Clinical Study

Effect of posterior instrumented fusion on three-dimensional volumetric growth of cervical ossification of the posterior longitudinal ligament: a multiple regression analysis

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Abstract: Background Context: Despite the fact that ossification of posterior longitudinal ligament (OPLL) is a three-dimensional disease, conventional studies have mainly focused on a two-dimensional measurement, and it is difficult to accurately determine the volume of OPLL growth and analyze the factors affecting OPLL growth after posterior decompression (laminoplasty or laminectomy and fusion).

Purpose: This study aimed to investigate the factors affecting OPLL volume growth using a three-dimensional measurement.

Study Design/Setting: This was a retrospective case study.

Patient Sample: Eighty-three patients with cervical OPLL who were diagnosed as having multilevel cervical OPLL of more than three levels on cervical computed tomography (CT) scans were retrospectively reviewed from June 1, 1998 to December 31, 2015.

Outcome Measures: The OPLL volume from the C1 vertebrae to the C7 vertebrae was measured on preoperative and the most recent follow-up CT scans.

Methods: Eighty-three patients were retrospectively examined for age, sex, body mass index, hypertension, diabetes, type of OPLL, surgical method, preoperative cervical curvature, and preoperative and postoperative cervical range of motion. Preoperative cervical CT and the most recent follow-up cervical CT scans were converted to digital imaging and communications in medicine data, and the OPLL volume was three-dimensionally measured using the Mimics® program (Materialise, Leuven, Belgium). The OPLL volume growth was analyzed using univariate and multivariate analyses.
Results: The average follow-up period was 32.36 (±23.39) months. Patients’ mean age was 54.92 (±8.21) years. In univariate analysis, younger age (p = 0.037) and laminoplasty (p = 0.012) were significantly associated with a higher mean annual growth rate of OPLL (%/year). In multivariate analysis, only laminoplasty (p = 0.027) was significantly associated with a higher mean annual growth rate of OPLL (%/year). The mean annual growth rate of OPLL was about 7 times faster with laminoplasty (8.00 ± 13.06%/year) than with laminectomy and fusion (1.16 ± 9.23%/year).

Conclusions: Posterior instrumented fusion has the effect of reducing OPLL growth rate rather than motion-preserving laminoplasty. Patients’ age and the surgical method need to be considered in surgically managing the multilevel OPLL.

Keywords: Ossification Posterior longitudinal ligament; Three-dimensional analysis; Laminoplasty; Laminectomy and Fusion; Progression; Mimics®

Introduction

Ossification of the posterior longitudinal ligament (OPLL) is a condition caused by abnormal calcification and growth of the posterior longitudinal ligament. The growth of OPLL sometimes causes narrowing of the spinal canal and cord compression, which may require surgical intervention (1, 2). Additionally, growth of OPLL after decompressive operation has been considered a main cause of delayed reoperation 2 years after the index operation (3-5). Therefore, it is clinically important to understand factors affecting OPLL volume growth in order to better counsel patients and to determine the optimal surgical method. In previous studies, the surgical intervention, a young age, the type of
OPLL and surgical methods have been indicated as factors for OPLL growth (6-10). However, these studies used two-dimensional measurements on plain radiographs and plain computed tomography (CT) scans, making it difficult to demonstrate the total volume and volumetric growth of OPLL. In addition, OPLL gradually increased over a long period, and sometimes OPLL increased by a small amount. Thus, it was difficult to quantify the exact growth volume of OPLL and to analyze various factors affecting OPLL growth. Recently, studies on the measurement of OPLL volume using three-dimensional (D) methods have been introduced (11-13). However, studies on factors that affect volumetric growth of OPLL are still inadequate (11-13). No previous reports have performed multivariate regression to identify factors exclusively associated with volumetric growth of OPLL. Therefore, in this study, we measured OPLL growth using a three-D measurement and analyzed the factors affecting OPLL growth after posterior decompressive operation. Moreover, we compared the growth rate between the surgical levels and non-surgical levels and determined whether instrumented fusion reduced OPLL growth.

**Materials and methods**

This study was approved by the institutional review board (IRB) of Yonsei University Severance Hospital (IRB number 4-2014-0529). We performed a retrospective analysis of patients with multilevel cervical OPLL (more than three levels) identified on cervical CT scans. We included patients surgically treated with laminoplasty (LP) or laminectomy/fusion (LF) at our institution from June 1, 1998 to December 31, 2015 by two senior authors (HCS and YH) with a minimum follow up of two years. We reviewed electronic medical records for demographic characteristics and surgical details.

Surgical decision making

Surgical intervention, laminoplasty (LP) or laminectomy/fusion (LF), was performed in patients who showed neurologic symptoms of myelopathy or myeloradiculopathy on physical examination and neural element compression on a cervical magnetic resonance imaging (MRI) scan. We determined
whether to perform LP or LF according to cervical lordosis, neck pain, and the surgeon’s preference.

Conservative treatment was performed on patients who did not show neural compression on cervical MRI scan or patients with axial neck pain who did not show neurologic symptoms on physical examination.

Surgical intervention was performed by two experienced neurosurgeons (HCS and YH). LF and LP were performed as described in the literature (14-17). Open-door LP was performed: the opening side was symptom-predominant, whereas the left side was the open side when symptoms were not dominant. LF was performed together with foraminotomy on the symptomatic side.

Radiologic assessment

We performed preoperative cervical CT, postoperative cervical CT within 7 days postoperatively, and follow-up cervical CT every 12 months. CT images were obtained with an axial cut of 3-mm thick. Preoperative cervical CT images and the most recent follow-up cervical CT images were converted to digital imaging and communications in medicine (DICOM) files, and the OPLL volume was measured three-dimensionally using the Mimics® program (Materialise, Leuven, Belgium). The OPLL volume was measured from the C1 vertebrae to the C7 vertebrae, and the OPLL volume was measured for each vertebra (Figure 1). Based on this, OPLL volumes of the vertebrae at the surgical level and non-surgical level were also calculated. Surgical level OPLL refers to the OPLL of the vertebrae with the lamina open in LP, and OPLL of the vertebrae with laminectomy and instrumentation in LF. Non-surgical level OPLL means OPLL of the vertebrae without the lamina open in LP, and OPLL of the vertebrae without laminectomy and instrumentation in LF. We calculated the change in OPLL volume as a mean annual growth rate of OPLL (AGRO), as in the previous study by Katsumi et al. (11). Additionally, the mean annual growth rate of OPLL (AGRO, %/year) was calculated using the following formula: \( \left( \frac{\text{postoperative volume} - \text{preoperative volume}}{\text{follow up months}} \times 12 \right) / \text{preoperative volume} \times 100 \). The OPLL type was classified into four categories according to the Investigation Committee (18) on OPLL on a preoperative CT scan, and the number of involved vertebrae was also determined. The C2-C7 curvature angle and range of
motion (ROM) on a cervical simple radiograph was compared preoperatively to that on the most recent follow-up radiograph (Figure 2).

Statistical analysis

We conducted univariate linear regression analysis to identify variables associated with mean AGRO. Then we performed multivariate linear regression analysis, including variables (p <0.05) from univariate analysis and variables (sex, preoperative curvature, preoperative curvature, number of involved vertebrae) reported to be considered meaningful variables in previous articles (6-10, 19). Descriptive statistics were used to summarize baseline demographic and radiologic data of 83 patients. LF and LP were compared by independent t-test and Mann-Whitney U test for continuous variables, and by chi-square tests for categorical variables. A p-value less than 0.05 was considered statistically significant. All analyses were performed by using SPSS software (version 18; SPSS Inc., Chicago, IL, USA).

Results

Patients’ demographic characteristics

Overall, we found a total of 282 patients with multilevel cervical OPLL, with 83 patients meeting inclusion criteria. We excluded a total of 199 patients: 13 patients with trauma and fracture or tumor, 85 who underwent anterior cervical surgery, 17 with previous history of cervical operation, 15 who underwent circumferential fusion, and 69 who were lost to follow-up. The mean follow-up period was 32.36 (±23.39) months, and patients’ mean age was 54.92 (±8.21) years. Fifty-six (67.50%) were men, and 27 (32.50%) were women. The mean BMI was 24.75 (±3.40) kg/m². Thirty-one (37.35%) patients were hypertensive, and 18 (21.69%) were diabetic. There was no localized type in OPLL type; 8 (9.64%) were the continuous type, 59 (71.08%) were mixed, and 16 (19.28%) were segmental.

Regarding the surgical method, 31 patients were in the LF group, and 52 were in the LP group (Table 1).
Univariate and multivariate analyses

In the univariate analysis of each independent variable, younger age (p = 0.037) and LP (p = 0.012) were statistically associated with a higher mean AGRO. In multivariate analysis, only LP (p = 0.027) was significantly associated with a higher mean AGRO (Table 2).

LP vs. LF

A comparison of 31 patients in the LF group and 52 patients in the LP group was performed. There was no statistically significant difference in age, sex, OPLL type and presence of HTN and DM between the two groups; however, there was a statistically significant difference in BMI between the two groups (p = 0.041, Table 1). Regarding the radiologic outcome between the two groups, the preoperative curvature angles were 13.93 ± 8.46 in the LF group and 9.43 ± 7.27 in the LP group, showing a larger preoperative curvature angle in the LF group (p = 0.020). Cervical ROM was smaller in the LF group than in the LP group postoperatively (p = 0.002). The mean AGROs were 1.16 ± 9.23 (%/year) and 8.00 ± 13.06 (%/year) in the LF and LP groups, respectively (p = 0.007) (Table 3).

Surgical level vs. non-surgical level

The mean AGRO was compared between the LF group and LP group at the surgical level and non-surgical level. At the surgical level, the mean AGROs were 0.81 ± 9.16 and 5.96 ± 12.78 in the LF and LP groups, respectively (p = 0.010). At the non-surgical level, the mean AGROs were 12.21 ± 25.29 and 15.03 ± 22.81 in the LF and LP groups, respectively, but there was no significant difference (p = 0.258) (Table 3).

Discussion

Previous literatures have compared LF and LP for OPLL growth. Ota et al. (17) reported that the progression of the thickness of OPLL was significantly smaller in the posterior decompression with instrumented fusion group (-0.1 ± 0.4 mm) than in the LP group (0.6 ± 0.7 mm, p = 0.0002). Lee et al. (20) found that OPLL growth was more frequently observed in LP than in LF (45.5% vs. 30.0%). In
the study by Katsumi et al. (11), 19 LF groups and 22 LP groups were compared using the three-D measurement method. OPLL progression was less in the LF group (2.0 ± 1.7%/year; range -3.0 to 5.3) than in the LP group (7.5 ± 5.6%/year; range 1.0-19.2) (p < 0.001). However, these previous studies used two-D images to measure OPLL growth, so it was difficult to determine the three-dimensional OPLL volume change accurately and the sample size was insufficient to compare the two groups. In Katsumi’s study, there was bias in selecting LF or LP as the surgical method, as described in the limitation of the paper. Patients with more severe and aggressive OPLL may have been selected to undergo LF, which may have served as a confounding factor. Therefore, we conducted multiple regression analysis of risk factors to rule out these problems. In our multiple regression analysis, the surgical method was only associated with OPLL growth. Recently, Katsumi et al. (19) performed risk factor analysis for OPLL progression in 41 non-surgically treated cervical OPLL patients using three-dimensional measurements. In univariate regression analysis, age (β=-0.48;p=0.001), body weight (β=0.36;p=0.02), and BMI (β=0.35;p=0.03) showed significant relationship with the annual rate of lesion increase. In multivariate regression analysis, only age was significant predictor of OPLL progression (R²=0.23;p=0.001). Additionally, in comparison between the two groups, OPLL growth at surgical level was significantly smaller in LF group than in LP group. It is speculated that stabilization reduced mechanical stress, and the decrease in mechanical stress affected the decrease in OPLL growth, as mentioned in previous studies (5, 13, 21, 22).

According to the literatures on comorbidity with OPLL (23-25), patients with non-insulin dependent DM (NIDDM) have been shown to have a higher prevalence of OPLL. Adult-onset obesity and NIDDM have also been identified as independent risk factors for OPLL. In addition, hypophosphatemic rickets and hypoparathyroidism have been reported to be associated with a high prevalence of OPLL (23-25). It is not known whether these factors will serve as a risk factor for the growth of OPLL. In the present study, BMI and the presence of HTN and DM did not show a statistically significant association with OPLL growth.
Chiba et al. (22) reported that OPLL progression was high in younger age and mixed, continuous type of OPLL, and ROM of the cervical spine increased at the time of diagnosis. In the present study, age was statistically significant in univariate analysis but not in multivariate analysis. ROM, the cervical curvature angle, as well as OPLL type did not associate with OPLL growth. Also, sex did not show any association with OPLL growth.

Matsunaga et al. (26) reported axial progression in 70 patients (42%) and longitudinal progression in 144 patients (86%) among 167 patients who underwent conservative treatment for an average of 11.2 years. Iwasaki et al. (14) reported radiologic progression in 41 (69%) of 59 patients undergoing LP and reported a median progression per year of 0.3 mm in thickness and 1 mm extension in the longitudinal direction. This is due to the two-dimensional measurement, which is unlikely to be directly comparable to the volume measurement performed in the current study. Izumi et al. (12) showed that in the three-D measurement analysis of OPLL patients with 20 conservatively treated patients, the initial preoperative mean OPLL volume was 1831.68 mm$^3$, and mean annual growth rate of OPLL was 3.33% (range 0.08-7.79%). In the study of Katsumi et al. (11), the preoperative OPLL volume was $2363 \pm 1823$ mm$^3$ in 19 LF groups and $2361 \pm 1962$ mm$^3$ in 22 LP groups. The annual growth rates were $2.0 \pm 1.7\%/year$ and $7.5 \pm 5.6\%/year$, respectively ($p < 0.001$). In the current study, the preoperative OPLL volume was $2858.16 \pm 1631.67$ mm$^3$, and the mean AGROs were $1.16 \pm 9.23\%/year$ and $8.00 \pm 13.06\%/year$ in the LF and LP groups, respectively. Additionally, in our study, standard deviations of OPLL volume and mean AGRO values were higher than those of previous studies, as OPLL volume had decreased in some cases in both LF and LP groups. (Figure 3). OPLL reduction has been reported after decompressive operation. Kimura et al. (27) reported a case of spontaneous reduction of thoracic OPLL after posterior spinal fusion operation. Koda et al. (28) measured OPLL before and after fusion operation in 29 patients with thoracic OPLL, and the average OPLL thickness decreased from 8.0 mm to 7.3 mm. The OPLL thickness reduction was also greater in the fusion group of the non-ossified segment than in the non-fusion group of the non-ossified segment.
They speculated that an increase in stabilization after posterior fixation would reduce the increase in the OPLL volume.

Limitations of the study

This study has some limitations. First, as described in the previous three-D studies (11, 28, 29), the three-D measurement process is semi-automatic, resulting in inter-observer and intra-observer errors. However, previous studies have shown high intra-observer and inter-observer reliability in three-D measurements (29, 30). It is also considered a more accurate method because it is fundamentally measured in several precise axial CT cuts rather than obscure two-D methods. Second, we measured the mean annual growth rate of OPLL rather than the actual annual growth rate of OPLL in each year after surgery, since we had only measured OPLL volume from the most recent CT and preoperative CT. Therefore, the mean AGRO obtained in this study did not show the details of growth rate in every years postoperatively. As previously reported, growth rate of OPLL is not always constant after surgery, but it can change according to the time of follow-up. Future studies measuring the volume of CT every year for a longer follow-up period may be needed to better understand the changing patterns of OPLL volume. Third, difference in follow-up periods between the two groups is also a limitation. Since the mean AGRO has a limitation that does not reflect the change in growth rate according to postoperative period, the mean annual growth rate of LF groups with longer follow-up periods would have been underestimated compared to that of LP groups with shorter follow-up periods. Fourth, because this study was performed only in patients who underwent operation, if a conservative treatment group was added, it would have been possible to obtain more introspection. Fifth, if clinical indicators were added, it would have been possible to obtain more meaningful results by confirming the relationship between clinical indicators and the OPLL volume growth. Lee et al. (31) reported that radiologic OPLL progression was observed more frequently in the LP group than in the LF group. However, late neurologic deterioration was reported to be rare in both groups. However, since this study was limited to the relationship of the growth of the OPLL volume radiographically, future
studies should clarify the association with clinical indicators. Sixth, it had a small sample size and retrospective study design.

Conclusions
The mean annual growth rate of OPLL was about seven times faster in the LP group (8.00 ± 13.06%/year) than in the LF group (1.16 ± 9.23%/year) in the present study. We conclude that posterior instrumented fusion has the effect of reducing OPLL growth rate rather than motion-preserving LP, which was similar results of previous studies (11, 17, 20). Patients’ age and the surgical method need to be considered in surgically managing the multilevel OPLL.

References


**Figure Legends**

Fig. 1 Measurement of OPLL volume using the Mimics® program. The total cervical OPLL volume was measured from the C1 vertebrae to the C7 vertebrae, and the OPLL volume was measured at each vertebral level. OPLL: Ossification of posterior longitudinal ligament

Fig. 2 The C2-C7 curvature was defined as the Cobb angle of the C2 and C7 lower endplates on a standing radiograph, and the range of motion was defined as the sum of the Cobb angles between the C2 and C7 lower endplates at the time of flexion and extension on a simple radiograph.

Fig. 3 Scatter plot of OPLL volume change between the most recent CT and preoperative CT in both LF and LP groups. OPLL: Ossification of posterior longitudinal ligament

Delta total (mm³) = (preoperative OPLL volume) – (most recent postoperative OPLL volume)
### Table 1: Comparison of the two surgical method groups (LF vs. LP)

<table>
<thead>
<tr>
<th></th>
<th>Total (n = 83)</th>
<th>LF group (n = 31)</th>
<th>LP group (n = 52)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) [min-max]</td>
<td>54.92 ± 8.21</td>
<td>56.97 ± 10.22</td>
<td>53.69 ± 6.56</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td>[39-76]</td>
<td>[42-76]</td>
<td>[39-71]</td>
<td></td>
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<tr>
<td>Sex (n, male:female)</td>
<td>56:27</td>
<td>19:12</td>
<td>37:15</td>
<td>0.353</td>
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<tr>
<td>Number of involved</td>
<td>5.17 ± 1.17 [3-7]</td>
<td>5.29 ± 1.22 [3-7]</td>
<td>5.10 ± 1.14 [3-7]</td>
<td>0.453</td>
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<td>vertebrae (n) [min-max]</td>
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<td>Type of OPLL (n)</td>
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<tr>
<td>Continuous</td>
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<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>59</td>
<td>24</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Segmental</td>
<td>16</td>
<td>4</td>
<td>12</td>
<td></td>
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<tr>
<td>Localized</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²) [min-max]</td>
<td>24.75 ± 3.40</td>
<td>25.54 ± 3.93</td>
<td>24.27 ± 2.97</td>
<td>0.041</td>
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<td></td>
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<td>[19.53-33.87]</td>
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<td>Presence of HTN</td>
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<td>16</td>
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<tr>
<td>Presence of DM</td>
<td>18</td>
<td>7</td>
<td>11</td>
<td>0.915</td>
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<tr>
<td>Follow-up period (months)</td>
<td>32.36 ± 23.39</td>
<td>45.84 ± 29.08</td>
<td>24.33 ± 14.35</td>
<td>0.001</td>
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<tr>
<td>[min-max]</td>
<td>[12.98]</td>
<td>[12.98]</td>
<td>[12.98]</td>
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</table>
LF: laminectomy and fusion, LP: laminoplasty, SD: standard deviation, IQR: interquartile range,
OPLL: ossification of posterior longitudinal ligament, BMI: body mass index, HTN: hypertension,
DM: diabetes mellitus.

*The independent t test and the Mann-Whitney U test were performed to compare the two groups.

**The chi-square test was performed to compare sex, OPLL type, HTN, and DM between the two groups.

***Bold letters indicate statistical significance (p-value <0.05).
Table 2 Results of univariate and multivariate linear regression analysis for OPLL progression

<table>
<thead>
<tr>
<th>Variable</th>
<th>Univariate analysis</th>
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<th>Multivariate analysis</th>
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<tr>
<td></td>
<td>β</td>
<td>p-value</td>
<td>β</td>
<td>p-value</td>
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<tr>
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<td>-0.003</td>
<td>0.037</td>
<td>-0.003</td>
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<td>Sex</td>
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<tr>
<td>BMI</td>
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<td>Presence of HTN</td>
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<td>Presence of DM</td>
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<td>Type of OPLL</td>
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<tr>
<td>Continuous</td>
<td>Reference</td>
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<td>Mixed</td>
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<td>Surgical method (LF vs. LP)</td>
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<td>Preoperative curvature</td>
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<td>0.302</td>
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<tr>
<td>Postoperative curvature</td>
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<td>0.253</td>
<td>0.001</td>
<td>0.743</td>
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<tr>
<td>Preoperative ROM</td>
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<tr>
<td>Postoperative ROM</td>
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<td>* (Post-Pre) ROM</td>
<td>0.001</td>
<td>0.408</td>
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<tr>
<td>Preoperative OPLL volume</td>
<td>0.000</td>
<td>0.731</td>
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<td>Follow-up period</td>
<td>0.000</td>
<td>0.659</td>
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<tr>
<td>Number of involved vertebrae</td>
<td>0.011</td>
<td>0.328</td>
<td>0.011</td>
<td>0.406</td>
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</table>


* (Post-pre) ROM = postoperative ROM – preoperative ROM
Variables with a p-value less than 0.05 in the univariate analysis and variable presumed to be associated with increased AGRO were included in the multivariate analysis.

Bold letters indicate statistical significance (p-value < 0.05).
Table 3 Comparison of radiologic outcomes between the two surgical method groups (LF vs. LP)

<table>
<thead>
<tr>
<th></th>
<th>Total (n = 83)</th>
<th>LF group (n = 31)</th>
<th>LP group (n = 52)</th>
<th>p-value</th>
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<td><strong>C2-C7 curvature [min-max]</strong></td>
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<td></td>
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<td>Preoperative (°)</td>
<td>10.87 ± 7.90</td>
<td>13.93 ± 8.46</td>
<td>9.43 ± 7.27</td>
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<td>[0.16-31.20]</td>
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<tr>
<td>Postoperative (°)</td>
<td>8.00 ± 7.52</td>
<td>8.07 ± 9.28</td>
<td>7.97 ± 6.71</td>
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<td><strong>Cervical ROM (°) [min-max]</strong></td>
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<td>Preoperative (°)</td>
<td>31.82 ± 10.89</td>
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<td>30.86 ± 10.02</td>
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<td></td>
<td>[0.00-60.60]</td>
<td>[7.98-60.60]</td>
<td>[0.00-56.50]</td>
<td></td>
</tr>
<tr>
<td>Postoperative (°)</td>
<td>21.84 ± 13.50</td>
<td>16.12 ± 16.13</td>
<td>24.46 ± 11.35</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>[1.86-67.30]</td>
<td>[1.86-67.30]</td>
<td>[4.50-45.80]</td>
<td></td>
</tr>
<tr>
<td><em>(Post-pre) ROM (°) [min-max]</em>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative (°)</td>
<td>-8.36 ± 14.14</td>
<td>-11.31 ± 18.12</td>
<td>-7.01 ± 11.85</td>
<td>0.327</td>
</tr>
<tr>
<td></td>
<td>[-52.49-19.10]</td>
<td>[-52.49-14.40]</td>
<td>[-36.60-19.10]</td>
<td></td>
</tr>
<tr>
<td><strong>Total OPLL volume (mm³) [min-max]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative (mm³)</td>
<td>2858.16 ± 1631.67</td>
<td>3272.29 ± 1587.15</td>
<td>2611.27 ± 1622.48</td>
<td>0.054</td>
</tr>
<tr>
<td></td>
<td>[456.07-6599.87]</td>
<td>[517.24-6358.59]</td>
<td>[456.07-6599.87]</td>
<td></td>
</tr>
</tbody>
</table>
Postoperative (mm³) & 3333.49 ± 2031.98 & 3565.54 ± 1845.61 & 3195.15 ± 2140.74 & 0.211
\[374.81-8570.76\] & \[499.28-7534.00\] & \[374.81-8570.76\] \\

**(Post-pre) OPLL volume (mm³) [min-max] & 475.33 ± 807.57 & 293.25 ± 784.04 & 583.88 ± 809.21 & 0.080
\[-1107.75-3482.01\] & \[-1107.75-2557.32\] & \[-336.02-3482.01\] \\

†Annual growth rate of OPLL (AGRO, %/year) [min-max] & 5.45 ± 12.18 & 1.16 ± 9.23 & 8.00 ± 13.06 & 0.007
\[-32.00-33.00\] & \[-20.00-30.00\] & \[-32.00-33.00\] \\

‡Surgical level (AGRO, %/year) [min-max] & 4.04 ± 11.77 & 0.81 ± 9.16 & 5.96 ± 12.78 & 0.010
\[-32.00-32.00\] & \[-20.00-30.00\] & \[-32.00-32.00\] \\

‡‡Non-surgical level (AGRO, %/year) [min-max] & 14.28 ± 23.27 & 12.21 ± 25.29 & 15.03 ± 22.81 & 0.258
\[-48.00-85.00\] & \[-16.00-85.00\] & \[-48.00-81.00\] \\

1 LF: laminectomy and fusion, LP: laminoplasty, IQR: interquartile range, SD: standard deviation,
2 ROM: range of motion, OPLL: ossification of posterior longitudinal ligament
3 *(Post-pre) ROM = postoperative ROM – preoperative ROM
4 **(Post-pre) OPLL volume = Postoperative OPLL volume – preoperative OPLL volume
5 ***The independent t test and the Mann-Whitney U test were performed to compare the two groups.
6 ****Bold letters indicate statistical significance (p-value <0.05).
Annual growth rate of OPLL (AGRO, %/year) = \[
\frac{[\text{postoperative volume (mm}^3\text{)} - \text{preoperative volume (mm}^3\text{)}]}{\text{follow-up period in months}} \times 12\]
\times \frac{1}{\text{preoperative volume (mm}^3\text{)} \times 100}

Surgical level AGRO (%/year) = \[
\frac{[\text{postoperative volume (mm}^3\text{)} - \text{preoperative volume (mm}^3\text{)}]}{\text{follow-up period in months}} \times 12\]
\times \frac{1}{\text{preoperative volume (mm}^3\text{)} \times 100}

Non-surgical level AGRO (%/year) = \[
\frac{[\text{postoperative volume (mm}^3\text{)} - \text{preoperative volume (mm}^3\text{)}]}{\text{follow-up period in months}} \times 12\]
\times \frac{1}{\text{preoperative volume (mm}^3\text{)} \times 100}
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