Turk Neurosurg 31(6):866-872, 2021

Original Investigation

DOI: 10.5137/1019-5149.JTN.31668-20.1

Received: 27.07.2020
Accepted: 16.10.2020

Published Online: 24.02.2021

A New Indicator Predicting the Degree of Cord Shift After Posterior Decompression of Cervical Ossification of the Posterior Longitudinal Ligament Extended to the C2 Level and Its Clinical Usefulness

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ABSTRACT

AIM: To evaluate the usefulness of the rostral line (R-line) as a new index for determining the degree of C2 lamina decompression in the context of ossification of the posterior longitudinal ligament (OPLL) extending to the C2 level.

MATERIAL and METHODS: The R-line was devised based on the mechanism by which the cord is shifted backward following cervical posterior decompression. According to their R-line status, 36 patients with cervical OPLL extending to the C2 level were divided into two groups of R-line (+) and R-line (–) cases, where the R-line touched the upper half of the posterior C2 lamina in the R-line (+) group and the inferior half of the posterior C2 lamina in the R-line (–) group, respectively.

RESULTS: Eighteen patients were classified as R-line (+) and 18 patients were classified as R-line (–). Total laminectomy of the C2 lamina was more common in the R-line (+) group, while dome-shape C2 laminectomy was more common in the R-line (–) group. All patients requiring reoperation were included in the R-line (+) group. Only the operation type showed a statistically significant difference according to the need for reoperation in the R-line (+) group; specifically, all patients who underwent reoperation in the R-line (+) group had dome-shape C2 laminectomy. It was determined that the risk factor for reoperation in the R-line (+) group was a history of dome-shape C2 laminectomy.

CONCLUSION: If the R-line touches the upper half of the posterior C2 lamina, total decompression of the C2 lamina should be performed.

KEYWORDS: Axis, Cervical vertebra, Laminectomy, Ossification of the posterior longitudinal ligament, Posterior decompression, R-line

ABBREVIATIONS: CSF: Cerebrospinal fluid, **JOA:** Japanese Orthopedic Association, **LCL:** Loss of cervical lordosis, **MEP:** Motor evoked potential, **MRI:** Magnetic resonance imaging, **OPLL:** Ossification of the posterior longitudinal ligament, **R-line:** Rostral line

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INTRODUCTION

Ossification of the posterior longitudinal ligament (OPLL) is characterized by the progressive heterotopic coalescence of centers for chondrification and ossification that may mimic symptoms of degenerative disc disease or spinal cord compression (6). OPLL can occur anywhere in the cervical region butonly rarely extends to the C2 level (10). Cervical laminoplasty is one of the most commonly used treatment methods for OPLL (1). However, because of the known importance of the muscle attached to the C2 spinous process, posterior dome-shape laminectomy of C2 is often conducted to preserve the muscle attached to this spinous process (13,14). Previously, we encountered seven patients showing incomplete decompression after dome-shape C2 laminectomy. Based on this experience, the presentstudy devised the rostral line (R-line) as a new index for determining the degree of C2 lamina decompression in the context of OPLL extending to the C2 level while considering the mechanism of postoperative C2 cord shifting (Figure 1) and evaluated its usefulness as an index.

MATERIAL and METHODS

The study protocol was approved by the Institutional Review Board of Asan Medical Center (IRB no. 2018-0537).

Patient Population

A total of 79 consecutive patients who underwent posterior cervical decompression for the treatment of OPLL extending to the C2 level without C1–2 or C2–3 instability from January 1999 to December 2016 at a single center were considered for inclusion in this study. Patients with instability of C1–2 and C2–3 before surgery had been considered for fusion surgery instead of posterior cervical decompression; 11 patients with myelopathy due to cervical disc herniation, cervical spondylotic myelopathy, craniocervical junction abnormality, or a history of previous anterior cervical spine surgery were excluded. Of the 68 remaining patients, 36 patients (31 men and five women) who underwent postoperative magnetic resonance imaging (MRI) were included in this study. The mean age of the study participants at surgery was 55.9 years (range: 43–77 years). Two types of decompression (i.e., total laminectomy C2 or dome-shape C2 laminectomy) at the C2 level were selected according to the presence of effacement of the posterior cerebrospinal fluid (CSF) buffer on T2-weighted sagittal and axial images taken at the C2 level (Figure 2A). Dome-shape C2 laminectomy involves removing the lower margin of the C2 lamina using a Kerrison punch and drill and, finally, a right-angle-curved curette (Figure 2B). All patients were seen for at least one year after surgery for follow-up assessments.

Clinical and Radiographic Assessments

The Japanese Orthopedic Association (JOA) scoring system was used to assess the degree of cervical myelopathy preoperatively and at one year postoperatively (11). Prior to surgery, the cervical lordotic angle (C2–7) on lateral radiographs for sagittal alignment and the maximal OPLL thickness on computed tomography images were measured. The maximal thickness of OPLL was defined as the thickness of OPLL at the level of maximal-cord compression by OPLL on the middle sagittal view of computed tomography images. The location of the upper edge of the OPLL and degree of instability of C1–2 and C2–3 were also measured because they canaffect cord shifting. The location of the upper edge of OPLL extended to C2 was defined as follows: the inferior end of the C2 body and the superior end of the dens were divided into the upper, middle, and lower thirds. According to this scheme, the extended OPLL was defined as being lower if it was in the lower one third; middle if it was in the middle one-third; and upper if it was in the upper one-third (Figure 2C).

Definition of the R-line

The R-line was devised based on the mechanism by which the cord was shifted backward after cervical posterior decompression. We established the R-line to determine the degree of C2 lamina decompression in OPLL extending to the C2 level. To draw the R-line, we principally used T2-weighted midsagittal MRI images. Taniyama et al. showed that the neck position should be similar to the neutral neck position when MRI is performed (18). At the most compressed area by OPLL (denoted with an asterisk in Figure 3) among the C2, 3, and 4 levels, it can be seen that the spinal cord diameter is expanded and the cord position is altered after decompression. The

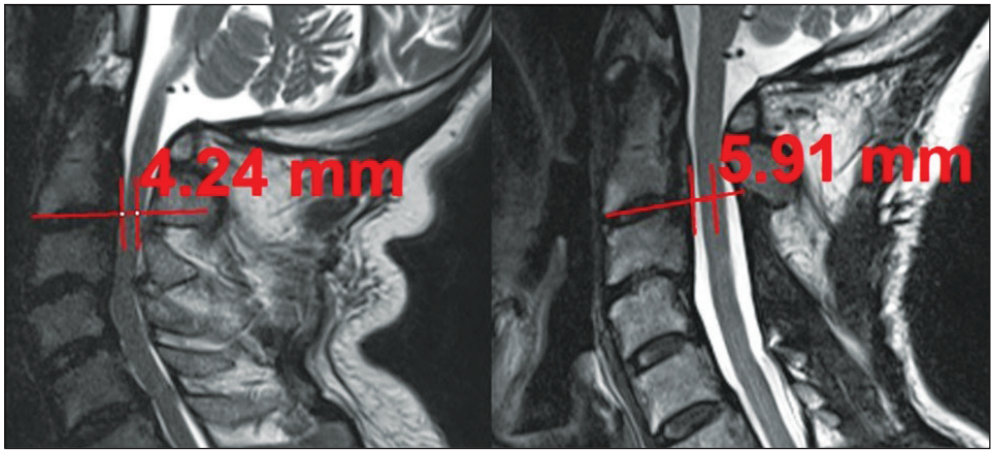

Figure 1: Cord shifting after posterior decompression. The distance between the midpoint of the spinal cord and the posterior edge of the ossification of the posterior longitudinal ligament (OPLL) at the C2 inferior end-plate level increased from 4.24 mm to 5.91 mm due to cord shifting after C2 decompression.

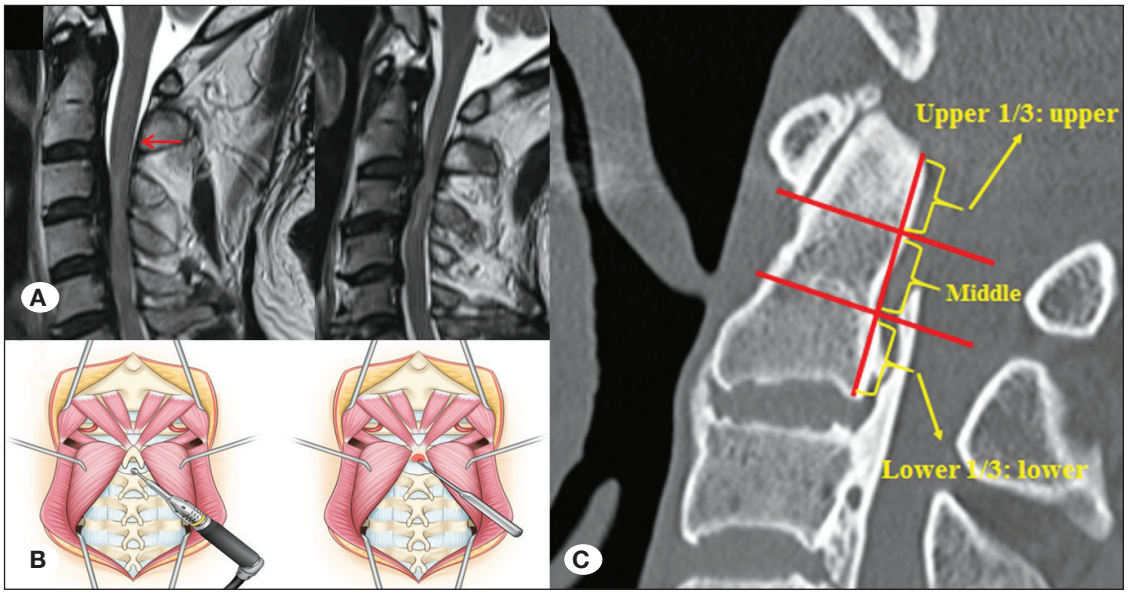

Figure 2: Determination of C2 level decompression and the location of the upper edge of the ossification of the posterior longitudinal ligament (OPLL) extended to C2. **A)** If the cerebrospinal fluid (CSF) buffer was observed at the C2 level (red arrow), then dome-shape C2 laminectomy was performed. If all CSF buffer at C2 level was lost, then total decompression of C2 lamina was performed. **B)** Dome-shape C2 laminectomy; **C)** location of the upper edge of the OPLL extending to the C2 upper third, middle third, and lower third.

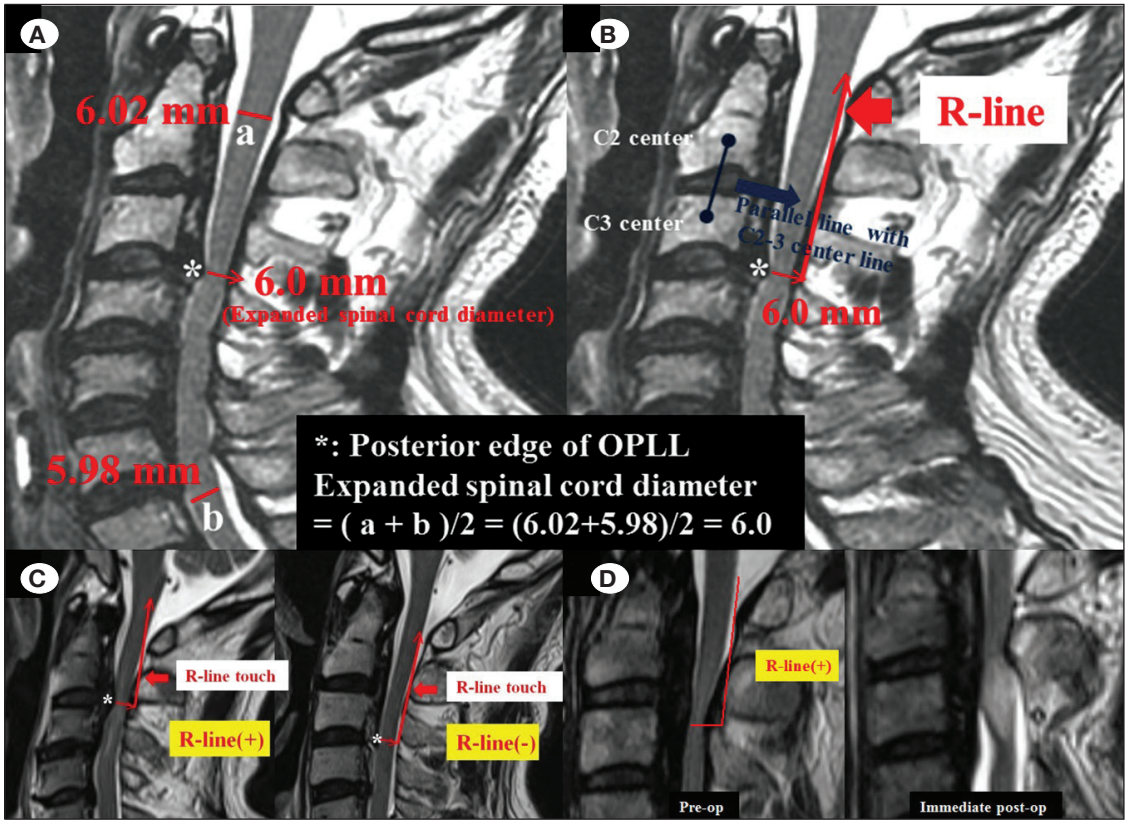

Figure 3: Definition of the rostral line (R-line). **A)** An expanded spinal cord diameter after decompression was expected with mean values above and below the normal spinal cord diameter. **B)** The R-line is parallel to the line passing through the center of the C2, located three vertebral bodies from the expanded spinal cord diameter. **C)** The R-line touches the upper half of the posterior C2 lamina in the R-line (+) group and touches the inferior half of the posterior C2 lamina in the R-line (–) group. **D)** The R-line touches the upper half of the posterior C2 lamina. Postoperative magnetic resonance imaging scan shows incomplete decompression after dome-shape C2 laminectomy.

expanded spinal-cord diameter after decompression, which was regarded as a normal cord diameter, was expected, with mean values above and below the normal spinal cord diameter value present at any level in the midline section of the MRI T2 sagittal image (Figure 3A). The R-line was defined as the parallel line with a C2–3 body center line drawn from the most dorsal spinal cord point, which was similarly expected with spinal cord expansion and shifting after decompression (Figure 3B). Based on their R-line status, patients with cervical OPLL extending to the C2 level were stratified into two groups of R-line (+) cases and R-line (–) cases, respectively. Notably, the R-line touched the upper half of the posterior C2 lamina in the R-line (+) group but the inferior half of the posterior C2 lamina in the R-line (–) group (Figure 3C).

Statistical Analysis

Measurement values were evaluated independently by two observers with more than five years of experience in the spine field. Intra-examiner reproducibility and inter-examiner reliability were evaluated using intra- and interclass correlation coefficients. The Student's t-test, chi-squared test, and Fisher's exact test were used to compare differences between the two groups. A p-value of less than 0.05 was considered to be statistically significant. All analyses were conducted using the SPSS Statistics version 20.0 software program (IBM Corporation, Armonk, NY, USA).

RESULTS

Of the 36 patients analyzed in this study, 12 patients underwent total laminectomy of C2 and 24 patients underwent dome-shape C2 laminectomy. The loss of cervical lordosis (LCL) on cervical X-ray at one year after surgery occurred in patients who had C2 laminectomy. The mean LCL overall was 5.47° ± 3.76° (range: –1° to 14°). The mean LCL was 8.08° ± 3.63° (range: 3°–14°) in the total laminectomy group and 4.17° ± 3.14° (range:–1° to 11°) in the dome-shape C2 laminectomy group. As such, there was a statistically significant difference noted between the two decompression groups (p=0.005). Moreover, the intra- and inter-examiner reliability values suggested strong agreement existed in dividing the R-line (+) and (–) groups according to R-line parameters (the intra- and interclass correlation coefficients were 0.86 and 0.84, respectively). The 36 identified patients were classified as R-line (+) cases (n=18) or as R-line (–) cases(n = 18).

The preoperative mean JOA score was 10.33 ± 0.84 (range: 9–11) points in the R-line (+) group and 10.61 ± 0.85 (range: 9–12) points in the R-line (–) group. The mean C2–7 lordotic angle (preoperative) was 13.33° ± 6.92° (range:1°–26°) in the R-line (+) group and 14.67° ± 7.73° (range:5°–29°) in the R-line (–) group. The mean thickness of the OPLL was 6.07 ± 1.29 (range: 3.8–8.8) mm in the R-line (+) group and 5.82 ± 0.75 (range: 4.8–7.6) mm in the R-line (–) group. In the R-line (+) group, the location of the upper edge of the OPLL was the upper third in six patients, the middle third in seven patients, and the lower third in five patients. In the R-line (–) group, the upper edge of the OPLL was present in the upper third in six patients, the middle third in 10 patients, and the lower third in two patients. Age, sex, preoperative JOA score, preoperative C2–7 lordotic angle, thickness of the OPLL, and location of the upper edge of the OPLL were not statistically different between the two groups, while the operation type and rate of reoperation did show a significant difference between the two groups. Notably, total laminectomy of the C2 lamina was more common in the R-line (+) group, while dome-shape C2 laminectomy was more common in the R-line (–) group. All patients experiencing reoperation were included in the R-line (+) group. Preoperative clinical and radiologic factors are summarized in Table I. The causes of reoperation in the R-line (+) group were analyzed and no differences in age, sex, preoperative JOA score, preoperative C2–7 lordotic angle, or thickness of the OPLL according to reoperation were present in the R-line (+) group. Instead, only the operation type showed a statistically significant difference according to reoperation in the R-line (+) group; specifically, all patients who underwent reoperation in the R-line (+) group had a history of dome-shape C2 laminectomy (Table II and Figure 3D). Thus, the incidence of reoperation was significantly higher in the R-line (+) group and the risk factor for reoperation in the R-line (+) group is a history of dome-shape C2 laminectomy.

DISCUSSION

The Need For a New Index of C2 Decompression

LCL and axial neck pain resulting from the detachment of the muscle attached to the C2 spinous process after laminoplasty are commonly reported (13,17). Nolan and Sherk showed that the removal of the semispinalis muscles attached to the C2 spinous process led to a loss of normal cervical sagittal alignment using biomechanical analysis (12). Other studies have also reported that preserving the muscle attached to the C2 spinous process reduced the loss of lordosis after laminoplasty (4,5). Thus, many surgeons undercut the C2 lamina when conducting C2 lamina decompression to preserve the muscle attached to the C2 spinous process. Since 2004, dome-shape C2 laminectomy has been used at our hospital; in this context, we generally decompress to the point where the CSF buffer of C2 level is lost in the OPLL extending to the C2 level. Nevertheless, seven patients had to undergo emergency reoperation due to incomplete decompression. Therefore, an index that can accurately indicate the degree of decompression of the C2 level is needed.

R-line Considering the Mechanism of Postoperative C2 Cord Shifting

Many factors have been proposed that are related to posterior cord shifting after laminoplasty, including preoperative cervical sagittal alignment and space available for the spinal cord at cephalad/caudal levels of decompression (2,3,7,9,16). Kong et al. reported the association between the space available for the spinal cord at the cephalad/caudal level of decompression and the occurrence of spinal cord shifting in patients who underwent C3–7 laminoplasty (8). Generally, the spinal cord moves backward, similar to a bowstring, after posterior decompression. Cervical lordosis is associated with posterior migration of the cervical spinal cord, which is correlated

Table I: Comparison of Clinical and Radiological Factors Between the R-line (+) and the R-line (–) Group

Variable	R-line (+)	R-line (–)	p
Age, years	56.00 ± 8.49 (45–77)	55.94 ± 6.51 (43–68)	0.98
Gender			1.0
Male	15	16	
Female	3	2	
JOA score (preoperative)	10.33 ± 0.84 (9–11)	10.61 ± 0.85 (9–12)	0.33
C2–7 lordotic angle (preoperative)	13.33 ± 6.92 (1–26)	14.67 ± 7.73 (5–29)	0.58
Thickness of OPLL	6.07 ± 1.29 (3.8–8.8)	5.82 ± 0.75 (4.8–7.6)	0.48
Location of the upper edge of the OPLL			
Upper	6	6	0.47
Middle	7	10	
Lower	5	2	
Operation type			**< 0.01***
Dome-shape C2 laminectomy	7	17	
Total laminectomy of C2 lamina	11	1	
Reoperation	7	0	**< 0.01***

Values are expressed as mean ± standard error (range).

Table II: Comparison of Clinical and Radiological Factors According to Reoperation in the R-line (+) Group

Variable	Reoperation (+)	Reoperation (–)	p
Mean age, years	58.71 (51–73)	54.27 (45–77)	0.15
Gender			0.24
Male	7	8	
Female	0	3	
Mean JOA score (preoperative)	10.42 (10–11)	10.27 (9–11)	1.0
C2–7 lordotic angle (preoperative)	15.28 (8–26)	12.09 (1–23)	0.32
Thickness of the OPLL	5.75 (3.8–7.3)	6.27 (4.6–8.8)	0.79
Location of the upper edge of the OPLL			
Upper	1	5	0.41
Middle	3	4	
Lower	3	2	
Operation type			**< 0.01***
Dome-shape C2 laminectomy	7	0	
Total laminectomy of C2 lamina	0	11	

with improved clinical outcomes (2). However, the effects of preoperative cervical sagittal alignment on postoperative cord shifting remain controversial (19). Yamazaki et al. showed that the anterior component that compressed the cord was a key factor in determining whether the spinal cord was completely free of the OPLL after posterior decompression (20). In this study, the location of the upper edge of the OPLL was not linked to reoperation after C2 posterior decompression in the OPLL extending to the C2 level. The cord space in the canal at the C1–2 level was wider than that at the subaxial level, so there was a CSF buffer at both the front and back of the cord, even if the OPLL extended beyond the middle one-third of the C2. Therefore, even if the OPLL was extended much above the C2 level, cord shifting after posterior decompression would not be significantly impacted.

The anterior subarachnoid space is lost as the cord is pushed by the OPLL. Moreover, when the spinal cord compression by OPLL is released after posterior decompression, the anterior subarachnoid space compressed by OPLL is also released. The anterior subarachnoid space that is lost as a result of the cord being pushed by the OPLL is expanded by CSF inflow. Finally, posterior cord shifting occurs depends on the degree by which the cord is pushed by the OPLL. Based on the experiences of our seven patients who underwent reoperation and previous studies in the literature (2,3,7), this study devised

the R-line as a new index for determining the degree of C2 lamina decompression in OPLL extending to the C2 level. This is a hypothetical line that predicts the degree to which the cord shifts backward following decompression of the C2 level. We thought that if the R-line touched the lower half of the C2 lamina, the amount of decompression would be sufficient to conduct dome-shape C2 laminectomy, while, if the upper half was touched by the R-line, then total decompression of C2 should be performed.

Interpretation of the Results

When we perform surgery due to the OPLL extending to the C2 level, we expect complete decompression of the spinal cord at the C2 level to be found. Thus, the most desirable postoperative MRI findings after posterior decompression include the loss of cord compression and the presence of the posterior CSF buffer at the C2 level. In this study, all patients who underwent reoperation were included in the R-line (+) group and all patients requiring reoperation had previously undergone dome-shape C2 laminectomy. These data indicate that dome-shape C2 laminectomy was insufficient for decompression in the R-line (+) group. In contrast, none of the included patients underwent reoperation due to incomplete decompression in the R-line (–) group, which indicated that, in the R-line (–) group, sufficient decompression is to be expected, even after dome-shape C2 laminectomy. If we perform dome-shape C2 laminectomy in the R-line (+) group, complete decompression may not be feasible after surgery and a neurologic deterioration requiring reoperation can occur. In this study, however, a significant occurrence rate of LCL was observed after total laminectomy. Recently, the muscle-preservation technique of cervical posterior decompression has been reported to reduce postoperative LCL (15). If total decompression of C2 is required, then this muscle-preservation C2 decompression technique could be used to limit the kyphotic deformity after surgery.

Study Limitations

The limitations of this study include its retrospective nature and small cohort size. From January 1999 to December 2016, only seven patients underwent reoperation with incomplete decompression. As such, the number of include patients is low and the statistical strength of this investigation is weak. However, it is meaningful to note that the risk factor for reoperation in the R (+) group is dome-shape C2 laminectomy. Thus, we suggest that, for patients in the R-line (+) group, dome-shape C2 laminectomy is not appropriate. We instead recommend total decompression of C2 lamina as the first surgical choice for patients in the R-line (+) group. Considering the above limitations, further studies will be needed, with a longer follow-up period and with a larger patient population.

CONCLUSION

The results of the present study showed that, if the R-line touches the upper half of the posterior C2 lamina, then total decompression of C2 lamina should be performed. Our new index, the R-line, is a simple and practical tool able to support decision-making regarding C2 lamina decompression when the OPLL extends to the C2 level.

REFERENCES

1. Abiola R, Rubery P, Mesfin A: Ossification of the posterior longitudinal ligament: Etiology, diagnosis, and outcomes of nonoperative and operative management. Global Spine Journal 6:195-204, 2016
2. Baba H, Uchida K, Maezawa Y, Furusawa N, Azuchi M, Imura S: Lordotic alignment and posterior migration of the spinal cord following en bloc open-door laminoplasty for cervical myelopathy: A magnetic resonance imaging study. J Neurology 243:626-632, 1996
3. Chiba K, Toyama Y, Watanabe M, Maruiwa H, Matsumoto M, Hirabayashi K: Impact of longitudinal distance of the cervical spine on the results of expansive open-door laminoplasty. Spine 25:2893-2898, 2000
4. Iizuka H, Nakajima T, Iizuka Y, Sorimachi Y, Ara T, Nishinome M, Takagishi K: Cervical malalignment after laminoplasty: Relationship to deep extensor musculature of the cervical spine and neurological outcome. J Neurosurg Spine 7:610-614, 2007
5. Iizuka H, Shimizu T, Tateno K, Toda N, Edakuni H, Shimada H, Takagishi K: Extensor musculature of the cervical spine after laminoplasty: Morphologic evaluation by coronal view of the magnetic resonance image. Spine 26:2220-2226, 2001
6. Kalb S, Martirosyan NL, Perez-Orribo L, Kalani MY, Theodore N: Analysis of demographics, risk factors, clinical presentation, and surgical treatment modalities for the ossified posterior longitudinal ligament. Neurosurgical Focus 30:E11, 2011
7. Kawakami M, Tamaki T, Ando M, Yamada H, Yoshida M: 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 Disorders & Techniques 15:391-397, 2002
8. Kong Q, Zhang L, Liu L, Li T, Gong Q, Zeng J, Song Y, Liu H, Wang S, Sun Y, Zhang F, Li M, Chen Z: Effect of the decompressive extent on the magnitude of the spinal cord shift after expansive open-door laminoplasty. Spine 36:1030-1036, 2011
9. Lee JY, Sharan A, Baron EM, Lim MR, Grossman E, Albert TJ, Vaccaro AR, Hilibrand AS: Quantitative prediction of spinal cord drift after cervical laminectomy and arthrodesis. Spine 31:1795-1798, 2006
10. Li Q, Kong Q, Zhang L, Sun T, Li T, Gong Q, Song Y, Liu H: Discussion of surgical indications for posterior expansive open-door laminoplasty extended to C1 level. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 27:1214-1220, 2013
11. Masaki Y, Yamazaki M, Okawa A, Aramomi M, Hashimoto M, Koda M, Mochizuki M, Moriya H: An analysis of factors causing poor surgical outcome in patients with cervical myelopathy due to ossification of the posterior longitudinal ligament: Anterior decompression with spinal fusion versus laminoplasty. J Spinal Disord Tech 20:7-13, 2007
12. Nolan JP Jr, Sherk HH: Biomechanical evaluation of the extensor musculature of the cervical spine. Spine 13:9-11, 1988

13. Sakaura H, Hosono N, Mukai Y, Fujimori T, Iwasaki M, Yoshikawa H: Preservation of muscles attached to the C2 and C7 spinous processes rather than subaxial deep extensors reduces adverse effects after cervical laminoplasty. Spine 35:E782-786, 2010
14. Secer HI, Harman F, Aytar MH, Kahraman S: Open-door laminoplasty with preservation of muscle attachments of C2 and C7 for cervical spondylotic myelopathy: Retrospective study. Turk Neurosurg 28:257-262, 2018
15. Shiraishi T: A new technique for exposure of the cervical spine laminae. Technical note. J Neurosurg 96:122-126, 2002
16. Sodeyama T, Goto S, Mochizuki M, Takahashi J, Moriya H: Effect of decompression enlargement laminoplasty for posterior shifting of the spinal cord. Spine 24:1527-1531; discussion 1531-1522, 1999
17. Takeshita K, Seichi A, Akune T, Kawamura N, Kawaguchi H, Nakamura K: Can laminoplasty maintain the cervical alignment even when the C2 lamina is contained? Spine 30:1294-1298, 2005
18. Taniyama T, Hirai T, Yamada T, Yuasa M, Enomoto M, Yoshii T, Kato T, Kawabata S, Inose H, Okawa A: Modified K-line in magnetic resonance imaging predicts insufficient decompression of cervical laminoplasty. Spine 38:496-501, 2013
19. Tashjian VS, Kohan E, McArthur DL, Holly LT: The relationship between preoperative cervical alignment and postoperative spinal cord drift after decompressive laminectomy and arthrodesis for cervical spondylotic myelopathy. Surgical Neurology 72:112-117, 2009
20. Yamazaki A, Homma T, Uchiyama S, Katsumi Y, Okumura H: Morphologic limitations of posterior decompression by midsagittal splitting method for myelopathy caused by ossification of the posterior longitudinal ligament in the cervical spine. Spine 24:32-34, 1999