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ORIGINAL ARTICLE

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

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Abstract

Purpose There is no definitive evidence that additional instrumented fusion following laminoplasty suppresses the progression of ossification of the posterior longitudinal ligament (OPLL). Recently, we reported a novel method involving the creation of three-dimensional (3D) model from computed tomography images to measure the volume of OPLL accurately. The study aim was to evaluate whether laminoplasty with instrumented fusion suppresses the progression of OPLL in comparison with stand-alone laminoplasty by our novel 3D analysis.

Methods The present study comprised of a group of 19 patients (14 men, five women) with OPLL treated with posterior decompression and fusion (PDF group), and a group of 22 patients (14 men, eight women) treated with laminoplasty alone (LP group). The volume of OPLL was evaluated three times during the follow-up period, and the volume change of OPLL was compared between the two groups.

Results The PDF group (2.0 ± 1.7 %/year; range, −3.0 to 5.3) demonstrated lower annual rate of lesion increase compared to the LP group (7.5 ± 5.6 %/year; range, 1.0–19.2) ($p < 0.001$). In a notable thing, the annual rate of increase from the 2nd to the 3rd measurement significantly decreased compared with that from the 1st to the 2nd measurement in the PDF group ($p < 0.05$).

Conclusion This is the first study to prove a possible suppressant effect of additional posterior instrumented fusion on OPLL progression using novel 3D analysis.

Keywords Ossification of posterior longitudinal ligament · Progression · Three-dimensional analysis · Laminoplasty · Posterior decompression and fusion

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Introduction

Ossification of the posterior longitudinal ligament (OPLL) was widely established since the report by Tsukimoto in 1960 [1]. OPLL had been recognized as one of the main causes of cervical myelopathy and as a progressive disease [2–4]. Several studies demonstrated that about 70 % of patients had radiographic evidence of OPLL progression after laminoplasty [5, 6]. Furthermore, it has been reported that progression of OPLL affects the surgical results in the long-term follow-up after laminoplasty [5, 7]. In general, laminoplasty results in long-term decreased range of motion (ROM) due to unintended autofusion along the lateral margins of the laminoplasty [3]. Chiba et al. [8] and Hirabayashi et al. [9] reported that the progression of OPLL was more likely to occur in the early phase after laminoplasty and was less likely to occur in the late phase. Moreover, some researchers have suggested that dynamic factors stimulate the progression of OPLL, and ROM stabilization may lead to the decreased progression of OPLL [3, 8–10].

These results suggest that the additional instrumented fusion following laminoplasty suppresses the progression of OPLL; however, there have been no reports to describe any definitive evidence on the matter. Furthermore, assessments in previous studies have been based on two-dimensional (2D) images of OPLL using plain radiography and plain computed tomography (CT), which cannot evaluate three-dimensional (3D) images and the volume of the ossified lesion. CT-based 3D imaging analysis has made accurate evaluation of OPLL possible [10, 11]. Recently, we reported on a new technique to measure ossification volume based on the creation of a 3D model from CT images [11].

The purpose of this study was to evaluate whether laminoplasty with instrumented fusion suppresses the progression of OPLL in comparison with stand-alone laminoplasty.

Materials and methods

This study was approved by the ethics committee of Niigata University Graduate School of Medical and Dental Sciences, and informed consent was obtained from all patients before enrollment.

The present study comprised of a group of 19 patients with OPLL treated with posterior decompression and fusion (PDF group), and a group of 22 patients treated with laminoplasty alone (LP group). In the PDF group, there were 14 men and five women treated at Niigata University Hospital or affiliated hospitals between 2006 and 2012. The mean age at operation was 61 years, and the mean follow-up period was 51 months. The type of OPLL was classified as continuous, segmented, and mixed in 1, 3, and 15 patients, respectively, and spinal canal occupation rate was 51.5 % (Table 1). The preoperative types of OPLL based on the multi-planar reconstruction-CT were classified as continuous, segmental, mixed, or circumscribed according to the criteria proposed by the Investigation Committee on Ossification of Spinal Ligaments of the Japanese Ministry of Public Health and Welfare [12]. The spinal canal occupation rate was expressed as the percentage ratio of the maximum thickness of ossification to the midsagittal diameter of the cervical canal using a CT axial view [13].

In the LP group, there were 14 men and eight women treated at Niigata University Hospital between 2005 and 2012. The mean age at operation was 59 years, and the mean follow-up period was 52 months. The type of OPLL was classified as segmented and mixed in 6 and 16 patients, respectively, and occupation rate was 45.7 % (Table 1).

The operation time, intraoperative blood loss, complications, C2–C7 lordotic angle, Japanese Orthopedic Association (JOA) score [14], recovery rate of JOA score [9], type change of OPLL, and volume change of OPLL were compared between the two groups. The cervical lordotic angle (C2–C7) was measured between the lower endplates of C2 and C7 on lateral radiographs. The neurologic severity was evaluated using the JOA score. The score is a 17-point instrument in which points are assigned based on the rating of motor function (upper and lower extremity), sensory function (upper extremity, lower extremity, and trunk), and urinary bladder function.

Measurement of the ossified lesion

As we have previously reported, all ossifications of the vertebrae were identified and detached from the posterior aspect of the vertebral body semi-automatically by two observers based on CT images using the MIMICS® software (Materialise Japan Co., Ltd., Yokohama, Japan), and a 3D model was created automatically (Fig. 1) [11]. OPLL measurements were obtained three times with an interval of at

Table 1 Demographic characteristics of the PDF and LP groups before surgery

	PDF group ($n = 19$)	LP group ($n = 22$)
Age at operation (years)	61 ± 9 (49–85)	59 ± 12 (39–77)
Sex (male:female)	14:5	14:8
Follow-up period (months)	51 ± 21 (17–103)	52 ± 19 (24–103)
Type of OPLL, number of patients		
Continuous	1	
Segmental	3	6
Mixed	15	16
Circumscribed		
Occupation ratio of OPLL (%)	51.5 ± 10.5 (34.3–77.8)	45.7 ± 13.3 (20.6–65.6)
Number of ossified vertebra	3.6 ± 1.4 (1–6)	3.8 ± 1.4 (1–6)
Ratio of laminoplasty techniques (double door:open door)	13:5	6:16
Number of opened lamina	4.1 ± 1.0 (2–6)	4.2 ± 1.1 (2–6)

LP laminoplasty, *OPLL* ossification of the posterior longitudinal ligament, *PDF* posterior decompression and fusion

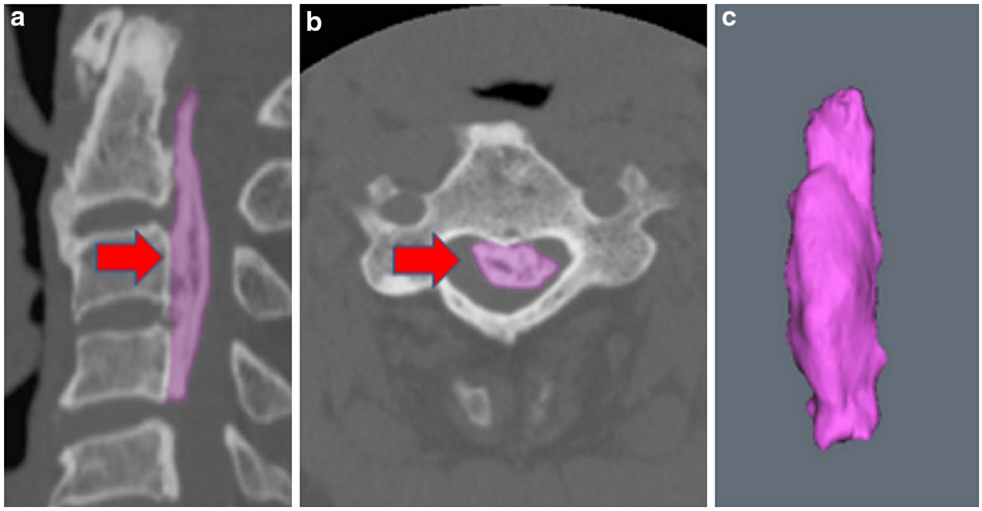

Fig. 1 **a**, **b** The ossification was detached from the affected vertebral body semi-automatically using both the computed tomography axial and sagittal planes, so-called segmentation (*arrows*). **c** The region of ossification was isolated, and a three-dimensional model was created

least 1 year (1st measurement, 2nd measurement, and 3rd measurement). The 1st measurement was performed before surgery, and the mean interval from the 1st measurement to surgery was 10.5 ± 12.6 days (range 1–52) in the PDF group and 6.5 ± 8.8 days (range 1–32) in the LP group, which was not significantly different. Both the 2nd and 3rd measurements were performed after surgery, and the mean interval from the 1st to the 2nd measurement was 20 ± 10 months (range 12–48) in the PDF group and 20 ± 12 months (range 12–47) in the LP group, and that from the 2nd to the 3rd measurement was 20 ± 9 months (range 12–36) and 20 ± 13 months (range 12–57), which were not significantly different. The volume of the ossified lesion has been calculated twice in each measurement to determine the mean volume and evaluate the intraobserver error. The mean intraobserver intra-class correlation coefficients (ICC) were 0.995 (0.993–0.996) in observer 1 and 0.997 (0.994–0.999) in observer 2. The mean interobserver ICC was 0.997 (0.966–0.999). We evaluated the volume change of OPLL by the annual rate of lesion increase. The annual rate of lesion increase between the 1st and 2nd measurement was calculated by the following formula (%/year): $(V_2 - V_1) \div V_1 \times 100 \times 12 \div (\mathrm{Int}_{1-2})$ [volume of the ossified lesion at the 1st measurement: V_1 (mm^3), volume of the ossified lesion at the 2nd measurement: V_2 (mm^3), interval from the 1st to the 2nd measurement: Int_{1-2} (month)].

Surgical procedure

We have commonly performed laminoplasty for patients with multi-level OPLL. However, we have performed laminoplasty concomitant with posterior instrumented fusion for patients with large size OPLL or cervical kyphotic alignment. We have referred to the K-line to make decisions on the indication of additional instrumented fusion. The K-line was defined as a line that connects the midpoints of the spinal canal at C2 and C7, and OPLL did not exceed the K-line in the K-line (+) group and did exceed it in the K-line (−) group [15]. As a basic principle, laminoplasty with instrumented fusion was performed using pedicle screws at the uppermost and lowermost instrumented levels, and lateral mass screws were used at the other levels. The area of instrumented vertebra was from C2–C7 in 14 patients, and from C2–C6, C3–C6, C3–C7, C4–C6, and C4–C7 in 1 patient, respectively, and the mean number of fixation levels was 4.5 ± 0.9 vertebrae (range 2–5). In the PDF group, double-door laminoplasty [16] was performed in 13 patients, open-door laminoplasty [17] in five, and laminectomy in one. In the LP group, open-door laminoplasty was performed in 16 patients, and double-door laminoplasty in six. Selection of the laminoplasty technique depended on the surgeon's preference. We performed laminoplasty through a standard posterior straight-incision approach using hydroxyapatite spacers as struts to prevent lamina closure. The mean number of opened lamina was 4.1 segments in the PDF group and 4.2 segments in the LP group.

Statistical analyses

The data were analyzed using SPSS software (version 19; SPSS Inc., Chicago, IL, USA). The change from baseline within each group was evaluated using paired *t* tests for clinical and radiological outcomes. Differences between the two groups were evaluated using the Mann–Whitney *U* tests for continuous variables and χ^2 tests for categorical variables. All *p* values less than 0.05 were considered statistically significant.

Results

There were no significant differences in age, sex, follow-up period, type of OPLL, occupation ratio of OPLL, number of ossified vertebra, and number of opened lamina between the two groups (Table 1). There were significant differences in the operation time, blood loss, and ratio of laminoplasty techniques between the two groups (all, $p < 0.01$) (Table 2). The C2–C7 lordotic angle in the PDF group was smaller than that in the LP group before surgery and at the final follow-up (both, $p < 0.05$), and the cervical alignment was maintained at the final follow-up in both groups. There were no significant differences in the recovery rate of the JOA score at the final follow-up between the two groups (Table 2).

With regard to 3D analysis of the OPLL, in the PDF group, the mixed-type OPLL changed to continuous type in five patients and the segmental-type OPLL changed to mixed type in one. In the LP group, the mixed-type OPLL changed to continuous type in one patient and the segmental-type OPLL changed to mixed type in one.

The volume of the ossified lesion significantly increased at the final follow-up in both groups (all, $p < 0.05$), whereas that from the 2nd to the 3rd measurement did not change in the PDF group (Table 3). The mean annual rate of lesion increase was 2.0 ± 1.7 %/year (range −3.0 to 5.3) in the PDF group and 7.5 ± 5.6 %/year (range 1.0–19.2) in the LP group, and there were significant differences in the annual rate of increase between the two groups ($p < 0.001$) (Fig. 2). In a notable thing, the annual rate of increase from the 2nd to the 3rd measurement significantly decreased compared with that from the 1st to the 2nd measurement in the PDF group ($p < 0.05$). There were no significant differences in the annual rate of OPLL increase between double-door laminoplasty and open-door laminoplasty in both groups (PDF: 2.1 ± 1.5, 2.7 ± 0.6 %/year, LP: 8.0 ± 6.4, 7.4 ± 5.5 %/year).

Illustrative case

A 57-year-old woman with mixed-type OPLL was referred to our hospital with a complaint of severe nape pain. The volume of the ossified lesion was 1909 mm^3 by 3D imaging analysis (Fig. 3a). Three years and 9 months later, she had progressive myelopathy and the volume of the ossified lesion increased to 2172 mm^3 (Fig. 3b). The annual rate of increase in the preoperative period was 3.7 %/year. PDF from C2 to C7 was performed (Fig. 3c). The JOA score improved from 13 to 16 points at 3 years after surgery (recovery rate: 75 %). The volume of the ossified lesion was 2199 mm^3, and the mean annual rate of increase in the postoperative period decreased to 0.4 %/year (Fig. 3d).

Discussion

OPLL has most commonly been treated with posterior decompression surgery such as laminoplasty, and has been reported to be a safe procedure with a satisfactory long-time outcome [6, 18]. However, regarding the factors causing poor surgical outcomes after laminoplasty for OPLL, previous reports have described kyphotic alignment of the cervical spine and a large size OPLL [2, 19]. Several studies reported that recovery rates of the JOA score with a high OPLL occupying ratio for anterior decompression fusion (ADF) and laminoplasty were 54–73 and 13–41 %, respectively, and recommend ADF [2, 20]. However, ADF in patients with OPLL is a technically demanding operation, and has been reported to cause higher rates of upper extremity palsy [21]. Since

Table 2 Comparison of the clinical and radiological outcomes between the PDF and LP groups

	PDF group ($n = 19$)	LP group ($n = 22$)	p
Operation time (min)	240 ± 71 (134–382)	174 ± 107 (55–520)	<0.01
Blood loss (mL)	432 ± 455 (80–2000)	182 ± 183 (20–692)	<0.01
Postoperative complications, number of patients	2 (C5 palsy)	3 (hematoma, deep SSI, suture abscess)	0.76
C2–C7 lordotic angle (°)			
Before surgery	−1.8 ± 16.9 (−45 to 30)	10.5 ± 8.7 (−3 to 26)	<0.01
Final follow-up	−0.6 ± 10.0 (−16 to 18)	8.4 ± 10.2 (−7 to 24)	<0.05
JOA score (point)			
Before surgery	10.8 ± 3.8 (2–17)	10.5 ± 2.7 (5–15)	0.57
Final follow-up	13.3 ± 3.6 (5–17)[a]	13.1 ± 3.0 (7–16)[b]	0.62
Recovery rate of the JOA score (%)	41.6 ± 28.5 (0–100)	36.1 ± 44.2 (−100 to 90)	0.81

JOA Japanese Orthopaedic Association

[a] The difference in the JOA score between before surgery and the final follow-up in the PDF group was statistically significant ($p < 0.001$)

[b] The difference in the JOA score between before surgery and the final follow-up in the LP group was statistically significant ($p < 0.001$)

Table 3 Comparison of the volume change of OPLL between the PDF and LP groups

	PDF group ($n = 19$)	LP group ($n = 22$)	p
Volume of ossified lesion (mm^3)			
1st measurement	2363 ± 1823 (292–6684)	2361 ± 1962 (123–6250)	0.90
2nd measurement	2471 ± 1926 (300–7112)[a]	2553 ± 2053 (128–6378)[b]	0.96
3rd measurement	2596 ± 2219 (306–7853)[a]	2889 ± 2196 (144–7197)[b]	0.64
Annual rate of increase (%/year)			
From 1st to 3rd measurement (overall)	2.0 ± 1.7 (−3.0 to 5.3)	7.5 ± 5.6 (1.0–19.2)	<0.001
From 1st to 2nd measurement	2.5 ± 2.3 (−3.3 to 6.9)	7.4 ± 4.7 (1.0–16.4)	<0.001
From 2nd to 3rd measurement	1.3 ± 1.7 (−2.7 to 3.5)[c]	7.8 ± 6.5 (0.5–22.2)	<0.001

1st measurement before surgery, *2nd measurement* approximately 20 months after surgery, *3rd measurement* approximately 40 months after surgery

[a] The difference in the volume of ossified lesion between the 1st and 2nd measurement, and that between the 1st and 3rd measurement in the PDF group was statistically significant (both, $p < 0.05$)

[b] The difference in the volume of ossified lesion between the 1st and 2nd, 1st and 3rd, and 2nd and 3rd measurement, respectively, in the LP group was statistically significant (all, $p < 0.001$)

[c] The difference in the annual rate of increase from the 1st to the 2nd measurement, and that from the 2nd to the 3rd measurement in the PDF group was statistically significant ($p < 0.05$)

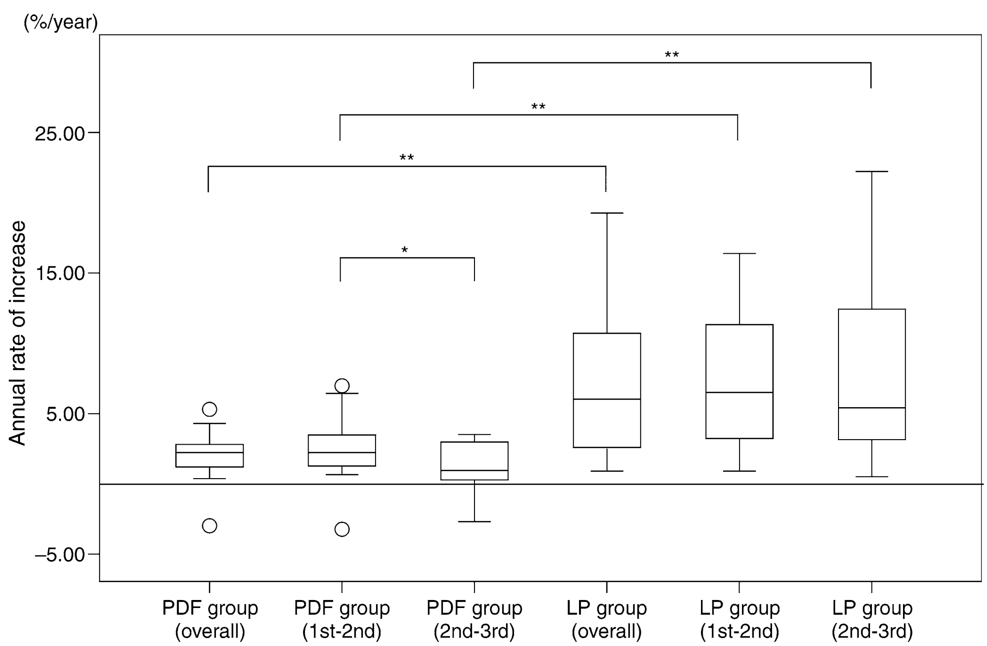

Fig. 2 The annual rate of lesion increase was evaluated in the PDF and LP groups. There was a significant difference in the annual rate of lesion increase between the two groups. In the PDF group, the annual rate of increase from the 1st to the 2nd measurement and from the 2nd to the 3rd measurement was significantly lower than that in the LP group. In the PDF group, the rate of increase from the 2nd to the 3rd measurement was significantly lower than that from the 1st to the 2nd measurement. *LP* laminoplasty, *PDF* posterior decompression and fusion

most of the surgeons hesitate to choose anterior surgery in elderly patients with multi-level OPLL or pulmonary comorbidity due to higher general and neurological complication rates, we have introduced PDF for patients with K-line (−)-type multi-level OPLL. Since the mean recovery rate of the JOA score (41.6 %) in the present study seemed to be equal to that in previous studies on PDF procedure for OPLL [22, 23], additional investigation is necessary to clarify the advantage of PDF compared to ADF [2, 20].

Progression of OPLL

In the present study, the mean annual rate of lesion increase in the PDF group was significantly lower than that in the LP group using novel 3D analysis. In a notable thing, the mean annual rate of increase was gradually decreasing over time in the PDF group, which might be related with the process of bony fusion after PDF. These findings suggested that additional posterior instrumented fusion following laminoplasty suppresses the progression of OPLL. In an

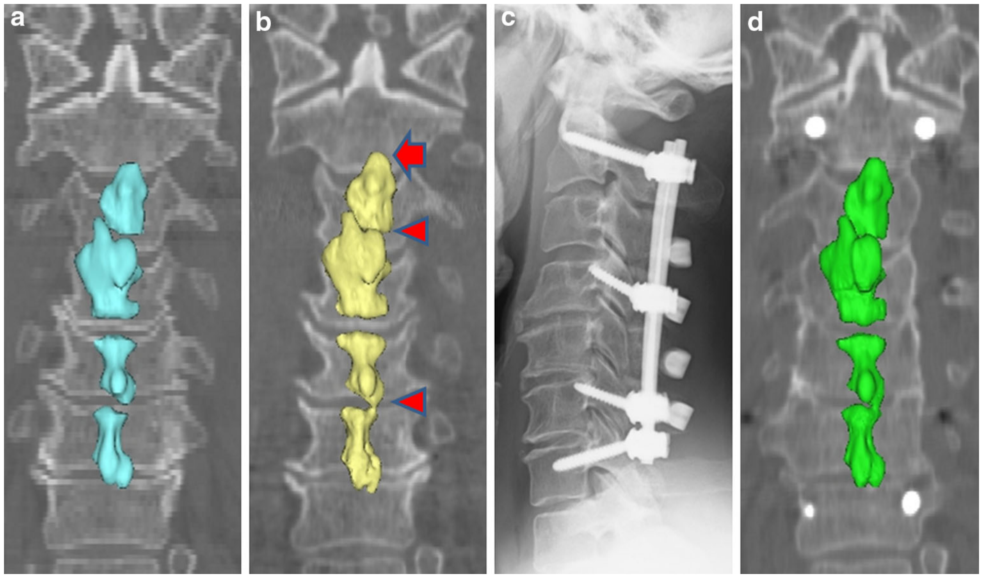

Fig. 3 **a** A 3D model of mixed-type OPLL showing the C3–C6 level at the initial visit. **b** A preoperative 3D model of OPLL showing progression at both the cranial potion of the OPLL (*arrow*) and C3/C4, C5/C6 intervertebral area (*arrowhead*). **c** A plain radiography showing the C2–C7 PDF. **d** A 3D model of OPLL at 3 years after the operation showing a lower progression of the OPLL. *OPLL* ossification of the posterior longitudinal ligament, *PDF* posterior decompression and fusion, *3D* three dimensional

in vitro study, Tanno et al. [24] provided evidence that mechanical stress plays a key role in the progression of OPLL through the induction of osteogenic differentiation in spinal ligament cells and the promotion of the mechanism of bone morphogenetic proteins. These results supported hypotheses that dynamic factors stimulate the progression of OPLL and stabilization may lead to the decreased progression of OPLL [3, 8–10, 24]. In the present study, the two groups were matched for age, sex, follow-up period, type of OPLL, occupation rate of OPLL, number of ossified vertebra, and preoperative JOA score, but not for the preoperative C2–C7 lordotic angle. Preoperative sagittal alignment may have influenced the rate of OPLL progression. However, Iwasaki et al. [6] and Hori et al. [25] have reported that there is no significant relationship between the progression of OPLL and cervical alignment. Therefore, we consider that preoperative sagittal alignment may not significantly affect OPLL progression.

This is the first study to prove a possible suppressant effect of posterior instrumented fusion on OPLL progression. Posterior decompression surgery is difficult to resect the ossified lesion itself, and may not avoid OPLL progression or kyphotic change of cervical alignment, which are risk factors for late neurological deterioration. However, additional posterior instrumented fusion is useful to maintain both the cervical alignment and clinical outcomes, by suppression of OPLL progression. Our results suggest that posterior instrumented fusion has a beneficial effect on the long-term outcomes of OPLL patients with K-line (−) group. Among the OPLL patients with K-line (+) type, PDF may be considered, especially for younger patients or those with continuous/mixed-type OPLL, which were previously reported as risk factors of OPLL progression [5, 6, 9, 25]. Since few reports have recommended PDF for patients with K-line (+)-type OPLL, further study is necessary to establish the indication for PDF.

Limitations of the present study

The method used for identification of ossification was semi-automatic; therefore, human errors may have occurred. However, we believe that evaluation of the ossification volume was accurate and valid because of the high intraobserver and interobserver ICCs. The second limitation was the small number of patients and short follow-up period in the present study. Although we believe that our conclusions are based on reliable facts, a larger number of patients and longer follow-up evaluation will be required to confirm our findings. Finally, this was a retrospective study that compared two groups based on the K-line type, which may have influenced the rate of OPLL progression.

Conclusions

This is the first study to prove that additional instrumented fusion following laminoplasty suppresses the progression of OPLL. The novel CT-based 3D analysis method described here can measure the volume of OPLL accurately, and thus can be useful for the examination of OPLL progression.

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Compliance with ethical standards

Conflict of interest The authors have no potential conflict of interest.

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