboye RM, Sheppard WL, et al. Spinal cord drift following laminoplasty versus laminectomy and fusion for cervical spondylotic myelopathy. Int J Spine Surg 2021; 15:205-12.
25. Katsumi K, Yamazaki A, Watanabe K, et al. Can prophylactic bilateral C4/C5 foraminotomy prevent postoperative C5 palsy after open-door laminoplasty?: a prospective study. Spine (Phila Pa 1976) 2012;37:748-54.
26. Oh JK, Hong JT, Kang DH, et al. Epidemiology of C5 palsy after cervical spine surgery: a 21-center study. Neurospine 2019;16:558-62.
27. Radcliff KE, Limthongkul W, Kepler CK, et al. Cervical laminectomy width and spinal cord drift are risk factors for postoperative C5 palsy. J Spinal Disord Tech 2014;27:86-92.
28. Suda K, Abumi K, Ito M, et al. Local kyphosis reduces surgical outcomes of expansive open-door laminoplasty for cer-

vical spondylotic myelopathy. Spine (Phila Pa 1976) 2003;28: 1258-62.
29. Funaba M, Suzuki H, Imajo Y, et al. Laminoplasty is relevant for degenerative cervical spondylolisthesis when there is little risk of postoperative excessive kyphosis during neck flexion. J Clin Neurosci 2023;111:26-31.
30. Fujishiro T, Nakano A, Yano T, et al. Significance of flexion range of motion as a risk factor for kyphotic change after cervical laminoplasty. J Clin Neurosci 2020;76:100-6.
31. Chi JH. A commentary on "The role of K-line and canal-occupying ratio in surgical outcomes for multilevel cervical ossification of the posterior longitudinal ligament: a retrospective multicenter study". Neurospine 2025;22:349-50.
32. 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) 2019;44:E456-64.
33. Lee JJ, Kim HC, Jeon HS, et al. Laminectomy with instrumented fusion vs. laminoplasty in the surgical treatment of cervical ossification of the posterior longitudinal ligament: a multicenter retrospective study. J Clin Neurosci 2021;94:271-80.
34. Sharma R, Borkar S, Katiyar V, et al. Interplay of dynamic extension reserve and T1 slope in determining the loss of cervical lordosis following laminoplasty: a novel classification system. World Neurosurg 2020;136:e33-40.
35. Inoue T, Maki S, Furuya T, et al. Differences in risk factors for decreased cervical lordosis after multiple-segment laminoplasty for cervical spondylotic myelopathy and ossification of the posterior longitudinal ligament: a pilot study. Asian Spine J 2023;17:712-20.
36. Alam I, Sharma R, Borkar SA, et al. Factors predicting loss of cervical lordosis following cervical laminoplasty: a critical review. J Craniovertebr Junction Spine 2020;11:163-8.

 https://doi.org/10.14245/ns.2551108.554