Clinical Article

The R-line: A New Imaging Index for Decision Making Regarding C2 Lamina Decompression in Cervical Ossification of the Posterior Longitudinal Ligament

Eun Ji Moon 1, Byung-Jou Lee 2, Subum Lee 1, Sang-Ryong Jeon 1, Sung Woo Roh 1, and Jin Hoon Park 1

1Department of Neurosurgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea
2Department of Neurosurgery, Inje University Ilsan Paik Hospital, Neuroscience & Radiosurgery Hybrid Research Center, College of Medicine, Goyang, Korea

ABSTRACT

Objective: The optimal treatment modality for cervical ossification of the posterior longitudinal ligament (OPLL) including the C2 level remains controversial. Cervical laminoplasty is a widely accepted considering of advantages such as development of few postoperative complications, including kyphosis or neck pain. We encountered seven patients with postoperative disabilities resulting from incomplete decompression after undercutting of the C2 lamina. Based on this experience, we developed a new index to determine the degree of decompression in cervical OPLL—the rostral line (R-line).

Methods: Total of 79 consecutive patients who underwent posterior decompression of cervical OPLL were included in this study. Mean age at the time of operation, the C2-C7 cervical lordotic angle and maximal degree of spinal cord compression by OPLL were independently correlated to postoperative C2 cord shifting. This result indicates that the R-line is a valid indicator to determine the degree of C2 lamina decompression using the R-line and actual degree of decompression.

Results: In all patients, the R-line touched the upper half of the C2 lamina on preoperative magnetic resonance imaging (MRI). The C2-C3 local segment lordotic angle and maximal degree of spinal cord compression by OPLL were independently correlated to postoperative C2 cord shifting. This result indicates that the R-line is a valid indicator to determine the degree of C2 lamina decompression in OPLL extending to the C2 level.

Conclusion: The results showed that undercutting the C2 lamina can result in incomplete spinal cord decompression and poor clinical outcome if the R-line touches the upper half of the C2 lamina on preoperative MRI.

Keywords: Ossification of the posterior longitudinal ligament; Cervical spondylotic myelopathy; Laminoplasty
INTRODUCTION

Ossification of the posterior longitudinal ligament (OPLL) can be defined as ectopic bone formation in the spinal ligament, resulting in spinal canal narrowing and consequent spinal cord compression.\(^9,13\) OPLL mostly develops in the cervical spine but rarely extends to the C2 level.\(^7,15\) The optimal treatment modality for cervical OPLL including the C2 level remains controversial.\(^1,6,12,18\) Cervical laminoplasty is a widely accepted indirect decompressive surgery with advantages such as development of few postoperative complications, including postoperative kyphosis or neck pain.\(^1,6,12\) Preservation of the cervical posterior extensor muscles is important to prevent neck pain and cervical lordosis loss following laminoplasty.\(^16,17\) Therefore, posterior decompression of the C2 level is performed as undercutting of the C2 lamina to preserve the musculature attached to the C2 spinous process. We encountered seven patients with postoperative disabilities resulting from incomplete decompression after undercutting of the C2 lamina. Based on this experience, we developed a new index to determine the degree of decompression in cervical OPLL—the rostral line (R-line). In this study, we analyzed the association between preoperative radiographic factors and postoperative C2 cord shifting and evaluated usefulness of the R-line for determining the degree of C2 lamina decompression in OPLL extending to the C2 level.

MATERIALS AND METHODS

Patients and clinical assessment

A total of 79 patients underwent posterior decompression of cervical OPLL between January 1999 and December 2017 in our institution. Of these, 7 patients (6 males and 1 female) who experienced postoperative neurologic deterioration due to incomplete C2 decompression were enrolled in this study. All patients were diagnosed with spinal cord compression of cervical OPLL extending to the C2 level, without spondylolisthesis or other instability. TABLE 1 shows characteristics of the study patients. Mean age at the time of operation was 58.8 (51–73) years. Undercutting of the C2 lamina was performed in all patients at the first operation. Degree of spinal cord decompression was evaluated using postoperative magnetic resonance imaging (MRI). MRI revealed incomplete rostral decompression in all patients. Postoperative neurologic deterioration was checked by Japanese Orthopedic Association (JOA) score, mean value as 10.42 (10–11) preoperatively and 3 (2–4) postoperatively. In addition, the C2-C7 cervical lordotic angle and OPLL thickness at the most stenotic level of the spinal canal were measured on preoperative lateral plain radiographs and MRI, respectively (FIGURE 1).

Definition and evaluation of the R-line

We established the R-line on T2-weighted midsagittal MR images to determine the degree of rostral C2 lamina decompression in relation to the maximum degree of spinal cord

| TABLE 1. Characteristics of the seven study patients |  |
|-----------------------------------------------------|--|
| Characteristics                                    | Mean (range) |
| Age at surgery (years)                             | 58.71 (51.0–73.0) |
| Sex (male: female)                                | 6:1 |
| Preoperative JOA score                            | 10.42 (10–11) |
| Postoperative JOA score                           | 3 (2–4) |
| Preoperative C2–C7 lordotic angle (°)             | 15.28 (8–26) |
| Thickness of OPLL (mm)                            | 5.75 (3.8–7.3) |

OPLL: ossification of posterior longitudinal ligament, JOA: Japanese Orthopedic Association.
compression by OPLL and the local segment lordotic angle at C2-C3. The R-line was defined as a line drawn through the posterior spinal canal parallel to the line connecting the center points of the C2 and C3 vertebral bodies at the level of maximum spinal cord compression (FIGURE 2). We hypothesized that laminar bone and ligament touching the R-line should be removed and that total laminectomy at C2 is necessary if the R-line touches the upper half of the posterior C2 lamina (FIGURE 3).

Statistical analysis
Multiple linear regression analysis was performed to investigate the association between radiographic factors and postoperative C2 cord shifting. The value of \( p < 0.05 \) was considered statistically significant. All analyses were performed using IBM SPSS Statistics version 20.0 (IBM Corporation, Armonk, NY, USA).

RESULTS
The R-line was retrospectively applied in seven patients with postoperative neurologic deterioration and incomplete posterior C2 cord decompression on postoperative MRI. In all
patients, the R-line touched the upper half of the C2 lamina on preoperative MRI. **TABLE 2** shows the clinical and radiographic characteristics of the seven study patients. The C2-C3 local segment lordotic angle (unstandardized coefficient, 0.222; \( p < 0.001 \)) and maximal degree of spinal cord compression by OPLL (unstandardized coefficient, 0.277; \( p = 0.001 \)) were independently correlated to postoperative C2 cord shifting (**TABLE 2**). This result indicates that the R-line is a valid indicator of laminar bone and ligament that should be surgically removed.

**FIGURE 3.** If the R-line touches the upper half of the posterior C2 lamina, total C2 laminectomy is necessary (R-line positive). In the R-line positive group, postoperative cord compression only through C2 undercutting results in neurologic deterioration due to incomplete decompression. R-line: rostral line.

**TABLE 2.** Clinical and radiologic characteristics of the seven study patients

| Case | Sex | Age (years) | Diagnosis | Level | OPLL thickness at the most severe site (mm) | Operation modality | Preoperative JOA score | Postoperative JOA score | Preoperative C2–C7 lordotic angle |
|------|-----|-------------|-----------|-------|-------------------------------------------|-------------------|------------------------|-------------------------|-------------------------------|
| 1    | M   | 56          | OPLL      | C2–C4 | 3.8                                      | Undercutting C2   | 10                     | 3                       | 3                             |
| 2    | M   | 64          | OPLL      | C2–C7 | 5.4                                      | Undercutting C2   | 11                     | 4                       | 13                            |
| 3    | M   | 51          | OPLL      | C2–C6 | 6.2                                      | Undercutting C2   | 10                     | 3                       | 14                            |
| 4    | M   | 51          | OPLL      | C2–C7 | 7.3                                      | Undercutting C2   | 11                     | 2                       | 8                             |
| 5    | F   | 58          | OPLL      | C2–C4 | 5.6                                      | Undercutting C2   | 11                     | 3                       | 18                            |
| 6    | M   | 58          | OPLL      | C2–C6 | 6.1                                      | Undercutting C2   | 10                     | 3                       | 16                            |
| 7    | M   | 73          | OPLL      | C2–C5 | 5.9                                      | Undercutting C2   | 10                     | 3                       | 12                            |

OPLL: ossification of posterior longitudinal ligament, JOA: Japanese Orthopedic Association.
DISCUSSION

Cervical laminoplasty is widely performed in patients with cervical myelopathy with cervical stenosis of OPLL. Postoperative kyphosis can occur when the semispinalis muscles attached to the C2 spinous process are removed during surgery.\(^\text{16,20}\) Numerous studies have reported that preserving the posterior cervical muscles attached to the C2 spinous process reduces the risk of lordosis loss following laminoplasty.\(^\text{4,5,14,16,17,20}\) Based on this hypothesis, many surgeons undercut the C2 lamina to decompress the spinal cord and preserve the muscles.\(^\text{16,17}\) We used this strategy and experienced seven patients with cervical OPLL involving the C2 level who developed postoperative neurologic deterioration; all patients showed incomplete decompression on postoperative MRI. Therefore, we developed a new index, the R-line, to determine the degree of C2 laminar decompression by OPLL. The R-line is based on postoperative posterior spinal cord shifting after laminoplasty, which is related to improved clinical outcomes. In this study, we applied the R-line in all patients and showed that the R-line touched the upper half of the posterior C2 lamina in all cases.

After posterior decompression, such as laminoplasty, the spinal cord shifts posteriorly similar to a bowstring. Posterior spinal cord shifting distance after laminoplasty depends on several factors, including cervical sagittal alignment and space available for the spinal cord at the level of decompression.\(^\text{2,3,8,11,19}\) Cervical lordosis can affect posterior migration of the spinal cord.\(^\text{2,10,21,22}\) In this study, the C2-C3 local segment lordotic angle but not the C2-C7 lordotic angle was significantly correlated to postoperative spinal cord shifting at the C2 level. The C2-C3 local segment lordotic angle is thought to affect spinal cord shifting at the C2 level and is maintained after surgery. Our study showed that the maximal degree of spinal cord compression by OPLL and C2-C3 segmental lordosis angle were independently correlated to postoperative C2 cord shifting.

All patients who only underwent undercutting of the C2 lamina despite the R-line touching the upper half of the posterior C2 lamina showed an insufficient decompression on postoperative MRI and experienced poor clinical outcomes. This indicates that incomplete decompression with devastating neurologic deterioration will likely result if total laminectomy of C2 is not performed when the R-line touches the upper half of the posterior C2 lamina. In an attempt to preserve the muscles attached to the C2 spinous process, decompression of the C2 lamina should be considered carefully. Use of the R-line on preoperative MRI can guide decision making regarding undercutting the C2 lamina or performing total C2 laminectomy or muscle preserving laminotomy.

This study is a retrospective review with a relatively small sample size; further prospective studies in a larger cohort are warranted to validate the efficiency and accuracy of the R-line.

CONCLUSION

The results of the present study showed that undercutting the C2 lamina to preserve the semispinalis muscles can result in incomplete spinal cord decompression and poor clinical outcome if the R-line touches the upper half of the C2 lamina on preoperative MRI.
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 J* 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 Neurol* 243:626-632, 1996

3. Chiba K, Toyama Y, Watanabe M, Maruwa 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, Shimizu T, Tateno K, Toda N, Edakuni H, Shimada H, et al. Extensor musculature of the cervical spine after laminoplasty: morphologic evaluation by coronal view of the magnetic resonance image. *Spine* 26:2220-2226, 2001

5. Iizuka H, Nakajima T, Iizuka Y, Sorimachi Y, Ara T, Nishinome M, et al. Cervical malalignment after laminoplasty: relationship to deep extensor musculature of the cervical spine and neurological outcome. *J Neurosurg Spine* 7:610-614, 2007

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. *Neurosurg Focus* 30:E11, 2011

7. Kawaguchi Y, Nakano M, Yasuda T, Seki S, Hori T, Kimura T. Ossification of the posterior longitudinal ligament in not only the cervical spine, but also other spinal regions: analysis using multidetector computed tomography of the whole spine. *Spine* 38:E1477-E1482, 2013

8. 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 Disord Tech* 15:391-397, 2002

9. Kim YH, Ha KY, Kim SI. Spinal cord injury and related clinical trials. *Clin Orthop Surg* 9:1-9, 2017

10. Kong Q, Zhang L, Liu L, Li T, Gong Q, Zeng J, et al. Effect of the decompressive extent on the magnitude of the spinal cord shift after expansive open-door laminoplasty. *Spine* 36:1030-1036, 2011

11. Lee JY, Sharan A, Baron EM, Lim MR, Grossman E, Albert TJ, et al. Quantitative prediction of spinal cord drift after cervical laminectomy and arthrodesis. *Spine* 31:1795-1798, 2006

12. Li Q, Kong Q, Zhang L, Sun T, Li T, Gong Q, et al. [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

13. Matsunaga S, Sakou T. Ossification of the posterior longitudinal ligament of the cervical spine: etiology and natural history. *Spine* 37:E309-E314, 2012

14. Nolan JP Jr, Sherk HH. Biomechanical evaluation of the extensor musculature of the cervical spine. *Spine* 13:9-11, 1988

15. Saetia K, Cho D, Lee S, Kim DH, Kim SD. Ossification of the posterior longitudinal ligament: a review. *Neurosurg. Focus* 30:E1, 2001

16. 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-E786, 2010

17. 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
18. Shin HK, Jeong HI, Kim E, Park JH, Park SJ, Cho Y. Should we check the routine postoperative MRI for hematoma in spinal decompression surgery? Clin Orthop Surg 9:184-189, 2017

19. 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, 1999

20. 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

21. 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. Surg Neurol 72:112-117, 2009

22. 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