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Original Article

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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

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Objective: To evaluate the impact of the K-line and canal-occupying ratio (COR) on surgical outcomes in patients with multilevel cervical ossification of the posterior longitudinal ligament (OPLL).
Methods: Patients with cervical myelopathy due to multilevel OPLL who underwent decompression surgery (anterior or posterior) from 2013 to 2022, with 2-year minimum follow-up, were enrolled. Radiological evaluations included K-line, COR, OPLL type/level, and cervical parameters (C2 slope [C2S], T1 slope [T1S], K-line tilt). Clinical outcomes included Japanese Orthopaedic Association (JOA) score and neck-pain visual analogue scale. Patients were categorized by K-line status (+/-) and COR (< 50% or ≥ 50%).
Results: Among 575 patients, JOA recovery was significantly better in the K-line (+) and in low COR (< 50%). In high COR (≥ 50%), K-line (-) was associated with poorer recovery. In low COR, outcomes were similar regardless of K-line. Anterior decompression with fusion (ADF) yielded the best outcomes. Laminoplasty (LP) was optimal for COR ≥ 50% and/or K-line (+), while laminectomy with fusion (LF) was better for COR ≥ 50% and K-line (-). In high COR, K-line was influenced by cervical alignment, C2S, and T1S, while in low COR, it was mainly affected by COR percentage.
Conclusion: Combining K-line and COR is essential for surgical planning in multilevel OPLL. When COR is high, K-line plays a significant role in predicting neurological recovery. ADF led to superior recovery, whereas for patients with K-line (-) and high COR, LF offered better results than LP. Cervical parameters at high COR influence the K-line more.

Keywords: K-line, Occupying ratio, Ossification of the posterior longitudinal ligament, Anterior decompression, Posterior decompression

INTRODUCTION

Ossification of the posterior longitudinal ligament (OPLL) occurs due to heterotopic bone formation in this ligament, leading to spinal canal encroachment and subsequent spinal cord compression; this causes cervical myelopathy and radiculopathy.[1,2] Surgical interventions relieve compression by excising the ossified ligament or widening the spinal canal, thereby alleviating symptoms and improving neurological recovery.[3-6] Selecting an appropriate surgical approach is essential to achieving favorable postoperative outcomes.[1,2,4]

The choice of surgical approach—anterior or posterior decompression—is influenced by factors such as the extent of ossification, cervical alignment, canal-occupying ratio (COR), and the level and type of OPLL.[1,2,7,8] Existing literature has primarily examined these factors independently, with few studies addressing their combined impact on surgical decision-making and outcomes.[9-15] Furthermore, cervical kyphosis, particularly when combined with extensive OPLL, presents additional challenges in surgical treatment. Kyphotic alignment increases spinal cord stress, complicates surgical decompression, and is associated with unfavorable neurological outcomes.[16-18] The optimal surgical approach for cervical OPLL remains controversial, particularly for cases involving multilevel extensive OPLL with a high occupying ratio and kyphosis.

This study retrospectively analyzed surgical techniques to improve outcomes and predict postoperative neurological function in patients with cervical myelopathy due to multilevel OPLL. The objective was to examine the relationship between the preoperative K-line, COR, cervical parameters, and surgical decompression (anterior or posterior) and to assess their impact on surgical outcomes. Additionally, this study aimed to explore how the integration of the preoperative K-line and COR of OPLL can guide surgical planning and predict neurological outcomes.

MATERIALS AND METHODS

1. Patient Demographics

This retrospective multicenter study involves patients with OPLL from 3 university-affiliated hospitals. From January 2013 to December 2022, 725 patients with spinal cord compression due to multilevel OPLL (ossification involving more than 3 vertebral levels) were treated. Of these, 138 patients were excluded from analysis due to an insufficient follow-up (85 patients) or other confirmed neurological disorders (42 patients), such as cerebral infarction or cerebral hemorrhage. Additionally, cases involving combined anterior-posterior decompression were excluded due to the small sample size (11 cases) for analysis. Twelve cases were excluded because K-line assessment could not be done on standing lateral radiographs due to severe obesity. Ultimately, 575 patients with a minimum follow-up of 2 years were included in the study (Fig. 1). The presence of OPLL was confirmed using plain radiographs and computed tomography (CT). Cervical myelopathy was diagnosed based on the evidence

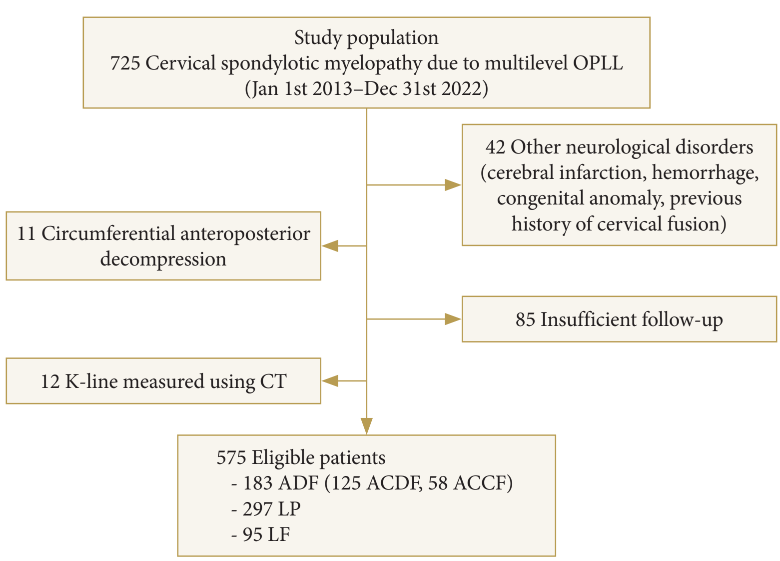

Fig. 1. Patient selection flowchart. OPLL, ossification of the posterior longitudinal ligament; CT, computed tomography; ADF, anterior decompression and fusion; ACDF, anterior cervical discectomy and fusion with partial corpectomy; ACCF, anterior cervical corpectomy and fusion; LP, laminoplasty; LF, laminectomy with fusion.

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of cord compression and upper motor neuron findings on neurological examination. Exclusion criteria included a follow-up period of less than 24 months, trauma, infection, tumor, previous cervical surgery, circumferential fusion (anterior and posterior fusion), or other confirmed neurological disorders.

2. Radiologic Assessment

Radiologic assessments of the cervical spine included the C2–7 Cobb angle (CA), C2 slope (C2S), T1 slope (T1S), C2–7 range of motion (ROM), COR, and OPLL type. 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; and T1S, the angle between the upper endplate of T1 and the horizontal plane on standing lateral view radiograph.[19,20] Preoperative CT scans were used to classify OPLL into 4 types: segmental, continuous, mixed, or localized.[1] COR was determined by calculating the maximum thickness of the OPLL as a percentage of the anterior-posterior diameter of the spinal canal at the site of the primary OPLL lesion. The K-line was determined by connecting the midpoints of the spinal canal at C2 and C7 on a standard lateral x-ray of the cervical spine, and K-line status evaluated whether the OPLL crossed (K-line [-]) or did not cross (K-line [+]) this line.[21] K-line tilt, the angle between the K-line and a line perpendicular to the horizon, was also measured. Radiographic measurements were collected from the database and independently reviewed by 2 surgeons (YH and JJS).

3. Assessment of Clinical Outcomes

Clinical outcomes were evaluated using the patient-reported visual analogue scale for neck pain (VAS-neck) and the Japanese Orthopaedic Association (JOA) score.[22] Data were collected for all patients both preoperatively and at a minimum of 24 months postoperatively.

4. Surgical Procedures

The policy for determining the surgical procedure involved attempting anterior decompression and fusion (ADF) if ventral compression due to OPLL was present, when feasible. When a high COR (≥50%) was observed, ADF was considered following a thorough evaluation of the patient's comorbidities. For more than 3 levels of OPLL, laminoplasty (LP) was preferred when preoperative lordosis was preserved, as ADF may lead to complications, such as pseudoarthrosis or screw dislodgment. If more than 3 levels of OPLL with preoperative kyphotic alignment over 10° are present, a laminectomy with fusion (LF) was performed to reduce the risk of loss of lordosis. In situations where multilevel OPLL affected the C7 or T1 levels, it was necessary to extend the fusion to lower levels across the cervicothoracic junction.

ADF involved multilevel anterior cervical discectomy and fusion with partial corpectomy (ACDF) and anterior cervical corpectomy and fusion (ACCF). In ACDF, the disc and ossified ligament were excised, with the margins removed in a wedge shape. In ACCF, corpectomy was performed on the vertebra with posterior ossification, which was separated from the dura using a micro dissector. If OPLL accompanied dural ossification, the dura was preserved using the anterior floating method to prevent cerebrospinal fluid leak. Titanium mesh cages were filled with autologous bone fragments from the excised vertebrae and allograft cancellous bone chips to restore the defect. For cases with more than 4 levels of OPLL, combination ACCF and ACDF were performed, specifically targeting the symptomatic vertebra. A titanium mesh cage and a PEEK cage containing autogenous and allograft cancellous bone were implanted using anterior screws and a plate system.

LP was performed with a midline incision made directly above the laminae, followed by detaching the bilateral paravertebral muscles from the spinous processes. After the spinous processes were removed, unilateral gutters were created on the affected side using a high-speed drill between the facet joints and laminae. Posterior cervical titanium miniplates (Centerpiece, Medtronic Sofamor Danek) were utilized to maintain the "door" in the open position.

LF involved posterior decompression via laminectomy and stabilization. After laminectomy at levels compressed by OPLL, posterior spinal fusion used lateral mass screws for C1 and C3–6 levels, and pedicle screws for C2 or C7 insertion. If OPLL affected C7 or T1, it was necessary to extend the fusion to lower levels across the cervicothoracic junction. After inserting lordotic rods, perizygapophysial joints were filled with autologous bone fragments from the excised tissue lamina.

Postoperatively, all patients were required to wear either a Miami neck collar or a Philadelphia brace for approximately 3 months. Patients were followed clinically with plain and dynamic radiography at 1, 3, and 6 months postoperative and every 6 months thereafter.

5. Statistical Analysis

All values are reported as mean ± standard deviation or percentage. Normally distributed data were analyzed using the Student t-test or the chi-square test, while nonnormally distributed data were evaluated using the Mann-Whitney U test for 2 groups and the Kruskal-Wallis test for 3 or more groups. Associations between variables and recovery were assessed using the independent sample Student t-test and analysis of variance. Pearson correlation analysis was used to evaluate relationships between the recovery ratio and various factors, including patient characteristics, imaging parameters, and both preoperative VAS and JOA scores. Receiver operating characteristic (ROC) curves were generated to evaluate the sensitivity and specificity of the COR as an objective measure for distinguishing K-line (+) from K-line (-). Optimal cutoff values for the COR were determined using the maximum Youden index, calculated as sensitivity−(1−specificity). All statistical analyses were conducted using MedCalc version 22.026 (MedCalc Software Ltd.). A p-value of < 0.05 was considered statistically significant.

RESULTS

Clinical and radiographic data were collected from 575 patients (404 men and 171 women) who underwent ADF (183 patients), including ACDF (125) and ACCF (58), or posterior decompression (392), including LP (297) or LF (95), for multilevel cervical OPLL. All patients underwent follow-up for more than 24 months (Table 1). The average follow-up duration was 45.22 ± 21.65 months (range, 25–142 months). Mean age at the time of surgery was 59.20 ± 9.89 years (range, 38–81 years). Baseline demographics, clinical characteristics, and clinical and surgical data stratified by K-line status are summarized in Table 1.

1. Clinical and Radiological Outcomes According to K-Line

Patients who were K-line (+) showed significantly greater C2–7 CA both preoperatively and postoperatively compared to those who were K-line (-). COR was significantly lower in the K-line (+) group than in the K-line (-) group ($p < 0.001$). JOA recovery rate was significantly higher in the K-line (+) group ($p < 0.001$). Improvement in JOA score was greater in K-line (+) patients than in K-line (-) patients following posterior decompression ($p < 0.001$). However, no significant difference in recovery was observed between K-line groups following ADF ($p = 0.900$). In the K-line (-) group, ADF resulted in significantly better neurological outcomes than posterior decompression ($p < 0.001$) (Table 1).

2. Clinical and Radiological Outcomes According to COR and K-Line

Among patients with COR < 50%, the JOA recovery rate did

Table 1. Clinical characteristics, clinical and radiological outcomes stratified by K-line status

Characteristic	K-line (+) (n = 395)	K-line (-) (n = 180)	p-value
Age (yr)	59.27 ± 9.66	59.03 ± 10.39	0.785
Sex, Male:female	281:114	123:57	0.495
Symptom duration (wk)	24.77 ± 45.06	22.79 ± 34.92	0.323
OPLL type			0.103
Segmental	163 (41.27)	55 (30.56)	
Continued	90 (22.79)	51 (28.33)	
Mixed	131 (33.16)	68 (37.78)	
Other	11 (2.78)	6 (3.33)	
No. of operated levels	3.12 ± 0.95	3.18 ± 0.94	0.438
Surgical technique			0.997
Ant decomp	126 (31.89)	57 (31.66)	
ACDF	90 (71.43)	35 (61.41)	
ACCF	36 (28.57)	22 (38.59)	
LP	204 (51.65)	93 (51.67)	
LF	65 (16.46)	30 (16.67)	
C2–7 CA (°)			
Preoperative	12.50 ± 9.54	9.68 ± 13.27	< 0.001*
Final	10.71 ± 9.82	9.43 ± 13.57	0.036*
C2–7 ROM (°)			
Preoperative	35.87 ± 13.32	36.04 ± 14.87	0.997
Final	21.47 ± 10.75	22.55 ± 13.89	0.817
OPLL size (mm)	5.18 ± 1.42	6.43 ± 1.92	< 0.001*
COR (%)	43.28 ± 13.06	55.43 ± 12.75	< 0.001*
JOA score			
Preoperative	11.90 ± 2.75	11.68 ± 2.69	0.207
Final	14.97 ± 2.30	14.35 ± 2.46	0.003*
Recovery ratio (%)	62.88 ± 31.03	52.84 ± 34.80	0.001*
Ant decomp	76.09 ± 22.17	72.87 ± 29.18	0.900
Post decomp	56.22 ± 32.35	43.55 ± 33.34	< 0.001*
Neck VAS			
Preoperative	35.14 ± 27.60	33.06 ± 26.33	0.539
Final	19.69 ± 21.50	16.67 ± 18.61	0.588

Values are presented as mean ± standard deviation or number (%).
OPLL, ossification of the posterior longitudinal ligament; Ant decomp, anterior decompression (ACDF and ACCF); ACDF, anterior cervical discectomy and fusion; ACCF, anterior cervical corpectomy and fusion; LP, laminoplasty; LF, laminectomy with fusion; CA, Cobb angle; ROM, range of motion; COR, canal-occupying ratio; JOA, Japanese Orthopaedic Association; Post decomp, posterior decompression (LP and LF); VAS, visual analogue scale.
*$p < 0.05$, statistically significant differences.

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Table 2. Radiological and clinical outcomes stratified by COR and K-line status

Variable	COR < 50%		p-value	COR ≥ 50%		p-value
	K-line (+) (n = 275)	K-line (-) (n = 50)		K-line (+) (n = 120)	K-line (-) (n = 130)	
C2S (°) preoperative	10.59 ± 8.47	14.97 ± 7.62	0.090	12.11 ± 8.31	17.23 ± 8.12	0.002*
T1S (°) preoperative	26.70 ± 6.69	20.38 ± 7.34	0.003*	27.86 ± 6.61	22.72 ± 5.57	< 0.001*
K-line tilt (°)	7.67 ± 7.14	9.66 ± 6.98	0.345	9.68 ± 7.23	10.45 ± 7.42	0.584
C2–7 CA (°) preoperavie	12.62 ± 9.71	9.83 ± 13.23	0.014*	12.21 ± 9.17	9.62 ± 13.34	0.002*
COR (%)	36.40 ± 8.09	40.19 ± 6.97	0.002*	59.03 ± 7.34	61.29 ± 9.07	0.063
JOA score						
Preoperative	11.90 ± 2.72	12.06 ± 2.87	0.544	11.89 ± 2.69	11.53 ± 2.62	0.110
Final	15.11 ± 2.06	14.83 ± 2.67	0.696	14.64 ± 2.76	14.17 ± 2.36	0.020*
Recovery ratio (%)	65.43 ± 28.94	61.69 ± 38.41	0.952	57.05 ± 34.78	49.44 ± 32.83	0.038*
Neck VAS						
Preoperative	41.34 ± 28.11	43.79 ± 26.79	0.568	41.88 ± 26.58	44.19 ± 25.66	0.839
Final	19.64 ± 22.60	17.02 ± 17.07	0.934	19.78 ± 19.04	16.54 ± 19.32	0.300

Values are presented as mean ± standard deviation.
COR, canal-occupying ratio; C2S, C2 slope; T1S, T1 slope; CA, Cobb angle; JOA, Japanese Orthopaedic Association; VAS, visual analogue scale.
*p < 0.05, statistically significant differences.

not significantly differ between the K-line (+) and K-line (-) groups (p = 0.952), suggesting that K-line status had minimal impact on recovery in low COR. In contrast, among patients with a COR ≥ 50%, those who were K-line (+) had significantly higher recovery rates than those who were K-line (-) (p = 0.038) (Table 2), highlighting the importance of K-line assessment in high COR (≥ 50%).

In the COR < 50% group, the K-line (+) subgroup had significantly lower COR than the K-line (-) subgroup (p = 0.002). Additionally, significant differences were observed in preoperative C2–7 CA and T1S, but not in C2S or K-line tilt. In the COR ≥ 50% group, COR itself was similar between K-line subgroups; however, the K-line (-) group had significantly lower C2–7 CA and higher C2S and T1S, suggesting that K-line status in high COR cases is influenced by cervical sagittal alignment (Table 2). No significant differences were observed in OPLL involvement at C2 or C7 based on COR and K-line status.

3. Relationships Between COR, K-Line, and Surgical Outcomes

In the COR < 50% and K-line (+) subgroup, ADF demonstrated the highest JOA recovery rates, followed by LP and LF (p < 0.001). In the K-line (-) subgroup with low COR, ADF exhibited superior recovery compared to LP or LF. However, the analysis was constrained by the small sample size (6) for LF (p = 0.054). Among patients with COR ≥ 50% and K-line (+), ADF had the best recovery rate, followed by LP and LF (p < 0.001). In patients with high COR and K-line (-), ADF resulted in the highest recovery rate, followed by LF and LP (p < 0.001) (Table 3). Overall, ADF provided the most favorable outcomes across all subgroups. Notably, in high COR and K-line (-), LF surpassed LP in neurological recovery. Representative cases are illustrated in Figs. 2–5.

ADF was associated with an increase in postoperative C2–7 CA, while LP led to a decrease, and LF maintained alignment. ROM was most restricted after LF and ADF and was best preserved with LP (p < 0.001). ADF had a longer operative time than LP but shorter than LF, while intraoperative blood loss was lowest in LP and highest in LF. ADF was associated with a higher rate of pseudoarthrosis (7 cases) and revision surgery, while LF had the highest incidence of C5 nerve palsy (Table 3).

DISCUSSION

This study highlights the importance of integrating K-line status and COR of the OPLL to guide surgical strategies and predict neurological outcomes. In patients with a high COR (≥ 50%), K-line status was more influenced by cervical parameters, such as C2–7 CA, C2S, and T1S, than in those with a low COR (< 50%). ADF was associated with superior JOA recovery ratio compared to posterior decompression in cervical myelopathy due to multilevel OPLL. LP yielded a better recovery rate,

Table 3. Clinical and radiological outcomes based on COR, K-line status, and surgical technique

Variable	ADF (n = 183)	LP (n = 297)	LF (n = 95)	p-value
Recovery ratio (%)				
COR < 50%				
K-line (+) (n = 275)	75.57 ± 22.56 (n = 93)	63.41 ± 28.72 (n = 152)	44.24 ± 34.49 (n = 30)	< 0.001*
K-line (-) (n = 50)	79.52 ± 24.91 (n = 16)	55.81 ± 42.73 (n = 28)	41.67 ± 32.28 (n = 6)	0.054
COR ≥ 50%				
K-line (+) (n = 120)	82.89 ± 20.44 (n = 33)	52.84 ± 34.24 (n = 52)	40.34 ± 34.35 (n = 35)	< 0.001*
K-line (-) (n = 130)	69.96 ± 31.33 (n = 41)	35.12 ± 27.35 (n = 65)	52.59 ± 31.26 (n = 24)	< 0.001*
C2–7 CA (°)				
Preoperative	8.98 ± 9.88	13.06 ± 12.08	11.54 ± 8.49	< 0.001*
Final	11.07 ± 8.38	9.59 ± 7.95	10.08 ± 7.63	0.432
ROM (°)				0.002*
Preoperative	38.45 ± 14.65	33.94 ± 13.33	37.32 ± 12.74	< 0.001*
Final	22.71 ± 9.81	22.97 ± 12.30	16.54 ± 11.23	< 0.001*
Operation time (min)	163.29 ± 71.22	135.93 ± 52.42	181.84 ± 55.63	< 0.001*
Blood loss (mL)	471.67 ± 511.53	358.44 ± 299.78	616.06 ± 664.75	< 0.001*
Complications	32	15	20	
C5 n palsy	6	8	14	
Pseudoarthrosis	7	0	1	
Revision	3	3	1	
Dura tear	16	4	4	

Values are presented as mean ± standard deviation or number.
COR, canal-occupying ratio; LP, laminoplasty; LF, laminectomy with fusion; ADF, anterior decompression and fusion; CA, Cobb angle; ROM, range of motion.
*$p < 0.05$, statistically significant differences.

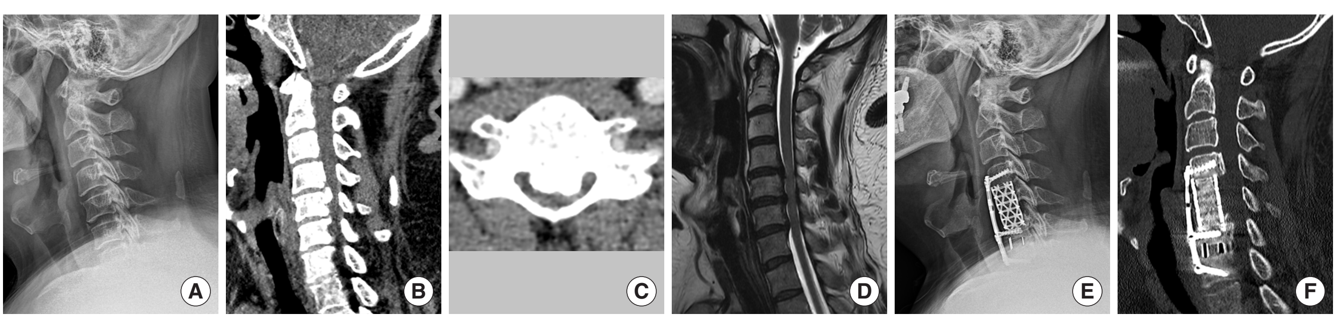

Fig. 2. ADF in a patient with high COR and K-line (-). A 42-year-old male with cervical OPLL affecting the C4–7 levels presented with bilateral upper extremity numbness, weakness, and an ataxic gait. (A) Preoperative plain radiograph shows kyphotic alignment and a negative K-line. (B) A sagittal CT scan demonstrates segmental OPLL at C4–7. (C) Axial CT scan indicated severe canal encroachment with a COR of 70.6%. (D) T2-weighted MRI confirms spinal cord compression at the same levels. (E) Postoperative plain radiograph following ADF, including C5 corpectomy and C6–7 segmental corpectomy. (F) Postoperative CT scan shows spinal canal widening and instrument fixation. JOA score improved from 10 to 16 (recovery rate: 85.7%) at the 2-year follow-up. ADF, anterior decompression and fusion; COR, canal-occupying ratio; OPLL, ossification of the posterior longitudinal ligament; CT, computed tomography; MRI, magnetic resonance image; JOA, Japanese Orthopaedic Association.

particularly in patients with lower COR or K-line (+), compared to LF. Notably, LF proved to be a more favorable option than LP in patients with high COR and K-line (-), demonstrating an approach-specific benefit in complex cases.

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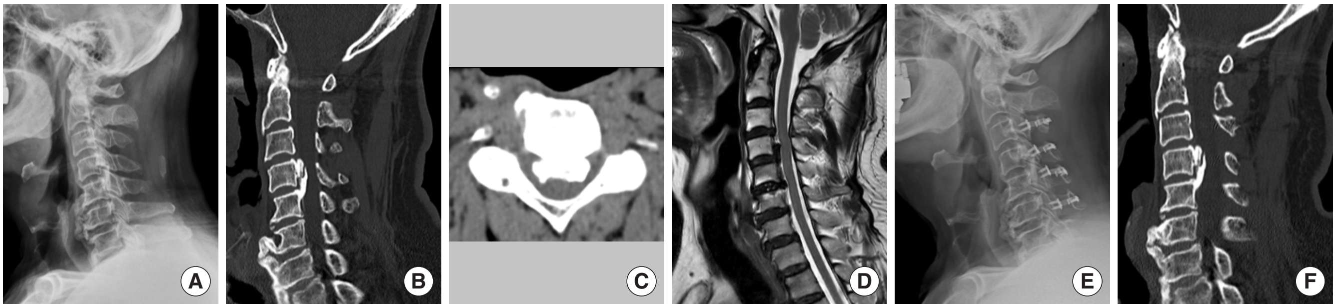

Fig. 3. LP in a patient with high COR and K-line (-). A 68-year-old male with cervical OPLL involving the C3–6 levels presented with bilateral numbness, weakness, and ataxia in the upper and lower extremities. (A) Preoperative radiograph revealed kyphotic alignment and negative K-line. (B) Sagittal CT scan demonstrated segmental OPLL at C4–6. (C) Axial CT scan indicated significant canal encroachment with a COR of 63.7%. (D) T2-weighted MRI showed marked spinal cord compression. (E) Postoperative radiograph following LP at the C3–6 levels. (F) Postoperative CT scan confirmed spinal canal widening. JOA score improved from 12 to 15 (recovery rate: 60%) at 2-year follow-up. LP, laminoplasty; COR, canal-occupying ratio; OPLL, ossification of the posterior longitudinal ligament; CT, computed tomography; MRI, magnetic resonance image; JOA, Japanese Orthopaedic Association.

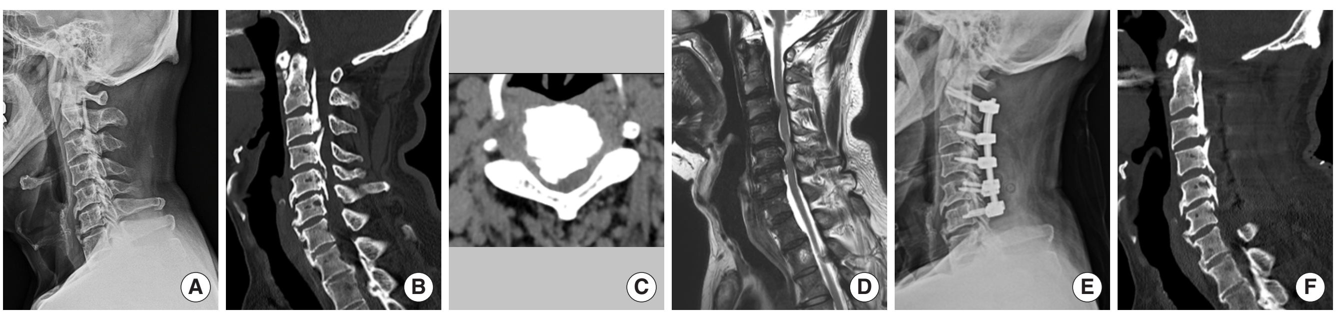

Fig. 4. LF in a patient with high COR and K-line (-). A 72-year-old male with cervical OPLL involving C2–6 presented with bilateral numbness and weakness in both upper and lower extremities. (A) Preoperative radiograph showed kyphotic alignment and a negative K-line. (B) Sagittal CT scan revealed mixed-type OPLL extending from C2 to C6. (C) Axial CT scan indicated severe canal encroachment with a COR of 82.4%. (D) T2-weighted MRI confirmed significant spinal cord compression. (E) Postoperative radiograph after LF at C2–6. (F) Postoperative CT scan confirmed effective spinal canal decompression. JOA score improved from 9 to 16 (recovery rate: 87.5%) at 2-year follow-up. LF, laminectomy with fusion; COR, canal-occupying ratio; OPLL, ossification of the posterior longitudinal ligament; CT, computed tomography; MRI, magnetic resonance image; JOA, Japanese Orthopaedic Association.

The K-line, a measure introduced by Fujiyoshi et al.,[21] is a valuable parameter that integrates OPLL and cervical alignment into a single, unified measure. It provides a practical approach for evaluating cervical curvature and guiding surgical strategies in patients with cervical OPLL.[21] However, no studies to date have combined K-line with the COR to determine surgical options. Although numerous studies have independently examined COR and cervical alignment, only a few review articles have suggested the potential benefits of integrating both parameters as predictive indicators.[1,4]

Surgical approaches for patients with K-line (-) OPLL should be carefully selected, balancing the surgeon's technical expertise and the risk of complications. Nagoshi et al. reported comparable clinical improvement between anterior and posterior fusion surgeries in patients with K-line (-) OPLL.[3] However, in patients with K-line (-) OPLL, posterior decompression surgery often fails to achieve satisfactory posterior shift of the spinal cord and sufficient neurological improvement.[15,21,23,24] A biomechanical study reported that cervical kyphotic alignment with K-line (-) exacerbates intraspinal stress, suggesting that posterior decompression yields poor outcomes due to insufficient decompression.[17] Our study found that ADF produced superior neurological outcomes compared to posterior decompression in patients who were K-line (-). K-line status may show changes with neck flexion and extension positions. In patients who are K-line (-) in the neutral position but K-line (+) in extension, LP has dem-

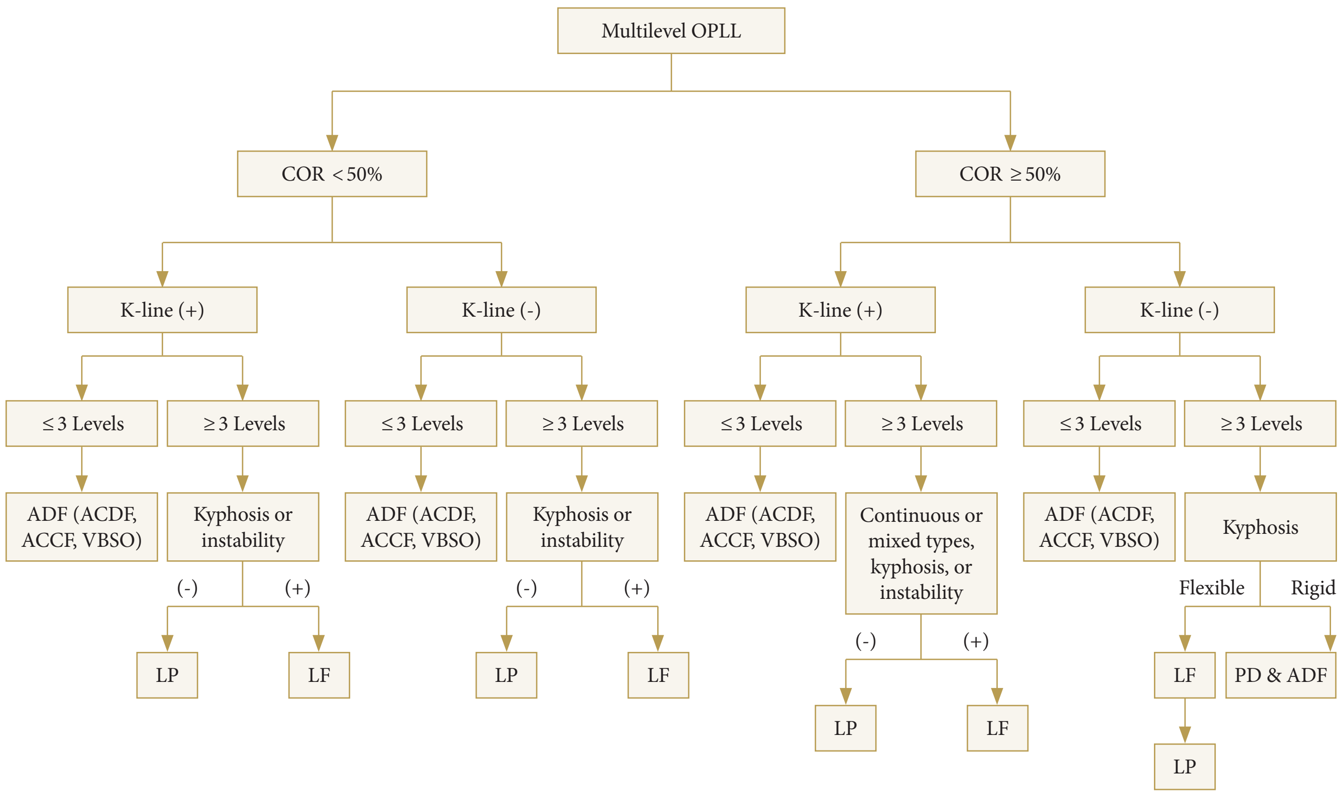

Fig. 5. Flowchart of surgical procedures for cervical myelopathy caused by multilevel OPLL. OPLL, ossification of the posterior longitudinal ligament; COR, canal-occupying ratio; ADF, anterior decompression and fusion; ACDF, anterior cervical discectomy and fusion with partial corpectomy; ACCF, anterior cervical corpectomy and fusion; VBSO, vertebral body sliding osteotomy; LP, laminoplasty; LF, laminectomy with fusion; PD, posterior decompression.

onstrated significant improvements in clinical outcomes and a reduction in COR.[25] In contrast, even for patients who are K-line (+) in the neutral position, K-line (-) status on flexion negatively affected the surgical outcomes of posterior decompression. Limiting the flexion of the cervical spine through fusion surgery yields better surgical outcomes for patients who are K-line (-) on neck flexion.[26] It is thus important to re-evaluate the K-line when treating cervical OPLL.

The K-line is not the only determinant when selecting surgical procedures.[2] The extent of cord compression is directly proportional to the severity of myelopathic symptoms and surgical outcomes.[1] Those with OPLL thickness exceeding 7 mm should undergo ADF rather than posterior decompression. Predicting the recovery rate alone based on OPLL thickness is challenging due to variability in spinal canal dimensions among individuals. There is strong evidence suggesting that COR is a more critical factor in surgical decision-making and clinical outcomes than maximal OPLL thickness.[11,13] Yoshii et al.[12] demonstrated that ADF provides superior neurological recovery in patients with a COR ≥ 60% and kyphotic alignment compared to LP. Sakai et al.[13] indicated that LP is less effective in patients with a COR ≥ 50% regardless of cervical kyphosis. Our study revealed that the recovery ratio after surgery was significantly higher in patients with low COR (< 50%) compared to those with high COR (≥ 50%). Among patients with lower COR, neurological recovery did not differ between the K-line (+) and (-) groups. However, among patients with a high COR, neurological recovery was poorer in the K-line (-) group compared to the K-line (+) group. Our findings indicate that in those with a COR < 50%, K-line minimally impacts clinical outcomes following surgery. Conversely, in high COR, K-line plays a critical role in neurological recovery. Through ROC curve analysis, we identified 48.79% as the optimal COR cutoff for predicting K-line (-) configuration. However, among patients with high COR, the K-line (+) and (-) distribution was relatively even, suggesting that cervical alignment parameters such as T1S, C2S, and K-line tilt also play critical roles in determining K-line status. In patients with high COR, those who were K-line (-) exhibited greater C2S and lower C2–7 CA, consistent with cervical compensatory mechanisms for maintaining horizontal gaze.[27,28] In our study, among

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patients with a high COR, those with K-line (+) exhibited significantly greater T1S compared to those who were K-line (-). Furthermore, patients who were K-line (-) demonstrated inadequate C2–7 lordosis, which was compensated for with increased C2S relative to K-line (+) patients. T1S positively correlated with C2S and negatively with C2–7 CA, reinforcing that inadequate lower cervical lordosis leads to increased upper cervical compensation.[28]

When the COR is high and the K-line is (-), it is crucial to achieve K-line (+) status to facilitate favorable outcomes.[1,4,29,30] ADF is particularly effective in correcting kyphotic deformities and decompressing the ventral spinal cord, although it carries risks such as pseudarthrosis, cerebrospinal fluid leakage, and implant-related complications.[11,31,32] Our study found that ADF resulted in superior neurological outcomes compared to posterior decompression for patients with significant canal compromise, such as high COR and K-line (-). ADF is the preferred surgical approach for managing patients with cervical OPLL, as it offers better therapeutic outcomes when the COR is ≥50% and/or K-line (-), and it preserves better cervical curvature and sagittal balance.[33]

LP is advantageous for preserving cervical ROM and reducing neck pain compared with LF.[34] LP is recommended for OPLL with cervical lordosis, considering its comparable neurological recovery, less axial pain, and better improvement in neck function.[35] However, LP yielded poor results in prior research, particularly in patients with K-line (-) OPLL or a high COR.[21,36,37] In our study, LP consistently produced better neurological recovery compared to LF, particularly in patients who were K-line (+) or a low COR. Preoperative cervical alignment with lower COR or K-line (+) exhibited greater lordosis than that with high COR or K-line (-). We demonstrated that LP yields better JOA recovery ratios, particularly in patients with lower COR or K-line (+), compared to LF, consistent with previous findings.[34,36]

LF maintains preoperative alignment and reduces lordosis loss and OPLL progression following surgery.[6,14,27] Chen et al.[38] reported that the LF could improve cervical lordosis while providing a better decompression effect and good prognosis for patients with OPLL on long-term follow-up. In our study, although the LP group had higher preoperative C2–7 CA, this alignment was better preserved postoperatively in the LF group. LF yielded more favorable outcomes than LP, demonstrating effectiveness in addressing kyphotic alignment for patients with a high COR who were K-line (-), as LF preserved the preoperative curve, consistent with previous research.[27,39] LF may be a favorable alternative to LP in patients with a high COR who are K-line (-), emphasizing the need for a customized approach based on patient-specific radiological characteristics.

This study had several limitations. First, it was a retrospective series, and selection bias arose from differing surgical indications for ADF, LP, and LF. Second, surgeon preference may have influenced the surgical procedures. Nonetheless, this study included a substantial cohort of patients from a retrospective case series with procedures performed by experienced surgeons using a standardized treatment technique across 3 university-affiliated hospitals. Third, follow-up averaged 45.9 months, and a longer follow-up is necessary to confirm durability findings. Fourth, cases involving combined anterior-posterior decompression surgery were excluded, as the number of such cases (n = 11) did not allow for thorough analysis. Finally, a limitation in the K-line strategy arises when the C7 vertebral body is obscured on standing radiographs due to shoulder anatomy. Twelve cases that were measured by CT were excluded from the analysis for this reason. Future multicenter studies are necessary to assess clinical outcomes for patients undergoing anterior, posterior, and circumferential decompression for cervical OPLL on flexion-positioned CT or MRI.

CONCLUSION

This study demonstrated the critical role of integrating COR and K-line in order to guide surgical strategy and predict clinical, radiological, and neurological outcomes in multilevel cervical OPLL. In cases with high COR (≥50%), K-line status was a significant predictor of neurological recovery following surgery. ADF led to superior neurological recovery, while LP provided better outcomes than LF, particularly in cases with a lower COR (<50%) or that were K-line (+). Notably, for patients with a higher COR who were K-line (-), LF yielded more favorable outcomes than LP. This study underscores the importance of integrating K-line and COR in surgical decision-making for multilevel OPLL.

NOTES

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