

Expansive open-door laminoplasty versus laminectomy and instrumented fusion for cases with cervical ossification of the posterior longitudinal ligament and straight lordosis

Xiaowei Liu¹ · Yu Chen² · Haisong Yang² · Tiefeng Li² · Bin Xu¹ · Deyu Chen²

Received: 25 April 2016/Revised: 6 November 2016/Accepted: 4 December 2016/Published online: 27 December 2016
© Springer-Verlag Berlin Heidelberg 2016

Abstract

Purpose To identify whether expansive open-door laminoplasty (Lam) is more appropriate than laminectomy and instrumented fusion (LIF) for cases with ossification of the posterior longitudinal ligament (OPLL) and straight cervical lordosis.

Methods A total of 67 cases were included and divided into Group Lam ($n = 32$) and Group LIF ($n = 35$), and the mean follow-up periods were 38 and 42 months, respectively. The cervical lordosis was elevated by C2–7 Cobb angle and cervical sagittal balance by C2–C7 sagittal vertical axis (SVA). Japanese Orthopedic Association (JOA), neurological recovery rate (RR) being calculated by the JOA, visual analog scale (VAS) and neck disability index (NDI) were used to assess clinical outcomes.

Results Differences in general data between two groups were not significant. Total blood loss and operation duration in Group Lam were both significantly less than that in the Group LIF. By the final follow-up, the cervical lordosis significantly decreased in Group Lam and increased in Group LIF, the SVA significantly increased in Group Lam and kept unchanged in Group LIF, and the JOA, VAS, NDI significantly improved in both groups. Although there was

no significant difference in RR between the two groups, cases in Group Lam had significantly larger incidence of postoperative kyphosis and kyphotic change rate, and less VAS, NDI and incidence of axial pain than cases in Group LIF.

Conclusions When compared with the LIF, the Lam is recommended for cases with OPLL and straight cervical lordosis when taking comparable neurological recovery, less axial pain and better neck function improvement into consideration.

Keywords Ossification of the posterior longitudinal ligament · Straight lordosis · Expansive open-door laminoplasty · Laminectomy and instrumented fusion

Introduction

For cases with cervical myelopathy due to ossification of the posterior longitudinal ligament (OPLL), anterior decompression and fusion (ADF) can provide direct ossification resection and decompression [1]. But risk of complications such as spinal cord injury, dural tears, and hemorrhage cannot be ignored. And for cases with three or more vertebrae resections, incidences of implant failure and non-fusion will grow higher [2]. Posterior decompression by spinal canal enlargement has been proved to be of comparable neurological outcome and less risk of complications when compared with the ADF, and these have made posterior approach a more attractive option [1].

Expansive open-door laminoplasty (Lam) which can preserve cervical range of motion (ROM) has been widely used in the treatment of the OPLL since the 1970s [3]. As preoperative straight lordosis which was between 0° and 10° could limit the spinal cord shift backward, loss of the

B. Xu is a co-corresponding author for this submitted manuscript.

X. Liu and Y. Chen have made equal contribution to this article, and should be regarded as co-first author.

✉ Deyu Chen
chenspinecz@hotmail.com

¹ Department of Orthopedics, Jinling Hospital, Medicine College, Nanjing University, Nanjing 210002, Jiangsu, China

² Department of Spine Surgery, Changzheng Hospital, Second Military Medical University, Shanghai 200003, China

lordosis after the Lam was common, and progressions of the OPLL and postoperative kyphosis might result in poor neurological recovery; the Lam was not recommended for cases with OPLL and straight lordosis in some previous studies [3–7]. Laminectomy and instrumented fusion (LIF) was indicated for any cases with OPLL without regard to preoperative cervical lordosis [8]. The effectiveness of correction and maintenance of the alignment made the LIF more suitable for cases with OPLL and straight or kyphotic alignment, but C5 palsy and sacrifice of the ROM affect patients' life quality [1, 9]. Although some recent studies pronounced that cervical lordosis did not influence clinical outcomes after the Lam, the relationship between them was still of controversy [10, 11]. To verify efficacy and safety of the Lam for treating cases with multilevel OPLL and straight lordosis seems to be meaningful for reducing cases' unpleasant experiences after the LIF, but few studies specially focusing on this had been carried out.

Materials and methods

Patients' selection

Clinical data of 326 cases who underwent the Lam or LIF from Jan 2010 to Dec 2013 for the treatment of OPLL were retrospectively reviewed. A total of 86 cases with (1) preoperative C2–C7 Cobb angle on lateral X-ray being between 0° and 10° , and (2) OPLL extent being ≥ 2 levels and combined with cervical spinal stenosis were included. Exclusion criteria were cases with (1) cervical ossification of the ligamenta flava (OLF, $n = 1$), (2) OPLL and/or OLF in the thoracic spine, or thoracolumbar spine deformity ($n = 3$), (3) traumatic spinal cord injury ($n = 9$), and (4) previous history of spinal surgery ($n = 6$). The LIF was our preferred choice for cases with OPLL and straight lordosis to prevent OPLL progression and kyphosis development postoperatively. If the case was younger than 60 years, willing to preserve neck movement, or fearing about postoperative nerve root palsy, the Lam would be recommended if there was not segmental instability. This study included 67 cases and we divided them into Group Lam ($n = 32$) and Group LIF ($n = 35$).

Surgical technique

After taking general anesthesia, patients in both groups were placed in standard prone position on the gypsum bed. A midline incision was made, and cervical musculature was dissected to expose bilateral facet joints according to predetermined decompression segments in both groups. Operative procedure from C3 to C6 was first considered if

sufficient decompression could be acquired in both groups. For cases who needed decompression at C2 or C7 in Group Lam, musculature attached at C2 or C7 was dissected, and spinous process of the C7 was partly resected for musculature reattachment, while in Group LIF, one-third to half spinous process and muscle attachment cephalad at C2 or caudally at C7 was preserved by a dome-shape laminectomy at C2 or C7. In Group Lam, interspinous ligaments were cut caudally and cephalad, and supra-spinous ligaments were entirely preserved. A high-speed burr was used to drill full-thickness groove at the junction of lateral mass and lamina at the open side, and a partial-thickness groove at the hinge side. At the open side, after the ligamentum flavum at target levels was removed, the lamina was lifted toward the hinge side and a mini-plate without bone graft (ARCH, Synthes; Fig. 1) was then fixed on the lamina and lateral mass one by one. Autogenous bone granula was implanted into hinge-side groove. In Group LIF, the Margerl technique was used to drill holes bilaterally from C3 to C7 in the lateral masses, and pedicle technique at C2 if necessary. Screws and pre-curved rods (Cervifix, Synthes, Medtronic Sofamor Danek; Fig. 2) were installed after removing spinous processes and bilateral laminae. Autogenous bone graft was placed at involved facet joints for fusion. All cases in both groups wore Philadelphia collar for 2–4 weeks postoperatively.

Outcome assessments

All cases took preoperative cervical spine radiographs, computed tomography (CT) and magnetic resonance imaging (MRI). Type of the OPLL was classified as localized, segmental, continuous or mixed morphology basing on the sagittal CT image. The OPLL occupying ratio (OR) was defined as the biggest ratio of OPLL thickness to antero-posterior diameter of the bony spinal canal on the axial CT image. The line connecting the center of the canal at C2 to the center at C7 on neutral radiographs was defined as kyphosis line (K-line). The K-line (–) and K-line (+) were, respectively, defined when the OPLL exceeded or did not exceed the K-line (Fig. 3). Cervical lordosis was evaluated by C2–C7 Cobb angle (Fig. 4) and classified as lordosis ($>10^\circ$), straight (between 0° and 10°) and kyphosis ($<0^\circ$). The change value being calculated by (final C2–C7 Cobb–preoperative C2–C7 Cobb) was used to evaluate kyphotic change (≤ 0) and lordotic change (>0). Cervical sagittal vertical axis (SVA), which was defined as the distance between a plumb line dropped from the center of C2 (or dens) and the postero-superior aspect of C7, was used to assess the cervical alignment (Fig. 4).

Symptomatic duration was calculated from the onset of symptoms to accepting the operation, and total blood loss

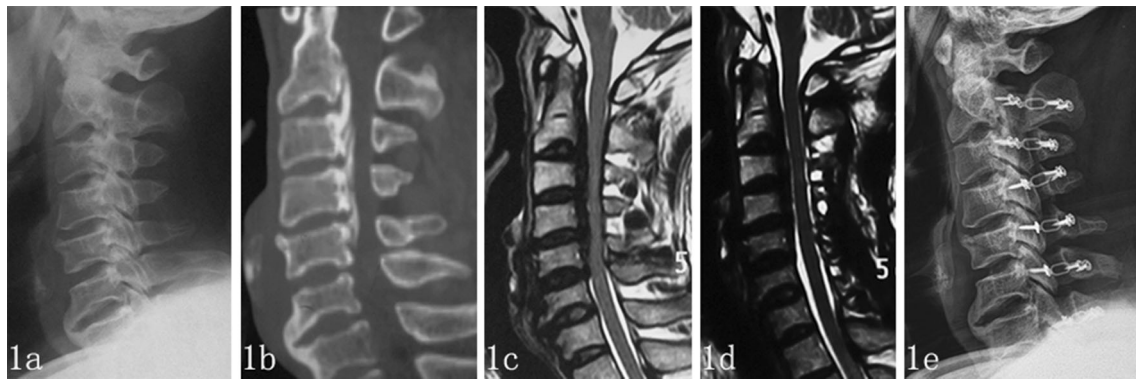


Fig. 1 A 41-year-old male case who had a straight lordosis (a, 8.5°) and the OPLL extending from C2 to C5 (b). The T2WI-MRI showed that there was compression of spinal cord at the levels of C2–C5 and

C5/6 (c). After the Lam from C2 to C7, there was complete decompression (d). At the end of 38-month follow-up, the cervical alignment developed to kyphosis (e, -5.0°)

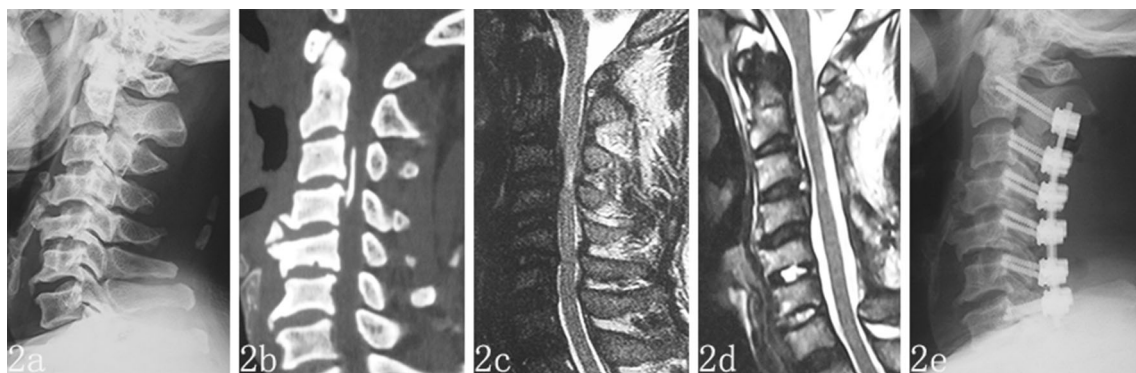


Fig. 2 A 54-year-old male patient. The C2–C7 Cobb angle was 9.3° (a), the OPLL extended from C3 to C4 and there was spinal stenosis from C2–C6 (b). The T2WI-MRI showed spinal cord compression at C3–C4 and C5–C6 (c). He accepted the LIF from C2 to C7 and

acquired sufficient decompression (d). The C2–C7 Cobb angle improved to be lordosis (12.1°) at the end of the 43-month follow-up (e)

was defined as the sum of intraoperative loss and postoperative volume of drainage. Neurological function was evaluated by Japanese Orthopedic Association (JOA) scoring system, and neurological recovery rate (RR) was calculated as $= (\text{final JOA} - \text{preoperative JOA}) / (17 - \text{preoperative JOA}) \times 100\%$. Visual analog scale (VAS) scoring system was used to assess axial pain around posterior neck or suprascapular areas, and neck function was evaluated by neck disability index (NDI). Number of cases who experienced complications including infection, cerebrospinal fluid leakage (CSFL), nerve root palsy, axial pain, neurological deterioration, implant failure and revision was recorded.

Statistical analysis

Inter-group comparisons were done by independent-samples *T* tests or Pearson's χ^2 tests, and intra-group comparisons by paired-samples *T* tests. The analysis was carried out by SPSS, version 18.0, and *p* value being less than 0.05 was defined as significant.

Results

Patients' general data were listed in Table 1, and there were no significant differences between the two groups. The mean follow-up was 38 ± 13 (range 20–60) months in Group Lam and 42 ± 9 (range 27–58) months in Group LIF, and difference between the two groups was not significant ($p = 0.297$).

As shown in Table 2, at the final follow-up, the C2–C7 Cobb angle significantly decreased in Group Lam ($p = 0.020$) and increased in Group LIF ($p < 0.001$). The SVA in Group Lam significantly increased ($p = 0.022$) and kept unchanged in Group LIF ($p = 0.382$). Differences in preoperative C2–C7 Cobb and SVA between two groups were not significant, but became significant at the final follow-up. Incidences of acquiring kyphotic change and developing into postoperative kyphosis in Group Lam were both significantly larger than that in Group LIF.

Mean total blood loss was 319 ± 84 (range 205–436) ml in Group Lam and 432 ± 107 (range 230–595) ml in Group LIF ($p < 0.001$). Mean operation

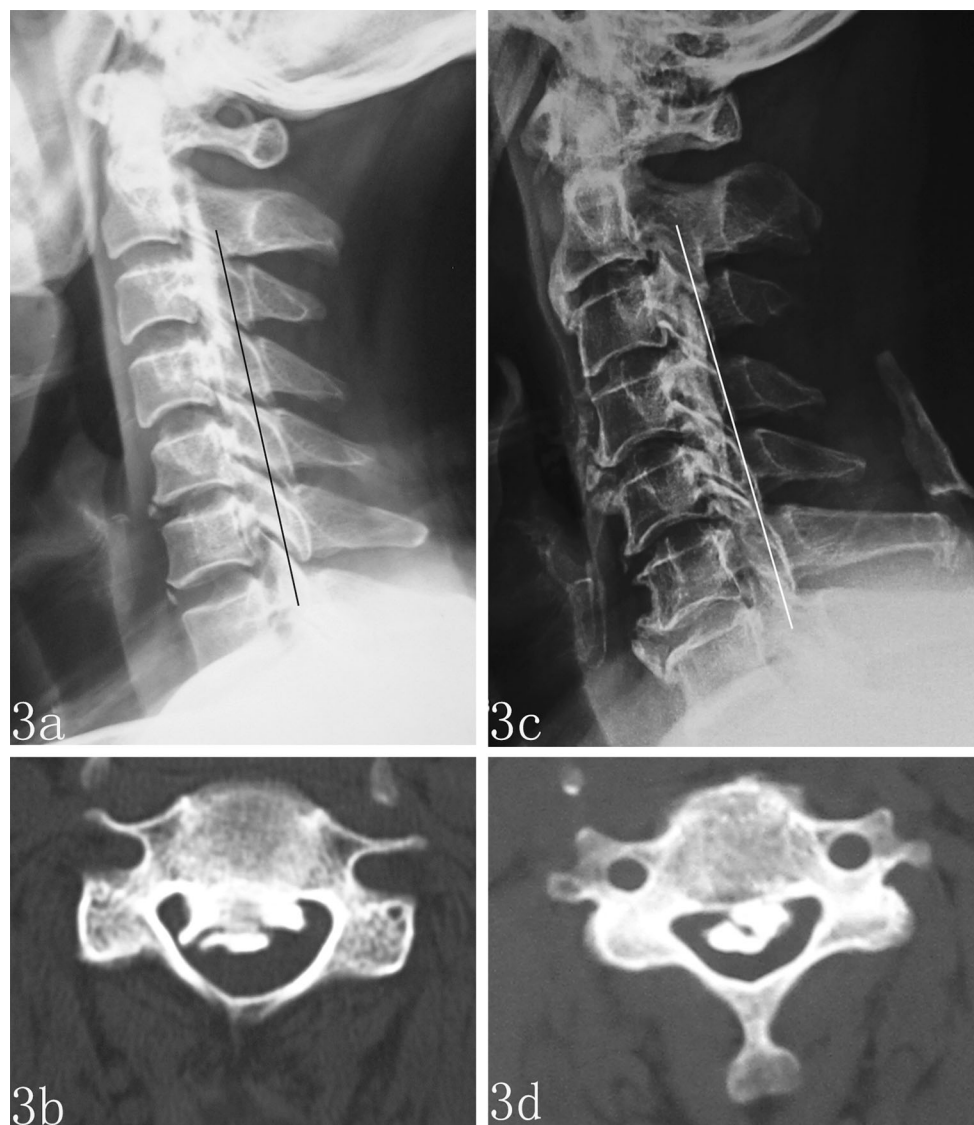


Fig. 3 **a, c** shows representatives of the K-line (+) and K-line (-), respectively. And the axial CT at level C3/4 (**b**, OR 61.1%) and C2 superior border (**d**, OR 67.3%) shows the biggest OR in cases with K-line (+) and K-line (-), respectively

duration was 114 ± 32 (range 80–150) min and 147 ± 55 (range 100–180) min in Group Lam and LIF, respectively ($p = 0.014$). There were no significant differences in preoperative JOA, VAS and NDI between the two groups (Table 2). At the final follow-up, cases in Groups Lam and LIF accepted significant increase in JOA (both $p < 0.001$), and significant decreases in VAS and NDI (both $p < 0.001$). Although differences in the JOA and RR between the two groups were not significant, the VAS and NDI were both significantly less in Group Lam than that in Group LIF at the final follow-up (Table 2). After being divided into groups according to OR and K-line, respectively, we found no significant differences in neurological recovery between cases who took Lam and LIF (Table 3).

There was one case in Group Lam and one in Group LIF who got incision infection, and only one case in Group LIF had leakage of cerebrospinal fluid. One case in Group Lam got paralysis after recovery from anesthesia. The hinge at C4 level was found broken and resected during the secondary exploration. Another one case in Group LIF got postoperative paralysis and a hematoma aspiration was then carried out. Both of the two cases got recovery after the revisions. Number of cases who experienced nerve root palsy was zero in Group Lam and two in Group LIF (both C5 palsy, $p = 0.493$), and there were eight cases in Group Lam and 18 cases in Group LIF who got postoperative axial pain ($p = 0.044$). Difference in total complication incidence between the two groups was significant (31.3 vs 65.7%, $p = 0.007$).

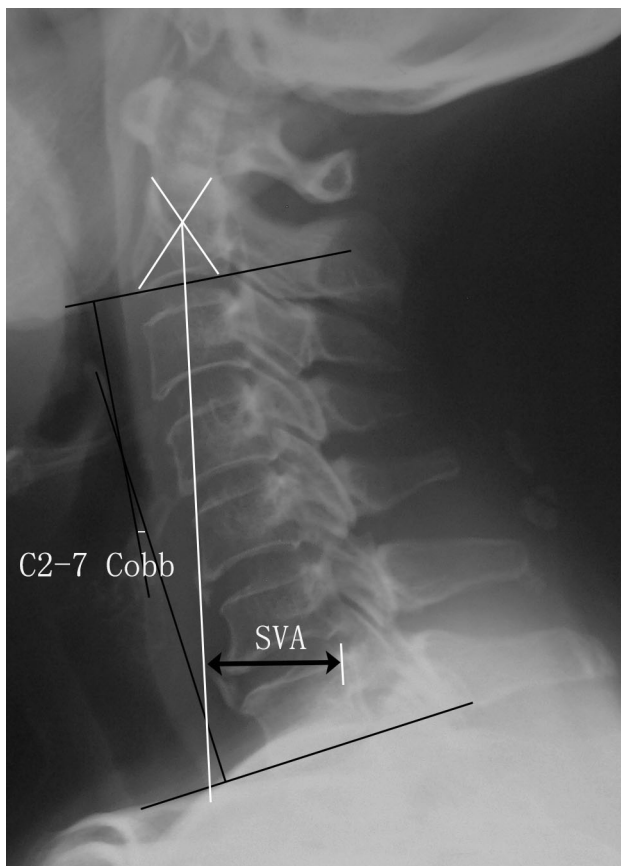


Fig. 4 The evaluation of the C2–C7 Cobb angle and the SVA

Discussion

Presence of the OPLL, especially non-segmental types, partly reduces cervical hypermobility and by limiting the ROM [12, 13]. But destructions of posterior bony elements, ligament complex and cervical muscles during the posterior approach can also result in cervical spine disability and losses of cervical lordosis [14]. What is more is that, as the progression of the un-resected OPLL is notable after the posterior approach, postoperative malalignment may contribute to the recompression of the spinal cord [15]. The C2–C7 Cobb angle was the commonest parameter for assessing the cervical lordosis. Researches of Iwasaki et al. and Lee et al. showed that cases with preoperative straight lordosis seemed to have the tendency to develop kyphosis after the Lam [3, 10]. Although cases with higher preoperative cervical lordosis and postoperative kyphotic alignment change after the Lam, detailed information about the incidence of kyphosis and its association with preoperative cervical lordosis had not been discussed [16]. On the other hand, our experiences were that the LIF could provide improvement and maintenance in cervical lordosis for cases with the OPLL in the long-term follow-up [6, 17]. And in this series, incidences of postoperative kyphosis and kyphotic change rate were significantly larger in Group Lam at the final follow-up (Table 2). The SVA was used to

Table 1 Comparisons of cases' general information between two groups

	Group Lam	Group LIF	Inter. <i>p</i> value
Gender (M/F, <i>n</i>)	26/6	25/10	0.400
Age (years)	59 ± 10	60 ± 8	0.505
Symptomatic duration (months)	40 ± 10	42 ± 11	0.126
Combined with DM (<i>n</i>)	9	13	0.450
Smoker (<i>n</i>)	13	11	0.457
High-intensity signal on T2WI-MRI (<i>n</i>)	10	9	0.787
OPLL classification (<i>n</i>)			0.687
Local	0	0	
Segmental	5	6	
Continuous	17	15	
Mixed	10	14	
OPLL OR (%)	49 ± 12	50 ± 11	0.519
K-line (+)/K-line (-) (<i>n</i>)	19/13	22/13	0.806
Surgical extent (<i>n</i>)			0.104
C2–C7	1	7	
C3–C6	9	8	
C3–C7	22	20	

DM diabetes mellitus, OPLL ossification of the posterior longitudinal ligament, OR occupying ratio of the OPLL

Table 2 Outcome comparisons between two groups

	Group Lam	Group LIF	Inter. <i>p</i> value
JOA (score)			
Preoperative	8.3 ± 1.1	8.7 ± 1.3	0.148
Final	12.3 ± 1.8	13.0 ± 1.5	0.114
RR (%)	46.3 ± 15.8	52.0 ± 15.3	0.155
VAS (score)			
Preoperative	3.8 ± 2.4	4.1 ± 2.8	0.326
Final	1.3 ± 1.2	2.4 ± 1.6	<0.001*
NDI (%)			
Preoperative	34.3 ± 5.5	35.2 ± 7.5	0.624
Final	15.7 ± 2.8	18.1 ± 4.4	0.031
SVA (mm)			
Preoperative	24.5 ± 13.7	25.3 ± 14.2	0.570
Final	29.7 ± 12.4	24.3 ± 11.8	0.043*
C2–7 Cobb angle (°)			
Preoperative	7.2 ± 2.4	7.6 ± 1.8	0.498
Final	5.6 ± 4.1	11.9 ± 2.6	<0.001*
Postoperative kyphosis (<i>n</i>)	5	0	0.021*
Kyphotic change rate (%)	34.4 (11/32)	2.9 (1/35)	0.001*

* *p* value of the intra-group comparison was <0.005

Table 3 Comparisons between the Groups Lam and LIF when cases were divided according to the OR and K-line

	Preoperative JOA	Final JOA	RR
OR ≤60% (inter. <i>p</i> value)	0.940	0.219	0.195
Group Lam (<i>n</i> = 23)	8.1 ± 1.0	11.2 ± 1.7	35.3 ± 14.7
Group LIF (<i>n</i> = 25)	8.0 ± 0.7	11.9 ± 1.3	42.6 ± 14.4
OR >60% (inter. <i>p</i> value)	0.127	0.123	0.464
Group Lam (<i>n</i> = 9)	8.2 ± 1.2	12.8 ± 1.6	53.0 ± 12.8
Group LIF (<i>n</i> = 10)	8.7 ± 1.3	13.6 ± 1.1	56.5 ± 11.7
K-line (+) (inter. <i>p</i> value)	0.249	0.894	0.481
Group Lam (<i>n</i> = 19)	8.3 ± 1.2	13.0 ± 1.5	51.4 ± 14.1
Group LIF (<i>n</i> = 22)	8.8 ± 1.2	13.2 ± 1.4	54.9 ± 12.3
K-line (−) (inter. <i>p</i> value)	0.835	1.000	0.078
Group Lam (<i>n</i> = 13)	7.9 ± 1.0	10.9 ± 1.5	33.5 ± 12.1
Group LIF (<i>n</i> = 13)	8.0 ± 0.8	12.0 ± 1.4	44.4 ± 15.6

OR occupying ratio of the ossification of the posterior longitudinal ligament, RR neurological recovery rate

measure the translation of cervical spine in the sagittal plane, and it was reported to be closely associated with the C2–C7 Cobb angle [18]. Our results showed that the SVA significantly increased in Group Lam and was maintained in Group LIF. This was similar with the result of Lee et al. [14]. Although recent studies reported that cervical deformity being evaluated by the SVA, C2–C7 Cobb angle or T1 slope would gradually progress in adult cases presenting with thoracolumbar deformity, cases with preoperative thoracolumbar deformity were excluded in this study [19]. So, taking these results into account, we suppose that cases

with the OPLL and straight lordosis will acquire better cervical lordosis and gravity line after the LIF.

We had found that the loss of cervical lordosis caused by subsidence of titanium mesh cage after the ADF was associated with neck pain, late neurological deterioration and implant failures [20]. And previous studies also reported that the postoperative kyphosis was associated with poor clinical outcomes after laminoplasty or laminectomy-alone [14]. As the longitudinal cord is tethered by the dentate ligaments and nerve roots, compression on spinal cord and small feeder blood vessels due to the

draping of spinal cord against the OPLL and vertebral bodies will increase with the loss of the cervical lordosis [18]. This might partly explain why the neurological outcome was not optimal in cases with preoperative or postoperative kyphosis [21]. However, the relationship between the spinal cord back shift and cervical alignment or neurological recovery rate is still controversial [22]. As shown in our study (Table 2), although the incidence of postoperative kyphosis and kyphotic change rate was higher, and the C2–7 Cobb angle was less in Group Lam, differences in the JOA and the RR were not significant between Group Lam and LIF at the final follow-up. This makes us believe that the Lam provides comparable neurological improvement with the LIF for cases with OPLL and cervical straight lordosis.

It was believed that the ADF provided significantly better neurological recovery rate than the Lam or LIF when the OPLL occupying ratio >50%, but the surgical difficulty and complication rates were higher, especially with the extent of OPLL being two or more [1, 4, 23]. The increase in spinal canal size after laminoplasty was reported to be less than the laminectomy and fusion, and the progression of OPLL after the laminoplasty was as high as 50% [24]. These risk factors combined with higher incidence of postoperative kyphosis might result in poorer neurological recovery and higher reoperation rate after the Lam, but no previous studies had focused on the outcome comparisons between the Lam and LIF [22]. In this study, difference in the RR between cases with OR >60% or ≤60% after accepting the Lam and LIF was not significant (Table 3). The K-line is a complex index infected by the OR and cervical alignment, and the K-line (–) is associated with insufficient posterior shift of the spinal cord and poor neurological recovery after the laminoplasty [25]. As the C2–7 Cobb angle will increase, cases with K-line (–) after the LIF may acquire better neurological outcome than cases who had the Lam, but the lordosis increase should be suitable [17]. However, after being divided into K-line (+) and K-line (–) groups, cases who accepted Lam and LIF had no significant differences in the RR (Table 3). So far, we suppose that influences of the OR and K-line on the choice of Lam or LIF in the treatment of cases with OPLL and straight lordosis may not be much important as we thought previously.

The incidence of axial pain was reported to range from 5.2 to 61.5% after the posterior approach, and destruction of muscles attached at C2 or C7 was believed to be the main risk factor [26]. But the influence of the surgical technique on axial pain was of controversy. Yang et al. reported that the incidences of axial pain and the VAS were both significantly less after the laminoplasty than the LIF, but Lee et al. found that the VAS after the LIF was less than the laminoplasty [14, 27]. In this study, we found that the incidences of axial pain and the VAS at final follow-up were both significantly less after the Lam. Incidence of

involvement of the C2 was 3.2% in Group Lam and 20% in Group LIF ($p = 0.037$), and the larger incidence in Group LIF might mostly be the reason, although the difference in surgical levels between the two groups was not significant (Table 1). The NDI is a method of assessing the impact of neck pain on activities of daily living, and it is associated with the VAS [28]. As the axial pain includes the pain around posterior neck, higher incidence of the axial pain and larger VAS result in poorer improvement of the NDI in Group LIF and it is consistent with previous studies [14, 27].

For cases with OPLL and accepting the Lam or LIF, nerve root palsy (especially C5 palsy) was among the most common complications, and the pathogenesis was still not clear [29]. For cases with preoperative kyphosis, deformity correction is one of the goals of the LIF, and this results in larger increase of cervical lordosis which was considered to be one risk factor of the nerve root palsy [20]. While for cases with straight lordosis, our experiences were to preserve or slightly improve the C2–7 Cobb angle to prevent the C5 palsy. This had reduced the incidence of C5 palsy but might also limit the advantage of the LIF in lordosis improvement and neurological outcome [17]. Intraoperative failure of hinge side after the Lam and postoperative hematoma after the LIF were the etiologies that led to revisions, and no other cases accepted secondary surgery due to implant failure or neurological deterioration during the follow-up.

Conclusion

Although postoperative kyphosis incidence and kyphotic change rate after the Lam were both larger than that after the LIF, cases with OPLL and straight lordosis would acquire comparable neurological outcomes. What is more is that the Lam would provide less axial pain and better neck function, postoperatively, than the LIF.

Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

The manuscript submitted does not contain information about medical device(s)/drug(s). And this study has been approved by the appropriate ethics committee and has, therefore, been performed in accordance with the Declaration of Helsinki's ethical standards.

References

1. An HS, Al-Shihabi L, Kurd M (2014) Surgical treatment for ossification of the posterior longitudinal ligament in the cervical spine. *J Am Acad Orthop Surg* 22:420–429. doi:10.5435/JAAOS-22-07-420

2. Chen Y, Yang L, Liu Y, Yang H, Wang X, Chen D (2014) Surgical results and prognostic factors of anterior cervical corpectomy and fusion for ossification of the posterior longitudinal ligament. *PLoS One* 9:e102008. doi:10.1371/journal.pone.0102008
3. Iwasaki M, Kawaguchi Y, Kimura T, Yonenobu K (2002) 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* 96:180–189
4. Suk KS, Kim KT, Lee JH, Lee SH, Lim YJ, Kim JS (2007) Sagittal alignment of the cervical spine after the laminoplasty. *Spine* 32:E656–660. doi:10.1097/BRS.0b013e318158c573
5. Iwasaki M, Okuda S, Miyauchi A, Sakaura H, Mukai Y, Yonenobu K, Yoshikawa H (2007) Surgical strategy for cervical myelopathy due to ossification of the posterior longitudinal ligament: Part 1: Clinical results and limitations of laminoplasty. *Spine* 32:647–653. doi:10.1097/01.brs.0000257560.91147.86
6. Chen Y, Liu X, Chen D, Wang X, Yuan W (2012) Surgical strategy for ossification of the posterior longitudinal ligament in the cervical spine. *Orthopedics* 35:e1231–1237. doi:10.3928/01477447-20120725-25
7. Hori T, Kawaguchi Y, Kimura T (2006) How does the ossification area of the posterior longitudinal ligament progress after cervical laminoplasty? *Spine* 31:2807–2812. doi:10.1097/01.brs.0000245870.97231.65
8. Anderson PA, Matz PG, Groff MW, Heary RF, Holly LT, Kaiser MG, Mummaneni PV, Ryken TC, Choudhri TF, Vresilovic EJ, Resnick DK; Joint Section on Disorders of the S; Peripheral Nerves of the American Association of Neurological S; Congress of Neurological S (2009) Laminectomy and fusion for the treatment of cervical degenerative myelopathy. *J Neurosurg Spine* 11:150–156. doi:10.3171/2009.2.SPINE08727
9. Chen Y, Chen D, Wang X, Guo Y, He Z (2007) C5 palsy after laminectomy and posterior cervical fixation for ossification of posterior longitudinal ligament. *J Spinal Disord Tech* 20:533–535. doi:10.1097/BSD.0b013e318042b655
10. Lee CK, Shin DA, Yi S, Kim KN, Shin HC, Yoon do H, Ha Y (2016) Correlation between cervical spine sagittal alignment and clinical outcome after cervical laminoplasty for ossification of the posterior longitudinal ligament. *J Neurosurg Spine* 24:100–107. doi:10.3171/2015.4.spine141004
11. Kim SW, Hai DM, Sundaram S, Kim YC, Park MS, Paik SH, Kwak YH, Kim TH (2013) Is cervical lordosis relevant in laminoplasty? *Spine J* 13:914–921. doi:10.1016/j.spinee.2013.02.032
12. Matsunaga S, Sakou T, Taketomi E, Yamaguchi M, Okano T (1994) The natural course of myelopathy caused by ossification of the posterior longitudinal ligament in the cervical spine. *Clin Orthop Relat Res* 168–177
13. Fujiyoshi T, Yamazaki M, Okawa A, Kawabe J, Hayashi K, Endo T, Furuya T, Koda M, Takahashi K (2010) Static versus dynamic factors for the development of myelopathy in patients with cervical ossification of the posterior longitudinal ligament. *J Clin Neurosci* 17:320–324. doi:10.1016/j.jocn.2009.06.023
14. Lee CH, Jahng TA, Hyun SJ, Kim KJ, Kim HJ (2016) Expansive laminoplasty versus laminectomy alone versus laminectomy and fusion for cervical ossification of the posterior longitudinal ligament: is there a difference in the clinical outcome and sagittal alignment? *Clin Spine Surg* 29:E9–15. doi:10.1097/BSD.000000000000058
15. Sakai K, Okawa A, Takahashi M, Arai Y, Kawabata S, Enomoto M, Kato T, Hirai T, Shinomiya K (2012) 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* 37:367–376. doi:10.1097/BRS.0b013e31821f4a51
16. Kim TH, Lee SY, Kim YC, Park MS, Kim SW (2013) T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy. *Spine* 38:E992–997. doi:10.1097/BRS.0b013e3182972e1b
17. Chen Y, Guo Y, Chen D, Wang X, Lu X, Yuan W (2009) Long-term outcome of laminectomy and instrumented fusion for cervical ossification of the posterior longitudinal ligament. *Int Orthop* 33:1075–1080. doi:10.1007/s00264-008-0609-9
18. Scheer JK, Tang JA, Smith JS, Acosta FL Jr, Protosaltis TS, Blondel B, Bess S, Shaffrey CI, Deviren V, Lafage V, Schwab F, Ames CP (2013) Cervical spine alignment, sagittal deformity, and clinical implications: a review. *J Neurosurg Spine* 19:141–159. doi:10.3171/2013.4.SPINE12838
19. Jalai CM, Passias PG, Lafage V, Smith JS, Lafage R, Poorman GW, Diebo B, Liabaud B, Neuman BJ, Scheer JK, Shaffrey CI, Bess S, Schwab F, Ames CP (2016) A comparative analysis of the prevalence and characteristics of cervical malalignment in adults presenting with thoracolumbar spine deformity based on variations in treatment approach over 2 years. *Eur Spine J* 25:2423–2432. doi:10.1007/s00586-00016-04564-00587 (Epub 02016 Apr 00513)
20. Chen Y, Chen D, Guo Y, Wang X, Lu X, He Z, Yuan W (2008) Subsidence of titanium mesh cage: a study based on 300 cases. *J Spinal Disord Tech* 21:489–492. doi:10.1097/BSD.0b013e318158de22
21. Shimizu K, Nakamura M, Nishikawa Y, Hijikata S, Chiba K, Toyama Y (2005) Spinal kyphosis causes demyelination and neuronal loss in the spinal cord: a new model of kyphotic deformity using juvenile Japanese small game fowls. *Spine* 30:2388–2392
22. Denaro V, Longo UG, Berton A, Salvatore G, Denaro L (2015) Cervical spondylotic myelopathy: the relevance of the spinal cord back shift after posterior multilevel decompression. A systematic review. *Eur Spine J* 24 Suppl 7:832–841. doi:10.1007/s00586-015-4299-x
23. Fujimori T, Iwasaki M, Okuda S, Takenaka S, Kashii M, Kaito T, Yoshikawa H (2014) Long-term results of cervical myelopathy due to ossification of the posterior longitudinal ligament with an occupying ratio of 60% or more. *Spine* 39:58–67. doi:10.1097/brs.0000000000000054
24. Manzano GR, Casella G, Wang MY, Vanni S, Levi AD (2012) A prospective, randomized trial comparing expansile cervical laminoplasty and cervical laminectomy and fusion for multilevel cervical myelopathy. *Neurosurgery* 70:264–277. doi:10.1227/NEU.0b013e3182305669
25. Fujiyoshi T, Yamazaki M, Kawabe J, Endo T, Furuya T, Koda M, Okawa A, Takahashi K, Konishi H (2008) A new concept for making decisions regarding the surgical approach for cervical ossification of the posterior longitudinal ligament: the K-line. *Spine* 33:E990–993. doi:10.1097/BRS.0b013e318188b300
26. Wang SJ, Jiang SD, Jiang LS, Dai LY (2011) Axial pain after posterior cervical spine surgery: a systematic review. *Eur Spine J* 20:185–194. doi:10.1007/s00586-010-1600-x
27. Yang L, Gu Y, Shi J, Gao R, Liu Y, Li J, Yuan W (2013) Modified plate-only open-door laminoplasty versus laminectomy and fusion for the treatment of cervical stenotic myelopathy. *Orthopedics* 36:e79–87. doi:10.3928/01477447-20121217-23
28. Resnick DN (2005) Subjective outcome assessments for cervical spine pathology: a narrative review. *J Chiropr Med* 4:113–134. doi:10.1016/S0899-3467(07)60121-9
29. Shou F, Li Z, Wang H, Yan C, Liu Q, Xiao C (2015) Prevalence of C5 nerve root palsy after cervical decompressive surgery: a meta-analysis. *Eur Spine J* 24:2724–2734. doi:10.1007/s00586-015-4186-5