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CERVICAL SPINE

Does K-line (−) in the Neck-flexed Position Predict Surgical Outcome of Cervical Spondylotic Myelopathy?

Results of a Multivariate Analysis After Muscle-preserving Selective Laminectomy

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Study Design. A retrospective single-center study.

Objective. The aim of this study was to investigate the influence of the K-line in the neck-flexed position (flexion K-line) on the surgical outcome after muscle-preserving selective laminectomy (SL) for cervical spondylotic myelopathy (CSM).

Summary of Background Data. Development of CSM is associated with dynamic factors and cervical alignment. The flexion K-line, which reflects both dynamic and alignment factors, provides an indicator of surgical outcome after posterior decompression surgery for patients with ossification of the posterior longitudinal ligament. However, the value of the flexion K-line for patients with CSM has not been evaluated.

Methods. Our study group included 159 patients treated with SL for CSM. Patients were divided into a flexion K-line (+) group and a flexion K-line (−) group. The influence of the flexion K-line on radiological and surgical outcomes was analyzed, with multivariate analysis conducted to identify factors affecting the surgical outcome.

Results. Patients in the flexion K-line (−) group were younger ($P = 0.003$), had a less lordotic cervical alignment (pre-and postoperatively, $P < 0.001$), a smaller C7 slope (pre-and postoperatively, $P < 0.001$), and a greater mismatch between the C7 slope and the C2-C7 angle (preoperatively, $P = 0.047$; postoperatively, $P = 0.001$). The postoperative increase in Japanese Orthopedic Association (JOA) score and the JOA score recovery rate (RR) were lower for the flexion K-line (−) than for the K-line (+) group ($P < 0.001$ and $P < 0.001$, respectively). On multivariate regression analysis, the flexion K-line (−) ($\beta = -0.282$, $P < 0.001$), high signal intensity (SI) changes on T2-weighted image (WI) combined with low SI changes on T1-WI in the spinal cord ($\beta = -0.266$, $P < 0.001$), and older age ($\beta = -0.248$, $P = 0.001$) were predictive of a lower JOA score RR.

Conclusion. The flexion K-line may be a useful predictor of surgical outcomes after SL in patients with CSM.

Key words: cervical alignment, cervical myelopathy, cervical sagittal balance, cervical spondylotic myelopathy, clinical outcome, flexion K-line, Japanese Orthopedic Association score, K-line, Laminectomy, laminoplasty, Minimally Invasive Surgery, muscle preservation, posterior surgery, selective laminectomy, surgical outcome.

Level of Evidence: 4

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Residual spinal cord compression after posterior cervical decompression surgery has been reported to hinder improvements in neurological outcome. A previous study reported that presence of anterior spinal cord compression after laminoplasty leads to poor upper extremity functional recovery in patients with cervical spondylotic myelopathy (CSM).[1] Another study, reporting on the usefulness of intraoperative ultrasound imaging to evaluate the status of spinal cord decompression, indicated that restoration of the anterior subarachnoid space was a significant factor of neurological improvement following laminoplasty.[2] Recently, magnetic resonance imaging (MRI) has been widely used to predict the surgical outcome of patients with CSM. Although MRI is suitable to evaluate spinal cord compression and the change in signal intensity (SI) of the spinal cord in supine in a neck-neutral position, standing cervical sagittal alignment or dynamic factors is not taken into consideration. Cervical alignment changes dramatically between a supine and a standing position, with the cervical spinal cord usually being shifted anteriorly in standing neck-flexed position.

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The K-line has been used as a preoperative parameter to predict surgical outcome for ossification of the posterior longitudinal ligament (OPLL), where the K-line accounts for the extent of ossification and standing cervical alignment.[3] Taniyama *et al*[4] used a modified K-line to predict the functional recovery of patients with CSM, where the K-line connects the midpoints of the spinal cord, from C2 to C7, on midsagittal MRI in the supine position. Although neurological outcome after laminoplasty for patients with CSM with a nonlordotic alignment can be predicted by the interval between the modified K-line and the anterior compression factors,[4] the modified K-line does not reflect the standing cervical alignment nor the dynamic factors. It has been reported that dynamic factors are also important for the development of myelopathy in patients with CSM and OPLL.[5–8] Recently, 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.[9] Previous studies have reported a worse functional recovery after posterior decompression surgery for patients with OPLL with a flexion K-line (−) than those with a flexion K-line (+).[9,10] In the present study, we applied the concept of the flexion K-line to patients with CSM and evaluated the association between the flexion K-line and radiological and surgical outcomes after muscle-preserving selective laminectomy (SL). A multivariate analysis was used to investigate the effect of the flexion K-line (−) on functional recovery after SL.

MATERIALS AND METHODS

Patients

Between April 2010 and March 2016, 774 consecutive patients with a cervical compressive myelopathy (CCM) underwent SL at our academic institution. The inclusion criteria were as follows: age ≥18 years; symptomatic CSM (at least 1 clinical sign of myelopathy); and evidence of CSM on cervical myelogram-computed tomography (CT). Excluded were patients who had undergone treatment for OPLL, cervical disc herniation, trauma, spinal tumors, or infection; patients who had undergone foraminotomy or previous cervical spine surgery; patients who presented with a radiculopathy without myelopathy; and patients whose follow-up period was <1 year. SL was not performed in patients who had a local kyphosis >20°,[11] an OPLL occupancy ratio >60%,[12] or a spondylolisthesis >3.5 mm.[13] A preoperative cervical myelogram-CT was performed in all patients, with OPLL defined as OPLL, with a thickness >2 mm, on axial image.[14,15] Osteophytes located at the corners of the vertebrae or near the uncovertebral joint were not considered to be OPLL. Patients with CSM for which the SL included ≥3 consecutive laminae, with the most cranial laminectomy level was C3 and the most caudal level was C7, were selected. After screening, 159 patients with CSM, who underwent SL at three or four consecutive levels, formed our study group. The distribution of affected levels, among patients who underwent SL at 3 consecutive levels, was as follows: C3–C5, 17 cases; C4–C6, 106 cases; and C5–C7, 2 cases. The distribution for patients who underwent SL at four consecutive levels was as follows: C3–C6, 33 cases and C4–C7, one case.

Surgical Procedure

The levels of decompression were selected based on observable obstruction of the subarachnoid space identified on myelogram-CT with the neck in neutral and in extended positions. We measured the width of the spinal cord at the upper edge of each lamina, planning the laminectomy to be 2 to 3 mm wider than the spinal cord.[11,16] The mean laminectomy width was 17 ± 2 mm.

Under the microscope field, SL was performed according to methods previously described.[11,16–18] For C4–C6 SL, the spinous processes of C4, C5, and C6 were split and divided at the base, preserving the attachments of the deep extensor muscles. The laminae from C4 to the upper half of the C7 lamina were exposed, but without exposing the bilateral facet joints. The C4, C5, and C6 laminae, the upper half of the C7 lamina, and the ligamentum flavum, from the ventral aspect of the C3 to C6 laminae, were removed, and the split halves of the spinous processes were sutured together.

Patient Characteristics and Clinical Outcomes

Patients' clinical characteristics (age, sex, diagnosis, and operative level) were recorded. The clinical outcome was evaluated using the JOA score preoperatively and at final follow-up (at least 1 year after surgery). The recovery rate (RR) of the Japanese Orthopedic Association (JOA) score was calculated using the method of Hirabayashi *et al*.[19]

Radiologic Evaluation

Radiologic evaluation was performed by four independent spinal surgeons, using a DICOM viewer (Synapse version 4.1.0, FUJIFILM Medical, Tokyo, Japan). Standing lateral view plain radiographs were obtained with the neck in neutral, flexion, and in extension postures, preoperatively and at the final follow-up at least 1 year after surgery. For neutral posture, lateral radiographs were obtained with the patient standing in a comfortable position, with the head facing forward for horizontal gaze. On this view, the K-line was drawn from the midpoint of the spinal canal at C2 to the midpoint of the spinal canal at C7.[3] The K-line (+) for CSM was defined by absence of any bony spur or the vertebral body crossing the K-line, whereas for the K-line (−), some portion of a bony spur or the vertebral body crossed the K-line posteriorly. The K-line, which is drawn in the neck-flexed position, was also evaluated[9,10]; again, patients were subclassified into the flexion K-line (+) and the flexion K-line (−) group. The C2–C7 angle was measured at the intersection of two tangential lines on the posterior edge of the C2 and C7 vertebral bodies. The C7 slope was measured as the angle between the superior endplate of C7 and a horizontal line. The C7 slope was used as a substitute for the T1 slope.[11,16,20] We defined the C2–C7 sagittal vertical axis

(SVA) as the distance between the C2 plumb line and the posterior superior corner of the C7 vertebral body. The range of motion (ROM) of the cervical spine was obtained by measuring the difference in the C2–C7 angle on the lateral flexion and extension radiographs. The postoperative spinal cord clearance from the anterior compression factors was determined as the distance between the nearest point of the anterior margin of the spinal cord and the posterior margin of the anterior compression factors using the postoperative T2-weighted image (WI) sagittal and axial MRI. The postoperative residual spinal cord compression was identified if both following criteria were satisfied: effacement of anterior cerebral spinal fluid buffer on the T2-WI sagittal and axial MRI and evidence of anterior compression of spinal cord substance on T1-WI sagittal and axial MRI.[21]

Statistical Analysis

Statistical analyses were performed using the SPSS software (version 22.0, IBM Corporation, Armonk, NY). An unpaired *t* test was used to compare continuous variables between the K-line (+) and K-line (−) groups, with the χ^2 test or Mann–Whitney *U* test used for discrete variables, as appropriate for the data distribution. The correlation between the JOA score RR and clinical and radiological factors was performed using Pearson correlation coefficient for continuous variables and Spearman correlation coefficient for discrete variables. A correlation coefficient (*r* value) was considered significant when >0.20. Factors with a *P* value <0.25 in the correlation analysis were examined using multiple linear regression analysis of the JOA score RR, with a standardized partial regression coefficient (β value) >0.20 was considered significant. Continuous variables are presented by mean ± standard deviation, with a $P < 0.05$ considered statistically significant.

RESULTS

Comparison of Patient Characteristics According to the Flexion K-line

A total of 159 CSM patients were enrolled in the study. The average follow-up period was 30.9 ± 16.5 months. At the time of surgery, patients were younger in the flexion K-line (−) than the K-line (+) group. Both the postoperative increase in JOA score and the JOA score RR were lower for those in the flexion K-line (−) than flexion K-line (+) group (Table 1).

Association Between the Flexion K-line and Radiological Parameters

Patients in the flexion K-line (−) group had a smaller C2-C7 angle and a smaller C7 slope than those in the flexion K-line (+) group, both pre- and postoperatively. The C7 slope minus the C2–C7 angle was greater in the flexion K-line (−) than (+) group, both pre- and postoperatively. The C2-C7 angle was smaller in the neck-flexed position in the flexion K-line (−) than (+) group, both pre- and postoperatively. Additionally, patients with a flexion K-line (−) had a smaller C2-C7 angle in extension, both pre- and postoperatively. The preoperative cervical ROM was greater in the flexion K-line (−) than (+) group, with a greater postoperative decrease in the C2-C7 angle in extension and a greater postoperative decrease in cervical ROM in patients with a flexion K-line (−) than (+). The presence of postoperative residual spinal cord compression tended to be higher in the flexion K-line (−) than (+) group (Table 2).

TABLE 1. Comparison of Patients' Characteristics According to the Flexion K-line

	Flexion K-line (+)	Flexion K-line (−)	*P*
No. of cases	129	30	
Age at surgery, y	66.0 ± 11.3	58.9 ± 10.7	0.002
Sex, male (%)	70.5	66.7	0.677
JOA score			
Preop.	11.0 ± 2.6	12.0 ± 2.5	0.071
Postop.	13.5 ± 2.4	13.1 ± 2.1	0.280
Postop. – Preop.	2.5 ± 1.9	1.2 ± 1.6	<0.001
RR (%)	43.5 ± 30.1	20.1 ± 28.9	<0.001
Surgical factors			
The number of consecutive laminae surgically treated	3.2 ± 0.4	3.2 ± 0.4	0.839
Operation time, min	140.2 ± 29.3	149.2 ± 32.1	0.137
Blood loss, g	10.3 ± 29.5	13.3 ± 41.4	0.642
Operative levels (%)			0.379
C3-C5	12.4	3.3	
C4-C6	65.1	73.3	
C5-C7	0.8	3.3	
C3-C6	20.9	20.0	
C4-C7	0.8	0	

JOA indicates Japanese Orthopaedic Association; Postop., postoperatively; Preop., preoperatively; RR, recovery rate.

TABLE 2. Radiological Parameters of Patients According to the Flexion K-line

	Flexion K-line (+)	Flexion K-line (−)	*P*
C2-C7 angle (°)			
Preop.	13.7 ± 13.2	1.5 ± 10.2	<0.001
Postop.	15.3 ± 12.6	1.5 ± 10.7	<0.001
Postop. – preop.	1.7 ± 6.7	-0.1 ± 7.4	0.215
C7 slope (°)			
Preop.	24.5 ± 8.3	16.4 ± 7.2	<0.001
Postop.	25.1 ± 9.4	17.6 ± 8.2	<0.001
Postop. – preop.	0.6 ± 6.6	1.2 ± 4.1	0.501
C7 slope minus C2-C7 angle (°)			
Preop.	10.8 ± 10.1	14.9 ± 9.3	0.047
Postop.	9.8 ± 9.4	16.2 ± 8.6	0.001
Postop. – preop.	-1.1 ± 7.5	1.3 ± 7.7	0.125
C2-C7 SVA, mm			
Preop.	24.2 ± 14.8	21.8 ± 15.2	0.428
Postop.	27.6 ± 15.9	25.5 ± 14.3	0.520
Postop. – preop.	3.4 ± 10.4	3.7 ± 8.4	0.865
C2-C7 angle in flexion (°)			
Preop.	-7.1 ± 11.7	-22.8 ± 10.0	<0.001
Postop.	-2.9 ± 14.1	-16.7 ± 12.0	<0.001
Postop. – preop.	4.3 ± 9.7	6.1 ± 8.8	0.360
C2-C7 angle in extension (°)			
Preop.	25.7 ± 12.8	18.4 ± 14.1	0.007
Postop.	24.4 ± 12.8	12.0 ± 14.1	<0.001
Postop. – preop.	-1.3 ± 7.1	-6.4 ± 8.3	0.001
Cervical range of motion (°)			
Preop.	32.8 ± 11.0	41.2 ± 14.9	0.006
Postop.	27.3 ± 10.6	28.7 ± 14.7	0.606
Postop. – preop.	-5.6 ± 12.0	-12.5 ± 11.3	0.005
Postop. spinal cord clearance, mm	1.2 ± 0.7	1.1 ± 0.8	0.508
Postop. residual spinal cord compression (%)	5.4	16.7	0.051
Preop. high SI changes on T2WI combined with low SI changes on T1WI (%)	35.7	36.7	0.917

Postop. indicates postoperatively; Preop., preoperatively; SI, signal intensity; SVA, sagittal vertical axis; WI, weighted image.

Correlation Between the JOA Score RR and Patients' Characteristics and Radiological Factors

The JOA score RR correlated with the flexion K-line (−), a preoperative high SI changes on T2-WI combined with low SI changes on T1-WI in the spinal cord, and postoperative residual spinal cord compression (Table 3).

Multiple Linear Regression Analysis of the JOA Score RR

A flexion K-line (−), a preoperative high SI changes on T2-WI combined with low SI changes on T1-WI in the spinal cord, and older age were associated to the JOA score RR (Table 4).

Case Presentation

A 52-year-old man underwent C4–C6 SL. A K-line (+) was measured with the neck in neutral position, and a K-line (−) on neck-flexed position on the preoperative radiographs. The preoperative JOA score was 12 and the postoperative score 13, with a JOA score RR of 20.0% (Figure 1A–C). A 53-year-old man underwent C3-C6 SL. A K-line (+) was measured in both neck-neutral and neck-flexed positions on the preoperative radiographs. The preoperative JOA score was 10 and the postoperative score 13, with a JOA score RR of 42.9% (Figure 2A–C).

DISCUSSION

In our study group, patients with CSM presenting with a flexion K-line (−) were younger, and had a less lordotic cervical alignment, a smaller C7 slope, and a greater mismatch between the C7 slope and the C2-C7 angle than patients with a flexion K-line (+). Patients with a flexion K-line (−) had a more kyphotic C2-C7 angle in flexion, as well as smaller lordotic C2-C7 angle in extension, with greater

TABLE 3. Correlation Between the JOA Score RR and Patients' Characteristics and Radiological Factors

	r	*P*
JOA score RR *vs.*		
Age at surgery	−0.151	0.058
Sex	0.031	0.695
Flexion K-line (−)	−0.301	<0.001
C2-C7 angle		
Preop.	−0.045	0.577
Postop.	0.079	0.320
C7 slope		
Preop.	0.030	0.711
Postop.	−0.062	0.440
C7 slope minus C2-C7 angle		
Preop.	0.085	0.286
Postop.	−0.173	0.029
C2-C7 SVA		
Preop.	0.071	0.374
Postop.	-0.064	0.425
C2-C7 angle in flexion		
Preop.	0.048	0.550
Postop.	0.049	0.540
C2-C7 angle in extension		
Preop.	0.011	0.891
Postop.	0.084	0.293
Cervical range of motion		
Preop.	−0.039	0.630
Postop.	0.039	0.628
Postop. spinal cord clearance	0.013	0.874
Postop. residual spinal cord compression	−0.201	0.011
Preop. high SI changes on T2-WI combined with low SI changes on T1-WI	−0.211	0.008

JOA indicates Japanese Orthopaedic Association; Postop., postoperatively; Preop., preoperatively; RR, recovery rate; SI, signal intensity; SVA, sagittal vertical axis; WI, weighted image.

TABLE 4. Multiple Linear Regression Analysis of the JOA Score RR

Characteristic	*B*	*P*
Age at surgery	−0.248	0.001
Flexion K-line (−)	−0.282	<0.001
Postop. C7 slope minus C2-C7 angle	−0.154	0.042
Postop. residual spinal cord compression	−0.178	0.014
Preop. high SI changes on T2-WI combined with low SI changes on T1-WI	−0.266	<0.001

JOA indicates Japanese Orthopaedic Association; Postop., postoperatively; Preop., preoperatively; RR, recovery rate; SI, signal intensity; WI, weighted image.

postoperative reduction of cervical extension and cervical ROM. Patients with a flexion K-line (−) demonstrated a smaller postoperative increase in JOA score and a worse JOA score RR than those with a K-line (+). Multiple linear regression analysis confirmed that the JOA score RR was influenced by a flexion K-line (−).

The smaller lordotic C2-C7 angle in the flexion K-line (−) group was associated with a smaller C7 slope and a greater C7 slope minus C2-C7 angle. A greater T1 (C7) slope minus C2–C7 angle is regarded as a mismatch of the cervical sagittal balance.[16,22,23] Therefore, an effective compensation of the cervical alignment was not achieved in the flexion K-line (−) group. Considering the kyphosis in cervical flexion and less lordosis in cervical extension, the flexion K-line (−) group was more likely to have a flexion oriented cervical alignment than the K-line (+) group. Postoperatively, the tendency to a flexion-oriented cervical alignment increased in the flexion K-line (−) group, with a greater reduction of cervical extension compared to the K-line (+) group.

Despite a tendency to greater incidence of postoperative residual spinal cord compression in the flexion K-line (−) than (+) group, there was no difference in the postoperative spinal cord clearance between the groups. In our study, MRI was performed in a supine neck-neutral position. The cervical alignment in the supine position is different from that in the standing position. Moreover, a standing neck-flexed position increases the risk for spinal cord compression in patients with less cervical lordosis. Therefore, even if postoperative spinal cord compression was not observed in the supine neck-neutral position, we can expect to observe a compression in the standing neck-flexed position, which would negatively impact the JOA score RR.

We conducted univariate and multivariate analyses of the JOA score RR to identify factors that influenced the surgical outcome. On multiple linear regression analysis, we identified the following factors as associated with a lower JOA score RR: a K-line (−) in the neck-flexed position; a preoperative high SI changes on T2-WI combined with low SI changes on T1-WI in the spinal cord; and older age. A poor surgical outcome may be induced by the cervical spinal cord being placed under tension and/or compression of the anterior horn of the spinal cord in the neck-flexed position. Therefore, the flexion K-line could provide a good indicator of surgical outcome after posterior decompression surgery.

Consistent with the results of our study, a previous systematic review conducted by Tetreault *et al*[24] identified that patients with high SI changes on T2-WI combined with low SI changes on T1-WI are likely to have poor neurological outcome after surgery for CCM. According to a prospective multicenter AO Spine international study of 479 patients with CCM, older age was identified as an independent predictor of poor surgical outcome.[25] Consistent with this finding, we identified older age as being associated with

Figure 1. Representative case in the flexion K-line (−) group. (A) Postoperative radiographs for a 52-year-old man who underwent C4–C6 SL. The preoperative (B) K-line and (C) flexion K-line are shown.

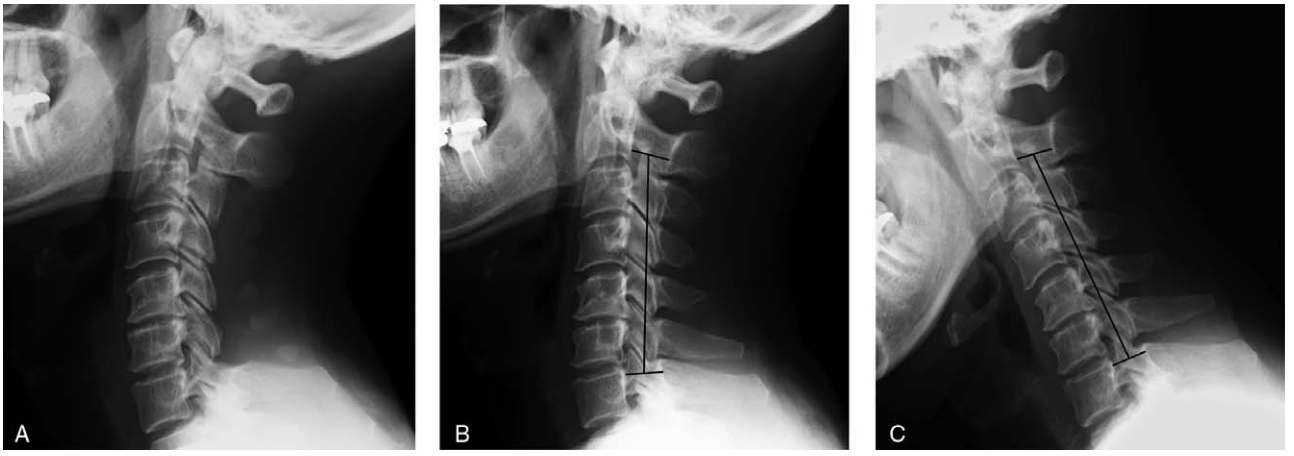

Figure 2. Representative case in the flexion K-line (+) group. (A) Postoperative radiographs for a 53-year-old man who underwent C3–C6 SL. The preoperative (B) K-line and (C) flexion K-line are shown.

a lower JOA score RR on multivariate analysis. It is interesting to note that the JOA score RR was worse for patients with a flexion K-line (−) than (+), although patients in the flexion K-line (−) group were younger than those in the flexion K-line (+) group. Therefore, a flexion K-line has a greater influence on the JOA score RR than age. This is consistent with the results of our multiple linear regression analysis of the JOA score RR which yielded a greater absolute value of the standard partial regression coefficient for the flexion K-line than age.

For patients with OPLL, the usefulness of the flexion K-line as an indicator of surgical outcome has been reported.[9,10] Our findings indicate that the flexion K-line, which considers dynamic factors and cervical alignment in standing position, can also be a good indicator of surgical outcome for patients with CSM. We suggest that posterior decompression and fusion, which limits the flexion of the cervical spine, results in better surgical outcome for patients with CSM having a flexion K-line (−).

The limits of our study should be acknowledged. First, this was a retrospective study which inherently included selection bias. Second, the flexion K-line does not consider spinal cord compression caused by soft tissues, such as a disc herniation, as the line was analyzed on radiographs. Therefore, the flexion K-line should not be used for patients diagnosed with cervical disc herniation. Third, the sample size of the present study was relatively small, and the number of patients in the flexion K-line (−) group was small compared to the number of patients in the flexion K-line (+) group. To confirm our results, prospective studies, with a larger sample size, are required.

CONCLUSION

Our study demonstrated that a K-line (−), measured in a neck-flexed position, negatively influenced the surgical outcome after SL in patients with CSM. For patients with CSM, the flexion K-line may be a useful indicator of surgical outcome after posterior decompression surgery.

➢ Key Points

- ❑ Younger age, a less lordotic cervical alignment, smaller C7 slope, greater mismatch between the C7 slope and the C2-C7 angle, and greater postoperative reduction of cervical range of motion were associated with a flexion K-line (−) in patients with CSM.
- ❑ The postoperative increase in JOA score was significantly lower ($P < 0.001$) in the flexion K-line (−) group (1.2 ± 1.6) than the flexion K-line (+) group (2.5 ± 1.9).
- ❑ The RR of the JOA score was significantly lower ($P < 0.001$) in the flexion K-line (−) group ($20.1\% \pm 28.9\%$) than the flexion K-line (+) group ($43.5\% \pm 30.1\%$).
- ❑ On multivariate regression analysis, a flexion K-line (−) ($\beta = -0.282$, $P < 0.001$), preoperative high SI changes on T2-WI combined with low SI changes on T1-WI in the spinal cord on MRI ($\beta = -0.266$, $P < 0.001$), and older age ($\beta = -0.248$, $P = 0.001$) were associated with a lower RR of the JOA score.
- ❑ For patients with CSM, a flexion K-line (−) can be a useful indicator of a lower RR of the JOA score after SL.

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