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Clinical outcome of laminoplasty for cervical ossification of the posterior longitudinal ligament with K-line (−) in the neck neutral position but K-line (+) in the neck extension position

A retrospective observational study

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Abstract

Patients with cervical ossification of the posterior longitudinal ligament (OPLL) who are K-line (−) are thought to have poor clinical outcomes after laminoplasty. The aim of this study is to compare the clinical results of patients with OPLL who were K-line (−) in the neck neutral position but K-line (+) in the neck extension position (NEP group) with patients with OPLL who were K-line (+) in the neck neutral position (NNP group).

Retrospectively, 42 patients who underwent cervical laminoplasty for OPLL by our surgical group during 2012 and 2013 were reviewed and were followed for at least 2 years. The patients were divided into 2 groups according to K-line status. Standing plain radiographs of the cervical spine were obtained pre- and postoperatively. Cervical spine alignment parameters included the C2–7 Cobb angle and range of motion (ROM) measured on lateral radiographs. Clinical evaluation included pre- and postoperative JOA, NDI, and VAS scores.

Ten patients were classified in the NEP group, and 32 patients were classified in the NNP group. Preoperatively, the OPLL involved segments were 4.10 ± 1.66 in the NEP group and 2.53 ± 1.16 in the NNP group ($P = .005$). The canal-occupying ratios were 58.40 ± 11.11% in the NEP group and 29.08 ± 11.38% in the NNP group ($P < .001$). The mean Cobb angle of both the groups had not changed significantly at the last follow-up. The mean cervical ROM of both the groups had decreased at the last follow-up. The mean JOA score of the NEP group improved significantly from 9.70 ± 2.16 to 12.50 ± 2.27 ($P = .014$). The mean JOA score of the NNP group improved significantly from 11.91 ± 1.69 to 14.93 ± 1.58 ($P < .001$). The mean JOA recovery rate was 32.71 ± 40.45% in the NEP group and 59.00 ± 33.80% in the NNP group ($P = .036$). The NDI scores of both groups were significantly decreased, and the VAS scores of both groups had not changed significantly at the last follow-up.

Laminoplasty is a relatively effective and safe procedure for patients with K-line (−) in the neck neutral position but K-line (+) in the neck extension position. Instead of anterior surgery, we recommend laminoplasty for those patients with OPLL extending to 3 or more segments.

Abbreviations: ACDF = anterior cervical decompression and fusion, CT = computed tomography, JOA = Japanese Orthopedic Association, MRI = magnetic resonance imaging, NDI = neck disability index, NEP = neck extension position, NNP = neck neutral position, OPLL = ossification of the posterior longitudinal ligament, ROM = range of motion, VAS = visual analog scale.

Keywords: alignment, cervical, K-line, laminoplasty, motion, ossification of the posterior longitudinal ligament

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1. Introduction

Ossification of the posterior longitudinal ligament (OPLL) is a common disease leading to cervical myelopathy and radiculopathy. It was first reported by Japanese doctors and its incidence rate has been reported to be 1.9% to 4.3% in the East Asian population.[1] However, OPLL also occurs in patients of other ethnicities. Reports from America and Europe describe its incidence as approximately 0.16% to 2.2%.[2,3] Surgical treatment for patients with OPLL has a higher risk of perioperative complications than for patients with other forms of degenerative cervical myelopathy, such as dural tears and graft complications.[4] With regard to the surgical strategy, although anterior cervical decompression and fusion (ACDF) provides superior recovery rates for patients with OPLL, especially for cases with over 50% canal occupancy,[5,6] posterior decompression surgery is the more common choice because of the technical ease and lower rate of complications, especially when 3 or more segments are involved.

The kyphosis line (K-line), which is drawn from the center of the canal at C2 to the center of the canal at C7, is widely used in making decisions regarding the surgical approach for patients with cervical OPLL. It was first described by Fujiyoshi et al[7] in 2008. It was demonstrated that neurological improvement will not be obtained after posterior decompression surgery in K-line (−) patients owing to insufficient posterior shift of the spinal cord. Recent reports also claim that the modified K-line, which is drawn on an MR image, is an effective index for the evaluation of posterior shifting of the spinal cord. Thus, it is useful for the prediction of clinical and radiological outcomes of cervical laminoplasty.[8,9]

In our spinal surgery practice, considering the technical difficulty and risks of ACDF, we perform laminoplasty for most patients with multilevel OPLL, and even some K-line (−) patients. Retrospectively, we found that for patients with a certain amount of cervical flexibility, their K-line (−) can be corrected and became K-line (+) in the neck extension position. Many of these patients achieved satisfactory clinical outcomes after laminoplasty. Thus, we speculated that patients with K-line (+) in the neck extension position may be good candidates for laminoplasty. The purpose of this study was to show the clinical and radiographic comparison of patients with OPLL who were K-line (−) in the neck neutral position but K-line (+) in the neck extension position with patients with OPLL who were K-line (+) in the neck neutral position.

2. Materials and methods

2.1. Patients

The study was approved by our Institutional Research Board. We retrospectively reviewed patients who underwent cervical laminoplasty for OPLL performed by our surgical group during 2012 and 2013 and were followed for at least 2 years to undergo medical record review and telephone interviews. The study included patients with OPLL who were K-line (+) in the neck neutral position (NNP group) and patients who were K-line (−) in the neck neutral position but K-line (+) in the neck extension position (NEP group) preoperatively. Patients were excluded if they suffered from diseases that may bias the results before and after the index surgery, such as neoplastic diseases, trauma, thoracic myelopathy, and lumbar radiculopathy. According to the aforementioned criteria, the NNP group included 21 men and 11 women, with a mean age of 55.56 ± 9.16 years at surgery. The NEP group included 5 men and 5 women, with a mean age of 53.30 ± 10.31 years at surgery (Table 1).

Table 1

Patient demographic data, radiological parameters, and clinical outcomes.

	K-line (+) NNP	K-line (+) NEP	*P* value
No. of patients	32	10	
Age at surgery	55.56 ± 9.16	53.30 ± 10.31	.544
Male:female	21:11	5:5	.465
Follow-up time	38.03 ± 9.09	39.30 ± 8.43	.668
Extent of OPLL (no. vertebrae)	2.53 ± 1.16	4.10 ± 1.66	.005
Occupying ratio (%)	29.08 ± 11.38	58.40 ± 11.12	<.001
Cobb C2–7, angle	10.65 ± 9.96	5.67 ± 7.67	.112
C2–7 ROM	35.99 ± 11.05	34.33 ± 12.34	.710
JOA score	11.91 ± 1.69	9.70 ± 2.16	.011
NDI score	11.19 ± 3.69	12.10 ± 4.12	.542
VAS score	3.44 ± 1.63	3.90 ± 1.45	.405

JOA = Japanese Orthopedic Association, NDI = neck disability index, NEP = neck extension position, NNP = neck neutral position, OPLL = ossification of the posterior longitudinal ligament, ROM = range of motion, VAS = visual analog scale.

2.2. Radiological and clinical assessments

Standing plain radiographs (anteroposterior, lateral, flexion, and extension) of the cervical spine were obtained pre- and postoperatively. Computed tomography (CT) and magnetic resonance imaging (MRI) were performed in all patients preoperatively and in selected patients postoperatively. The cervical spine alignment parameters included the C2–7 Cobb (Fig. 1) angle and C2–7 range of motion (ROM) measured on lateral radiographs. An increase of over 5° was defined as lordotic change; a decrease of over 5° was defined as kyphotic change. The canal occupation ratio of OPLL at the most stenotic level of the spinal canal was measured on CT and defined as follows: OPLL occupation ratio = (thickness of OPLL/anteroposterior diameter of the bony spinal canal) × 100%. Radiographic measurement data were collected by 2 observers. Each of them measured twice, and the mean value was used for analysis.

The patients were evaluated using pre- and postoperative Japanese Orthopedic Association (JOA), Neck Disability Index (NDI), and Visual Analog Scale (VAS) neck pain scores. The JOA score was used to measure improvement of the neurological status. The JOA score improvement rate = (postoperative score – preoperative score)/(17 – preoperative score) × 100%. An improvement rate of >75% was considered excellent, 50% to 74% good, 25% to 49% fair, and < 25% poor. Complications and morbidity related to other diseases that may influence the results during the follow-up were also recorded.

2.3. Surgical techniques

All the patients underwent unilateral open-door laminoplasty, also called the Hirabayashi technique. A high-speed drill was used to open the lamina on the right or left side. A shallow trough was drilled in the contralateral lamina, which was used as a hinge to open the lamina. This procedure, generally performed at C3–7, included removal of the C4–6 processes. For the sake of a less invasive and less costly procedure, we used titanium miniplates (Sanyou, China) to secure the opened laminae, generally at the level of C3, C5, and C7. The laminae of C4 and C6 were kept open with anchor sutures in the deep fascia. The patients got out

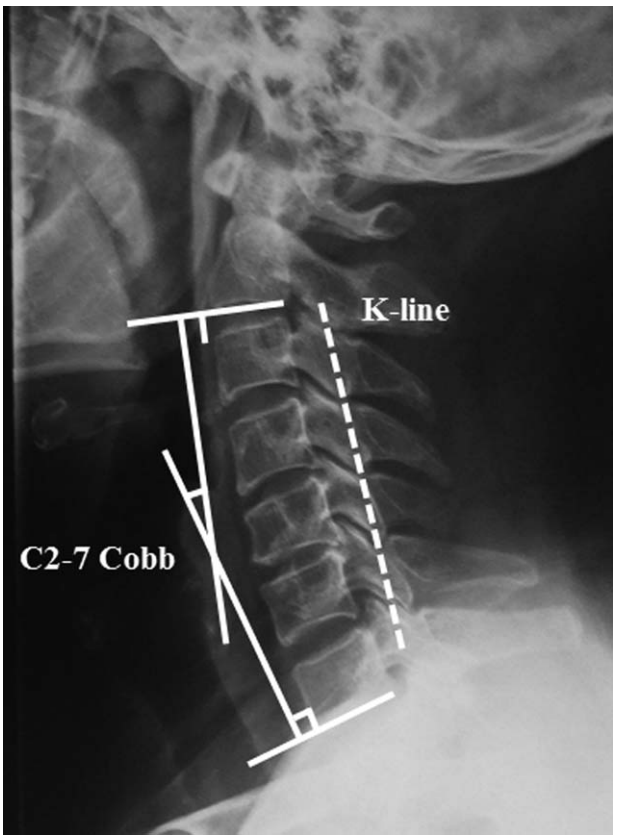

Figure 1. Determination of the K-line and Cobb angle. The K-line is a virtual line that connects the midpoints of the anteroposterior diameter of the spinal canal at C2 and C7 on lateral cervical radiographs. The C2–7 angle was measured from the inferior C2 endplate and the superior C 7 endplate.

of bed and undertook moderate physical exercise 1 day after surgery, and wore a Philadelphia collar for 1 month.

2.4. Statistical analysis

Descriptive data are represented as means ± SD. Statistical analysis involved independent sample *t* tests, paired samples *t* tests, χ^2 tests, nonparametric test, and repeated measure ANOVA. The data collected were processed using PASW Statistics 18.0 (SPSS Inc). Values of $p < .05$ were considered to indicate statistical significance.

3. Results

3.1. General characteristics

All the patients were followed for at least 2 years. Of the 42 patients with OPLL analyzed in this study, 32 were classified in the NNP group, and 10 were classified in the NEP group. The patients' general characteristics are shown in Table 1. There were no significant differences in the comparison of sex, age at surgery, or follow-up time between the 2 groups. The mean preoperative canal occupying ratio in the NEP group was 58.40 ± 11.11%, which was significantly more severe than that of the NNP group (29.08 ± 11.38%). The NEP group had significantly more involved OPLL segments than the NNP group (4.10 ± 1.66 vs 2.53 ± 1.16) ($P = .005$). In addition, the mean preoperative JOA score was 9.70 ± 2.16 in the NEP group, and 11.91 ± 1.69 in the NNP group. Thus, neurological function was far better in the NNP group ($P = .011$). The other preoperative radiographic and clinical parameters were not significantly different between the 2 groups.

3.2. Radiological results

The mean C2–7 Cobb angle in the NNP group decreased from 10.65 ± 9.96° before surgery to 10.49 ± 7.31° at the last follow-up ($P = .915$). Over 5° lordotic change was found in 7 patients, and over 5° kyphotic change was found in 6 patients. The mean C2–7 Cobb angle of the NEP group improved from 5.67 ± 7.67° to 7.20 ± 7.10° at the last follow-up ($P = .285$). Over 5° lordotic change was found in 2 patients (Fig. 2). The C2–7 ROM of both groups had decreased at the last follow-up. The C2–7 ROM of the NNP group decreased from 35.99 ± 11.05 to 27.34 ± 9.89 ($P < .001$), and that of the NEP group decreased from 34.33 ± 12.34 to 29.38 ± 17.26 ($P = .287$) (Table 2). Many patients complaint of neck stiffness and reduced neck ROM vertically and horizontally at the last follow-up.

3.3. Clinical results

In the K-line (+) NNP group, the mean JOA score improved significantly from 11.91 ± 1.69 before surgery to 14.93 ± 1.58 at the last follow-up ($P < .001$), with a mean recovery rate of 59.00 ± 33.80%. There were 13 excellent cases, 13 good cases, 3 fair cases, and 3 poor cases. Excellent or good results were achieved in 81.25% patients. A small decrease in the JOA score was seen in 2 patients. In the K-line (+) NEP group, the mean JOA score improved significantly from 9.70 ± 2.16 before surgery to 12.50 ± 2.27 at the last follow-up ($P = .014$), with a mean recovery rate of 32.71 ± 40.45%. There were 1 excellent case, 4 good cases, 3 fair cases, and 2 poor cases. Excellent or good results were achieved in 50% patients. One patient had developed weakness in the lower extremities by the last follow-up, and her JOA score had decreased from 14 to 13. One patient developed severe neurological deterioration with obvious limb weakness and numbness and walking disability. His JOA score had decreased from 10 to 7 at the last follow-up. The JOA improvement of the NEP group is significantly less than that of the NNP group ($P < .001$). It is the same with the mean JOA recovery rate ($P = .036$). The mean NDI score decreased significantly in both groups at the last follow-up (Table 3). The mean VAS for neck pain score did not change significantly in either group (Table 3).

The surgery-related complications found were as follows: there were 3 cases of C5 palsy in the NNP group and 2 cases in the NEP group. Axial neck pain was more common. There were 7 cases of axial pain in the NNP group and 3 cases in the NEP group. Their C5 palsy and axial neck pain had disappeared at the last follow-up. However, many patients complained about neck stiffness and discomfort at the last follow-up. Wound infection occurred in 1 case in the NNP group. Neurological deterioration during and early after surgery was not found in both the groups. Late neurological deterioration was found in 2 cases in both the groups at the last follow-up. Among them, only 1 case in the NEP group needed surgical treatment. However, the patient refused operation. No postoperative cerebrospinal fluid leak or epidural hematoma occurred, and no revision surgery was performed in either group.

4. Discussion

The K-line reflects both cervical alignment and the thickness of OPLL in 1 parameter. It is a simple and practical tool for deciding

Figure 2. A 55-year-old woman presented with cervical spondylotic myelopathy caused by OPLL; her C2–7 Cobb angle was −4.32° and cervical ROM 36.66° preoperatively. A, OPLL exceeded the K-line in the neck neutral position. B, OPLL did not exceed the K-line in neck extension position. C, CT showed that the occupying ratio at the level with most compression was 50%. D–F, 55 months after surgery, the Cobb angle had increased to 5.32° and the cervical ROM had decreased to 28.45°. OPLL = ossification of the posterior longitudinal ligament, ROM = range of motion.

on surgical strategy and prediction of surgical outcome for patients with cervical OPLL.[7,9–12] Studies have shown poor clinical outcome after laminoplasty in patients with K-line (−) OPLL or thick OPLL (occupation ratio>60%).[7,11,13] However, retrospectively, we found that some of our patients with K-line (−) OPLL achieved satisfactory results after laminoplasty. In this study, the mean JOA score of the NEP group improved significantly, from 9.70±2.16 before surgery to 12.50±2.27 at the last follow-up (P=.014), with a mean recovery rate of 32.71±40.45%. Although their JOA recovery rate was lower than that of the NNP group (P=.036), the results are satisfactory considering their preoperative canal occupying ratios and poor neurological function.

Generally, patients with K-line (−) OPLL are not good candidates for laminoplasty, because laminoplasty itself damages the posterior structure of the cervical spine and may lead to progression of cervical instability and cervical kyphosis. Moreover, preoperative misalignments are thought to result in insufficient posterior shift of the spinal cord after laminoplasty, leading to poor clinical outcomes. However, the relationship between cervical misalignment and the postoperative clinical outcome after laminoplasty is still controversial. Many studies have reported that, as long as the spinal cord has been decompressed, poor cervical alignment does not necessarily result in a poor clinical outcome after laminoplasty and laminectomy.[14,15] In a study with a mean follow-up period of 3.8 years, Kawakami et al[14] reported

Table 2

Comparison of radiological outcome between groups.

	K-line (+) NNP			K-line (+) NEP		
	Preoperative	Final follow-up	*P*	Preoperative	Final follow-up	*P*
C2–7 angle	10.65±9.96	10.49±7.31	.915	5.67±7.67	7.20±7.10	.285
C2–7 ROM	35.99±11.05	27.34±9.89	<.001	34.33±12.34	29.38±17.26	.287

NEP = neck extension position, NNP = neck neutral position, ROM = range of motion.

Table 3

Comparison of clinical outcome between groups.

	K-line (+) NNP			K-line (+) NEP		
	Preoperative	Final follow-up	*P*	Preoperative	Final follow-up	*P*
JOA score	11.91 ± 1.69	14.93 ± 1.58	<.001	9.70 ± 2.16	12.50 ± 2.27	.014
JOA RR (%)*		59.00 ± 33.80			32.71 ± 40.45	.036†
NDI score	11.19 ± 3.69	7.56 ± 3.10	<.001	12.10 ± 4.12	8.50 ± 2.42	.041
VAS score	3.44 ± 1.63	2.67 ± 1.51	.070	3.90 ± 1.45	2.55 ± 1.07	.077

JOA = Japanese Orthopedic Association, NDI = neck disability index, NEP = neck extension position, NNP = neck neutral position, VAS = visual analog scale.

* JOA RR indicates JOA recovery rate.

† This *P* value is the result of comparison between K-line (+) NNP and K-line (+) NEP.

that cervical kyphosis did not influence clinical outcomes, including axial pain, JOA score, and recovery rate, following expansive laminoplasty. With a mean follow-up of 18.8 months, Kim et al[16] found no significant difference in clinical and radiographical outcomes between patients with lordosis and those with kyphosis after laminoplasty. For patients with OPLL, Iwasaki et al[17] observed deterioration of cervical alignment after laminoplasty, but there was no significant difference in surgery-related outcomes between patients with lordotic and those with kyphotic alignment. Lee et al[18] reported that, although laminoplasty increased the probability of kyphosis, the cervical sagittal alignment and clinical outcome were not clearly related in patients with OPLL. In this study, we attributed the lower JOA recovery rate of the NEP group to their severe canal occupying ratio and poor preoperative neurological function. In addition, most patients in our NEP group had thick and multilevel OPLL, which may enhance spinal column stability and prevent postoperative kyphosis.

Furthermore, instead of postoperative kyphosis, several studies have described lordotic change in the cervical spine after laminoplasty. With preservation of all bilateral muscles attached to the C2 and C7 spinous processes, Sakaura et al[19] reported that the mean cervical angle increased significantly from 16.8° before surgery to 21.1° at 5 years after laminoplasty. Data from 520 consecutive CMS patients[20] showed that, with an average follow-up period of 33.3 months, the mean cervical angle in the neutral position increased from 11.9° preoperatively to 13.6° postoperatively. In our study, the mean C2–7 Cobb angle of the NEP group had improved from 5.67 ± 7.67° to 7.20 ± 7.10° at the last follow-up ($P = .285$). Over 5° improvement of the C2–7 Cobb angle was found in 2 patients. This is partly attributed to technical modifications including less surgical exposure and preservation of the semispinalis cervicis muscle from the C2 spinous process. Another reason is that the preoperative misalignment in some patients may have been caused by muscular restraint from neck pain and discomfort before surgery, which could be corrected once their neck discomfort was relieved after surgery.

It is because the NEP patients reserved a certain amount of cervical flexibility that they became K-line (+) in the neck extension position. However, we do not think that the cervical ROM of the NEP group was an important factor contributing to their satisfactory outcome. On the contrary, it is widely believed that dynamic factors contribute to the development of myelopathy in patients with cervical OPLL.[21,22] Moreover, Matsunaga et al[23] reported that static compression by the OPLL above a certain critical point may be the most significant factor in inducing myelopathy, whereas below that point dynamic factors may be largely involved in inducing myelopathy. We speculate that a considerable amount of lordotic alignment on cervical extension might predict a good clinical outcome after laminoplasty. Suk et al[24] reported that, when compared with a lower degree of lordosis, a good lordotic angle during extension preoperatively may result in a better Cobb angle after laminoplasty. On the other hand, the preoperative extension angle was larger in postoperative lordotic patients than in those with postoperative kyphosis. Further investigation of the preoperative extension angle and its association with clinical outcomes is required.

A major concern in this study is whether ACDF would have been a better surgical choice for the NEP patients. A large amount of published research has recommended ACDF for patients with massive OPLL. Tani et al[25] reported that ACDF for massive OPLL seems counterintuitively safer than laminoplasty. Iwasaki et al[26] reported that the neurologic outcome of laminoplasty for cervical OPLL was poor or fair in patients with occupying ratio greater than 60% and/or hill-shaped ossification. At the same time, they found that the ACDF group had a significantly better recovery rate than the laminoplasty group (53% vs 30%).[27]

In our study, patients in the NEP group had severe spinal cord compression; 90% (9/10) of them had multilevel OPLL. For these patients, ACDF may be associated with a high risk of intraoperative spinal cord injury, massive trauma, and complications such as cerebrospinal fluid leakage, graft failure, or hematoma. In contrast, laminoplasty is technically less demanding and associated with fewer complications. Although their mean JOA recovery rate was poorer than that reported for ACDF,[11,15,27] 80% of the patients achieved neurological improvement. Only 1 patient with focal hill-shaped OPLL suffered severe late neurological deterioration and surgical intervention was recommended. However, long-term follow-up of our patients is needed to clarify our conclusion further. To prevent progression of kyphosis and subsequent neurological deterioration, laminoplasty with fusion may be another choice for these patients. A long-term follow-up study[28] showed that laminoplasty with lateral mass screw fusion maintains cervical lodosis and achieves significant neurological function improvement in patients with cervical spondylotic myelopathy. In addition, a recent study[29] showed that laminoplasty with fusion suppresses the progression of OPLL.

There are some limitations in this study including the small sample size, the limited follow-up, and the retrospective nature of the study. A major limitation is that we did not elucidate the relationship between cervical extension angle and clinical outcomes after laminoplasty. A comparative study between patients with OPLL who were K-line (−) in the neck extension position and who were K-line (+) in the neck extension position may provide further insights into our speculation.

5. Conclusion

In conclusion, the present study demonstrates that laminoplasty is a relatively effective and safe procedure for patients with K-line

(−) in neck neutral position combined but K-line (+) in the neck extension position. Because ACDF is technically difficult and risky for those patients, we recommend laminoplasty as the first choice, especially in those with multilevel OPLL. However, long-term results are necessary to further support this conclusion.

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References

[1] Matsunaga S, Sakou T. Ossification of the posterior longitudinal ligament of the cervical spine: etiology and natural history. Spine (Phila Pa 1976) 2012;37:E309–14.
[2] McAfee PC, Regan JJ, Bohlman HH. Cervical cord compression from ossification of the posterior longitudinal ligament in non-orientals. J Bone Joint Surg Br 1987;69:569–75.
[3] Fujimori T, Le H, Hu SS, et al. Ossification of the posterior longitudinal ligament of the cervical spine in 3161 patients: a CT-based study. Spine (Phila Pa 1976) 2015;40:E394–403.
[4] Nakashima H, Tetreault L, Nagoshi N, et al. Comparison of outcomes of surgical treatment for ossification of the posterior longitudinal ligament versus other forms of degenerative cervical myelopathy: results from the Prospective, Multicenter AOSpine CSM-International Study of 479 patients. J Bone Joint Surg Am 2016;98:370–8.
[5] Iwasaki M, Okuda S, Miyauchi A, et al. Surgical strategy for cervical myelopathy due to ossification of the posterior longitudinal ligament: Part 2: advantages of anterior decompression and fusion over laminoplasty. Spine (Phila Pa 1976) 2007;32:654–60.
[6] Sakai K, Okawa A, Takahashi M, et al. Five-year follow-up evaluation of surgical treatment for cervical myelopathy caused by ossification of the posterior longitudinal ligament: a prospective comparative study of anterior decompression and fusion with floating method versus laminoplasty. Spine (Phila Pa 1976) 2012;37:367–76.
[7] 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.
[8] Taniyama T, Hirai T, Yoshii T, et al. Modified K-line in magnetic resonance imaging predicts clinical outcome in patients with nonlordotic alignment after laminoplasty for cervical spondylotic myelopathy. Spine (Phila Pa 1976) 2014;39:E1261–8.
[9] Sun LQ, Li M, Li YM. Prediction of incomplete decompression after cervical laminoplasty on magnetic resonance imaging: the modified K-line. Clin Neurol Neurosurg 2016;146:12–7.
[10] Taniyama T, Hirai T, Yamada T, et al. Modified K-line in magnetic resonance imaging predicts insufficient decompression of cervical laminoplasty. Spine (Phila Pa 1976) 2013;38:496–501.
[11] Koda M, Mochizuki M, Konishi H, et al. Comparison of clinical outcomes between laminoplasty, posterior decompression with instrumented fusion, and anterior decompression with fusion for K-line (-) cervical ossification of the posterior longitudinal ligament. Eur Spine J 2016;25:2294–301.
[12] 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.
[13] Kim B, Yoon DH, Shin HC, et al. Surgical outcome and prognostic factors of anterior decompression and fusion for cervical compressive myelopathy due to ossification of the posterior longitudinal ligament. Spine J 2015;15:875–84.
[14] Kawakami M, Tamaki T, Ando M, et al. Relationships between sagittal alignment of the cervical spine and morphology of the spinal cord and clinical outcomes in patients with cervical spondylotic myelopathy treated with expansive laminoplasty. J Spinal Disord Tech 2002;15:391–7.
[15] Kaptain GJ, Simmons NE, Replogle RE, et al. Incidence and outcome of kyphotic deformity following laminectomy for cervical spondylotic myelopathy. J Neurosurg 2000;93(2 suppl):199–204.
[16] Kim SW, Hai DM, Sundaram S, et al. Is cervical lordosis relevant in laminoplasty? Spine J 2013;13:914–21.
[17] Iwasaki M, Kawaguchi Y, Kimura T, et al. Long-term results of expansive laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine: more than 10 years follow up. J Neurosurg 2002;96(2 suppl):180–9.
[18] Lee CK, Shin DA, Yi S, et al. Correlation between cervical spine sagittal alignment and clinical outcome after cervical laminoplasty for ossification of the posterior longitudinal ligament. J Neurosurg Spine 2016;24:100–7.
[19] Sakaura H, Hosono N, Mukai Y, et al. Medium-term outcomes of C3-6 laminoplasty for cervical myelopathy: a prospective study with a minimum 5-year follow-up. Eur Spine J 2011;20:928–33.
[20] Machino M, Yukawa Y, Hida T, et al. Cervical alignment and range of motion after laminoplasty: radiographical data from more than 500 cases with cervical spondylotic myelopathy and a review of the literature. Spine (Phila Pa 1976) 2012;37:E1243–50.
[21] Fujiyoshi T, Yamazaki M, Okawa A, et al. Static versus dynamic factors for the development of myelopathy in patients with cervical ossification of the posterior longitudinal ligament. J Clin Neurosci 2010;17:320–4.
[22] Nishida N, Kanchiku T, Kato Y, et al. Cervical ossification of the posterior longitudinal ligament: biomechanical analysis of the influence of static and dynamic factors. J Spinal Cord Med 2015;38:593–8.
[23] Matsunaga S, Kukita M, Hayashi K, et al. Pathogenesis of myelopathy in patients with ossification of the posterior longitudinal ligament. J Neurosurg 2002;96(2 suppl):168–72.
[24] Suk KS, Kim KT, Lee JH, et al. Sagittal alignment of the cervical spine after the laminoplasty. Spine (Phila Pa 1976) 2007;32:E656–60.
[25] Tani T, Ushida T, Ishida K, et al. Relative safety of anterior microsurgical decompression versus laminoplasty for cervical myelopathy with a massive ossified posterior longitudinal ligament. Spine (Phila Pa 1976) 2002;27:2491–8.
[26] Iwasaki M, Okuda S, Miyauchi A, et al. Surgical strategy for cervical myelopathy due to ossification of the posterior longitudinal ligament: Part 1: Clinical results and limitations of laminoplasty. Spine (Phila Pa 1976) 2007;32:647–53.
[27] Fujimori T, Iwasaki M, Okuda S, et al. Long-term results of cervical myelopathy due to ossification of the posterior longitudinal ligament with an occupying ratio of 60% or more. Spine (Phila Pa 1976) 2014;39:58–67.
[28] Miyamoto H, Maeno K, Uno K, et al. Outcomes of surgical intervention for cervical spondylotic myelopathy accompanying local kyphosis (comparison between laminoplasty alone and posterior reconstruction surgery using the screw-rod system). Eur Spine J 2014;23:341–6.
[29] Katsumi K, Izumi T, Ito T, et al. Posterior instrumented fusion suppresses the progression of ossification of the posterior longitudinal ligament: a comparison of laminoplasty with and without instrumented fusion by three-dimensional analysis. Eur Spine J 2016;25:1634–40.