Ossified Posterior Longitudinal Ligament Existing at an Intervertebral Level Limits Compensatory Mechanism of Cervical Lordosis after Muscle-Preserving Selective Laminectomy

Satoshi Nori¹, Ryoma Aoyama¹, Ken Ninomiya¹, Satoshi Suzuki², Ukei Anazawa¹, and Tateru Shiraishi³

¹) Department of Orthopaedic Surgery, Tokyo Dental College Ichikawa General Hospital, Chiba, Japan
²) Department of Orthopaedic Surgery, Keio University School of Medicine, Tokyo, Japan
³) Shiraishi Spine Clinic, Tokyo, Japan

Abstract:
Introduction: As C7 slope increases, lordotic change of C2-C7 angle compensates for adjustments in cervical sagittal balance. However, ossification of the posterior longitudinal ligament (OPLL) may affect the compensatory mechanism of the cervical spine. This study aims to evaluate the impact of OPLL on cervical lordotic compensation after muscle-preserving selective laminectomy (SL).

Methods: This study involved 235 patients with cervical spondylotic myelopathy (CSM) and OPLL who underwent consecutive levels of SL. OPLL was classified into continuous, segmental, mixed, or localized type on the basis of the criteria previously reported. In this study, based on the motion preservation at the intervertebral level, patients were divided into CSM (n = 114), OPLL segmental type (OPLL-S; n = 44), and other types of OPLL (OPLL-O; i.e., continuous, mixed, and localized; n = 77). The cervical sagittal alignment, degree of spinal cord decompression, and surgical outcomes were compared among the three groups.

Results: The OPLL-O group had a larger postoperative C7 slope (p = 0.020), larger pre- (p = 0.021) and postoperative (p = 0.001) C2-C7 sagittal vertical axis, and greater pre- (p = 0.034) and postoperative (p = 0.002) C7 slope minus C2-C7 angle. Narrower postoperative spinal cord clearance (PSCC) from OPLL (p < 0.001) and more residual spinal cord compression (p < 0.001) were observed in the OPLL-O group. Correlation between postoperative C7 slope minus C2-C7 angle and PSCC was detected (r = −0.238, p < 0.001). The recovery rate of the Japanese Orthopedic Association score was slightly lower in the OPLL-O group (p < 0.001), and it was correlated with postoperative residual spinal cord compression (r = −0.305, p < 0.001).

Conclusions: OPLL-O limits cervical lordotic compensation, resulting in cervical sagittal balance mismatch. It affects the degree of spinal cord decompression, which might be related to surgical outcome.

Keywords:
cervical alignment, cervical sagittal balance mismatch, cervical lordotic compensation, ossification of the posterior longitudinal ligament, cervical spondylotic myelopathy, muscle-preserving selective laminectomy, minimally invasive surgery, laminoplasty

Spine Surg Relat Res 2019; 3(4): 312-318
dx.doi.org/10.22603/ssrr.2019-0036

Introduction
Cervical sagittal alignment has been investigated as a crucial determinant of surgical and radiological outcomes after cervical spine surgery. C7 slope behaves as an important marker of the sagittal spinal alignment, linking the occipitocervical and thoracolumbar spine. To adjust cervical sagittal alignment or horizontal gaze, lordotic change of C2-C7 angle occurs when C7 slope increases. For the posterior decompression of cervical compressive myelopathy (CCM), we have used muscle-preserving selective laminectomy (SL) for more than 13 years, which selects decompression laminae without disturbing deep extensor muscles or facet joints. It has been reported that SL preserves the compen-
satory mechanism of cervical lordosis after surgery for cervi-
cal spondylotic myelopathy (CSM) and ossification of the posterior
longitudinal ligament (OPLL), segmental type (OPLL-S)\(^2\).

OPLL is a hyperostotic condition resulting from the ecto-
cpic calcification of the posterior longitudinal ligament\(^3\).
The OPLL patients with kyphotic cervical spine, or postop-
erative changes in cervical alignment from lordotic to
straight, tend to have poor surgical outcomes after lamino-
plasty\(^4\). A reduced cervical range of motion (ROM) can be
caused by OPLL existing at the intervertebral level, which
may affect the compensatory mechanism of the cervical
spine. However, to the best of our knowledge, there is no
study focusing on cervical lordotic compensation in OPLL
patients after posterior decompression, nor comparing the
compensatory mechanism between CSM and OPLL patients.

On the basis of the criteria previously reported, OPLL was
classified into the following four types: continuous, segmen-
tal, mixed, and localized\(^5\). In the current study, based on
the motion preservation at the intervertebral level, we di-
vided OPLL into OPLL-S and other types of OPLL (OPLL-
O; i.e., continuous, mixed, and localized). The purpose of
this study was to evaluate the difference in cervical sagittal
alignment and cervical lordotic compensation among pa-
tients with CSM, OPLL-S, and OPLL-O, and evaluate the
influence of the compensatory mechanism on functional out-
comes.

Materials and Methods

Subjects

Between January 2010 and March 2017, 891 consecutive patients underwent SL for CCM at a single academic institu-
tion. SL was not performed for patients who had 1) a lo-
kal kyphosis of $>20^\circ$, 2) spondylolisthesis of $>3.5$ mm\(^6\), or
3) an OPLL occupancy ratio of $>60%$\(^7\). Patients who pre-
sented with radiculopathy without myelopathy patients who
had undergone foraminotomy or previous surgery for cervi-
cal spine, and patients who had undergone treatment for spi-
nal tumors, trauma, or infection were excluded. Preopera-
tively, all patients underwent cervical myelogram-computed
tomography (CT), and the presence and type of OPLL was
identified. Because OPLL patients usually undergo at least
three consecutive levels of posterior decompression, patients
whose SL included $\geq3$ consecutive laminae (CLs) were se-
lected. The most cranial laminectomy level was C3 and the
most caudal level was C7. The study involved 235 CCM pa-
tients who underwent three consecutive levels of SL (C3-C5
SL, 12 cases; C4-C6 SL, 127 cases; C5-C7 SL, three cases),
four consecutive levels of SL (C3-C6 SL, 71 cases; C4-C7
SL, 10 cases), and five consecutive levels of SL (C3-C7 SL,
12 cases).

Surgical procedure

Patients underwent SL as described previously\(^7,8\). For C4-
C7 SL, the C4, C5, C6, and C7 spinous processes were split
longitudinally and divided at the base, without damaging the
deep extensor muscles. We removed the C4, C5, C6, and C7
laminae, the upper half of the T1 lamina, and the yellow
ligament of the ventral aspect of the C3 lamina. Through
this procedure, we completed adjacent five-level (C3/4, C4/
5, C5/6, C6/7, and C7/T1) decompression. Then, the frag-
ments of the split C4, C5, C6, and C7 spinous processes
were sutured together.

Prior to surgery, cervical myelogram-CT with the pa-
tients’ necks in neutral and extended positions was per-
formed, and the results were assessed. We determined the
decompression laminae through the obstruction of the suba-
rachnoid space at the intervertebral levels. The width of the
spinal cord at the upper edge of each lamina was measured
using myelogram-CT. We determined that the laminectomy
width was no more than 2-3 mm wider than the spinal cord
width\(^9\). Normally, the mean laminectomy width was 15-19
mm. Bilateral facet joints were never exposed during sur-
gery.

Patients’ characteristics and outcome measures

The clinical characteristics of the patients, including age,
sex, diagnosis, and operative levels, were recorded. Clinical
outcomes were measured by the Japanese Orthopedic Assos-
iation (JOA) score system for cervical myelopathy at the
preoperative stage and final follow-up (at least one year af-
ter surgery). The recovery rate (RR) of the JOA score was
calculated using the Hirabayashi’s method\(^10\).

Radiological assessments

Standing plain radiographs (anteroposterior, neutral lat-
eral, flexion, and extension) of the cervical spine were ob-
tained at the preoperative stage and final follow-up. A neu-
ral lateral radiograph was obtained with patients in a com-
fortable standing position facing forward for horizontal gaze.
The C2-C7, C2-C5, and C5-C7 angles were obtained by
measuring the tangential lines along the posterior borders of
the C2 and C7, C2 and C5, or C5 and C7 vertebral bodies.
The C7 slope was measured as the angle between the supe-
rior end plate of C7 and a horizontal line. Due to difficulties
measuring the T1 slope in many patients, we used the C7
slope instead\(^11,12,13\). The C2-C7 sagittal vertical axis (SVA)
was measured as the distance between the C2 plumb line
and the posterior superior corner of the C7 vertebral body.
The difference in C2-C7 angle during flexion and extension
was determined as the cervical ROM. Magnetic resonance
imaging (MRI) of the cervical spine was obtained pre- and
postoperatively (i.e., at least three months after surgery). The
postoperative spinal cord clearance (PSCC) from the anterior
compression factors was measured as the distance between
the posterior margin of the largest anterior compression fac-
tor (i.e., vertebral disk, bony spur, or OPLL) and the nearest
point of the anterior margin of the spinal cord on postopera-
tive T2-weighted mid-sagittal MRI. The presence of postop-
erative residual spinal cord compression by the anterior
Table 1. Patients’ Characteristics.

|                                | CSM   | OPLL-S | OPLL-O | p-value |
|--------------------------------|-------|--------|--------|---------|
| Number of cases                | 114   | 44     | 77     |         |
| Age at surgery                 | 63.0±12.4 | 60.7±11.2 | 63.7±9.6 | 0.361   |
| Sex (male, %)                  | 72.8  | 77.3   | 72.7   | 0.830   |
| JOA score                      |       |        |        |         |
| Preop.                         | 11.3±2.3 | 11.6±2.6 | 11.7±2.5 | 0.330   |
| Postop.                        | 13.8±2.2 | 13.9±2.0 | 13.3±2.0 | 0.163   |
| RR (%)                         | 46.1±28.0 | 40.2±29.7 | 26.8±30.3 | <0.001  |
| Surgical factors               |       |        |        |         |
| The number of CLs surgically treated | 3.3±0.5 | 3.4±0.6 | 3.6±0.6 | 0.001   |
| Operation time (min)           | 143.9±34.2 | 146.9±32.9 | 162.9±41.1 | 0.002   |
| Blood loss (g)                 | 8.4±26.0 | 21.6±52.2 | 15.8±36.8 | 0.128   |
| Operative levels (%)           |       |        |        | 0.012   |
| C3-C5                          | 7.0   | 4.5    | 2.6    |         |
| C4-C6                          | 63.2  | 59.1   | 37.7   |         |
| C5-C7                          | 0.9   | 2.3    | 1.3    |         |
| C3-C6                          | 23.7  | 22.7   | 44.2   |         |
| C4-C7                          | 2.6   | 4.5    | 6.5    |         |
| C3-C7                          | 2.6   | 6.8    | 7.8    |         |
| Operative levels including C6 (%) | 93.0  | 95.5   | 97.4   | 0.389   |
| Operative levels including C7 (%) | 6.1   | 13.6   | 15.6   | 0.090   |

CSM, cervical spondylotic myelopathy; OPLL-S, ossification of posterior longitudinal ligament, segmental type; OPLL-O, ossification of posterior longitudinal ligament, other types; JOA, Japanese Orthopedic Association; RR, recovery rate; CLs, consecutive laminae

Compression factors was assessed on postoperative T2-weighted sagittal MRI. OPLL was defined as ossification of the posterior longitudinal ligament with a thickness of more than 2 mm in the axial image of the myelogram-CT. Osteophytes located at the corners of the vertebrae or near the uncovertebral joint were not considered to be OPLL. OPLL was classified into four types (i.e., continuous, segmental, mixed, and localized) on the basis of the criteria previously reported. In this study, based on the motion preservation at the intervertebral level, we divided OPLL into OPLL-S and OPLL-O (i.e., continuous, mixed, and localized). In OPLL-S, ossifications were observed only behind the vertebral body and extended ossifications were not observed along the posterior margin of both the vertebral body levels and the intervertebral disc levels in the myelogram-CT. Four independent spine surgeons analyzed the images using a DICOM viewer (Synapse version 4.1.0; FUJIFILM Medical, Tokyo, Japan).

Statistical analysis

Comparisons of each independent variable between the CSM, OPLL-S, and OPLL-O groups were performed using an analysis of variance and Tukey’s honest significant difference test or Games-Howel’s post hoc test for continuous variables, and the chi-squared test or Kruskal-Wallis test for discrete variables. The correlation analyses were performed using Pearson’s correlation coefficient for continuous variables and Spearman’s correlation coefficient for discrete variables. We considered statistically significant correlation with \( r \) values > 0.20. All statistical analyses were performed using SPSS software (version 22.0; IBM Corporation, Armonk, NY, USA). Means ± standard deviations were used to describe continuous variables. A \( p \)-value < 0.05 was considered statistically significant.

Results

Characteristics of patients in CSM, OPLL-S, and OPLL-O groups

This study involved 235 patients (173 males and 62 females). The mean follow-up period was 30.7 ± 15.0 months. Patients were divided into the following three groups: CSM, OPLL-S, and OPLL-O. The RR of the JOA score was lower for those in the OPLL-O group than in the CSM (\( p < 0.001 \)) or OPLL-S (\( p = 0.041 \)) group. The number of CLs surgically treated was greater in the OPLL-O than in the CSM group (\( p < 0.001 \)). The operation time was longer in the OPLL-O than in the CSM group (\( p = 0.002 \)). The operative levels were significantly different between the OPLL-O and CSM groups (\( p = 0.012 \)). C4-C6 SL was more frequently performed in the CSM group (adjusted residuals = 2.7) than in the OPLL-O group (adjusted residuals = −3.5). On the other hand, C3-C6 SL was more frequently performed in the OPLL-O group (adjusted residuals = 3.2) than in the CSM group (adjusted residuals = −2.1). No significant differences existed in other patient characteristics among the three groups (Table 1).
Patients in the CSM group had a greater lordotic C2-C5 angle than did those in the OPLL-S group pre- (<i>p</i> = 0.024) and postoperatively (<i>p</i> = 0.019). Although a greater postoperative C7 slope was observed in the OPLL-O than in the CSM group (<i>p</i> = 0.032), the postoperative C2-C7 angle was comparable among the three groups (<i>p</i> = 0.383). A greater C7 slope minus C2-C7 angle was observed in the OPLL-O group than in CSM group pre- (<i>p</i> = 0.041) and postoperatively (<i>p</i> = 0.002). Preoperative C2-C7 SVA was greater in the OPLL-O group than in the CSM group (<i>p</i> = 0.019). Postoperative C2-C7 SVA was greater in the OPLL-O group than in the CSM and OPLL-S groups (<i>p</i> = 0.001 and <i>p</i> = 0.017, respectively). Cervical ROM was worse in the OPLL-O group than in CSM group pre- (<i>p</i> = 0.022) and postoperatively (<i>p</i> = 0.010). PSCC was narrower in the OPLL-O group than in the CSM and OPLL-S groups (<i>p</i> < 0.001 and <i>p</i> = 0.002, respectively). Consistently, more patients with postoperative residual spinal cord compression were observed in the OPLL-O group (adjusted residuals = 4.6) than in the CSM group (adjusted residuals = −2.8) (<i>p</i> < 0.001; Table 2, 3).

### Correlation of RR of JOA score and C7 slope minus C2-C7 angle with postoperative decompression factors

The RR of JOA score was correlated with postoperative residual spinal cord compression (<i>r</i> = −0.305, <i>p</i> < 0.001). The pre- and postoperative C7 slope minus C2-C7 angle were correlated with PSCC (<i>r</i> = −0.207, <i>p</i> = 0.001 and <i>r</i> = −0.238, <i>p</i> < 0.001, respectively; Table 4).

### Case presentation

A 42-year-old man (of the OPLL-O group) underwent C3-C6 SL (Fig. 1). A postoperative increase in C2-C7 SVA and C7 slope minus C2-C7 angle were observed. The RR of JOA score was 0%.

### Discussion

The current study revealed that the patients with OPLL-O had a larger C7 slope, larger C2-C7 SVA, and greater mismatch between C7 slope and C2-C7 angle. Due to the limited lordotic compensation, a greater cervical sagittal balance mismatch was detected in OPLL-O. The PSCC was narrower, and more postoperative residual spinal cord compression was observed in OPLL-O patients. A correlation between cervical sagittal balance mismatch and PSCC was detected. Surgical outcomes were slightly worse among

---

**Table 2.** Patients’ Radiological Parameters.

|                  | CSM       | OPLL-S    | OPLL-O    | <i>p</i>-value |
|------------------|-----------|-----------|-----------|----------------|
| C2-C7 angle (°)  |           |           |           |                |
| Preop.           | 12.6±13.2 | 8.6±10.4  | 11.2±11.2 | 0.177          |
| Postop.          | 13.1±12.9 | 10.3±10.7 | 11.9±10.9 | 0.383          |
| C2-C5 angle (°)  |           |           |           |                |
| Preop.           | 8.0±11.6  | 2.9±10.5  | 6.3±10.2  | 0.032          |
| Postop.          | 12.6±12.0 | 7.3±10.4  | 9.1±8.9   | 0.012          |
| C5-C7 angle (°)  |           |           |           |                |
| Preop.           | 4.8±8.7   | 5.7±6.5   | 4.7±7.8   | 0.794          |
| Postop.          | 0.4±9.7   | 2.8±7.7   | 3.0±8.6   | 0.103          |
| C7 slope (°)     |           |           |           |                |
| Preop.           | 23.4±8.7  | 22.3±7.2  | 25.3±9.1  | 0.135          |
| Postop.          | 23.2±9.1  | 22.7±7.9  | 26.6±9.8  | 0.020          |
| C7 slope minus C2-C7 angle (°) |       |           |           |                |
| Preop.           | 10.7±9.9  | 13.6±8.6  | 14.1±9.0  | 0.034          |
| Postop.          | 10.1±9.5  | 12.4±9.2  | 14.8±8.4  | 0.002          |
| C2-C7 SVA (mm)   |           |           |           |                |
| Preop.           | 21.9±15.8 | 22.5±13.2 | 27.9±15.0 | 0.021          |
| Postop.          | 24.8±15.8 | 25.2±14.3 | 33.5±17.1 | 0.001          |
| Cervical ROM (°) |           |           |           |                |
| Preop.           | 35.1±12.7 | 30.5±11.6 | 30.4±10.6 | 0.012          |
| Postop.          | 27.6±11.2 | 25.0±10.4 | 22.9±10.6 | 0.013          |
| PSCC from the anterior compression factors (mm) |       |           |           |                |
| Preop.           | 1.3±0.9   | 1.3±1.2   | 0.6±1.2   | <0.001         |
| Postoperative residual spinal cord compression (%) | 1.8     | 0         | 16.9      | <0.001         |

CSM, cervical spondylotic myelopathy; OPLL-S, ossification of posterior longitudinal ligament, segmental type; OPLL-O, ossification of posterior longitudinal ligament, other types; SVA, sagittal vertical axis; ROM, range of motion; PSCC, postoperative spinal cord clearance.
OPLL-O patients, correlating with postoperative residual spinal cord compression.

In the current study, although the postoperative C7 slope was greater in the OPLL-O than in the CSM group, the postoperative C2-C7 angle was comparable among the three groups. T1 (C7) slope minus C2-C7 angle is considered the cervical analog to the pelvic incidence minus lumbar lordosis mismatch. A higher T1 (C7) slope minus C2-C7 angle, therefore, demonstrates uncompensated cervical alignment or cervical kyphosis. A greater C7 slope minus C2-C7 angle, as well as a greater C2-C7 SVA, were observed in the OPLL-O group, suggesting that the cervical alignment was not well compensated in OPLL-O patients. Limited cervical lordotic compensation in the OPLL-O group caused greater cervical sagittal balance mismatch. As a reduced cervical ROM was observed in OPLL-O patients, we suggest that a decrease in ROM at the intervertebral level caused the limited lordotic compensation. Interestingly, OPLL-O patients had narrower PSCC and more postoperative residual spinal cord compression. Because the postoperative residual spinal cord compression was negatively correlated with the RR of JOA score, it affected the functional recovery in OPLL-O patients. Furthermore, C7 slope minus C2-C7 angle was negatively correlated with PSCC. These findings indicate that the cervical sagittal balance mismatch negatively influenced the degree of spinal cord decompression. Subsequently, the postoperative residual spinal cord compression affected functional recovery.

The number of CLs surgically treated was greater in the OPLL-O than in the CSM group. The operative levels were also significantly different between the OPLL-O and CSM groups. While C4-C6 SL (three CLs surgically treated) was more frequently performed in CSM patients, C3-C6 SL (four CLs surgically treated) was more frequently performed in OPLL-O patients. Compared with the CSM group, the OPLL-O group required more CLs decompression. Previous studies reported that dissection of the nuchal ligament that is attached to the C7 spinous process affected axial pain after laminoplasty. Another study demonstrated that the preserved funicular section of the nuchal ligament attached both to the C6 and C7 spinous processes played a crucial role in preventing loss of cervical lordosis after laminoplasty. In the current study, since the proportion of operative levels including C6 or C7 was not different among the three groups, surgical invasion of C6 or C7 did not affect our results.

This study has some limitations. The first limitation concerns the relatively small size of the retrospective sample, which included selection bias. In addition, the results may

| Table 3. p-values of Patients’ Radiological Parameters between Two Groups. |
|-----------------------------------------------|
| p-value | |
| Preop. C2-C5 angle | |
| CSM vs. OPLL-S | 0.024 |
| CSM vs. OPLL-O | 0.546 |
| OPLL-S vs. OPLL-O | 0.225 |
| Postop. C2-C5 angle | |
| CSM vs. OPLL-S | 0.019 |
| CSM vs. OPLL-O | 0.050 |
| OPLL-S vs. OPLL-O | 0.627 |
| Postop. C7 slope | |
| CSM vs. OPLL-S | 0.940 |
| CSM vs. OPLL-O | 0.032 |
| OPLL-S vs. OPLL-O | 0.059 |
| Preop. C7 slope minus C2-C7 angle | |
| CSM vs. OPLL-S | 0.198 |
| CSM vs. OPLL-O | 0.041 |
| OPLL-S vs. OPLL-O | 0.957 |
| Postop. C7 slope minus C2-C7 angle | |
| CSM vs. OPLL-S | 0.321 |
| CSM vs. OPLL-O | 0.002 |
| OPLL-S vs. OPLL-O | 0.348 |
| Preop. C2-C7 SVA | |
| CSM vs. OPLL-S | 0.967 |
| CSM vs. OPLL-O | 0.019 |
| OPLL-S vs. OPLL-O | 0.144 |
| Postop. C2-C7 SVA | |
| CSM vs. OPLL-S | 0.987 |
| CSM vs. OPLL-O | 0.001 |
| OPLL-S vs. OPLL-O | 0.017 |
| Preop. cervical ROM | |
| CSM vs. OPLL-S | 0.075 |
| CSM vs. OPLL-O | 0.022 |
| OPLL-S vs. OPLL-O | 0.999 |
| Postop. cervical ROM | |
| CSM vs. OPLL-S | 0.374 |
| CSM vs. OPLL-O | 0.010 |
| OPLL-S vs. OPLL-O | 0.553 |
| PSCC from the anterior compression factors | |
| CSM vs. OPLL-S | 0.999 |
| CSM vs. OPLL-O | <0.001 |
| OPLL-S vs. OPLL-O | 0.002 |

CSM, cervical spondylotic myopathy; OPLL-S, ossification of posterior longitudinal ligament, segmental type; OPLL-O, ossification of posterior longitudinal ligament, other types; SVA, sagittal vertical axis; ROM, range of motion; PSCC, postoperative spinal cord clearance

| Table 4. Correlation of RR of JOA Score and C7 Slope Minus C2-C7 Angle with Postoperative Decompression Factors. |
|-----------------------------------------------|
| p-value | |
| RR of JOA score vs. | |
| PSCC from the anterior compression factors | 0.191 | 0.003 |
| Postoperative residual spinal cord compression | −0.305 | <0.001 |
| Preop. C7 slope minus C2-C7 angle vs. | |
| PSCC from the anterior compression factors | −0.207 | 0.001 |
| Postoperative residual spinal cord compression | 0.090 | 0.169 |
| Postop. C7 slope minus C2-C7 angle vs. | |
| PSCC from the anterior compression factors | −0.238 | <0.001 |
| Postoperative residual spinal cord compression | 0.090 | 0.168 |

RR, recovery rate; JOA, Japanese Orthopedic Association; PSCC, postoperative spinal cord clearance
Figure 1. Case presentation.
A 42-year-old man (of the OPLL-O group) underwent a C3-C6 SL. The preoperative JOA score, postoperative JOA score, and RR of JOA score were 13, 13, and 0%. a: The preoperative C2-C7 angle, C7 slope, C7 slope minus C2-C7 angle, and C2-C7 SVA were 4.2°, 18.0°, 13.8°, and 20.6 mm, respectively. b: The one-year postoperative C2-C7 angle, C2-C7 angle, C7 slope, C7 slope minus C2-C7 angle, and C2-C7 SVA were −5.3°, 18.1°, 23.4°, and 27.9 mm, respectively. Note that a postoperative increase in C2-C7 SVA (+7.9 mm) and C7 slope minus C2-C7 angle (+9.6°) were observed.

have been influenced by several confounding factors. As the full-length spine radiograph was not obtained, we could not examine the relationship of cervical parameters with thoracolumbar or spinopelvic parameters. Finally, because we did not acquire the health-related quality of life outcomes, we could not evaluate the influence of cervical sagittal alignment on these.

Conclusion

Limited cervical lordotic compensation in OPLL-O patients causes greater cervical sagittal balance mismatch after SL. It negatively affects the degree of spinal cord decompression, which might be related to functional recovery.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Author Contributions: Conception and design: Nori. Acquisition of data: Nori, Aoyama, Ninomiya, Suzuki. Analysis and interpretation of data: Nori. Drafting the article: Nori. Statistical analysis: Nori. Study supervision: Aoyama, Anazawa, Shiraishi. Reviewed submitted version of manuscript: Nori, Aoyama, Ninomiya, Suzuki, Anazawa, Shiraishi.

Informed Consent: Informed consent was obtained from all participants in this study.

References
1. Tang JA, Scheer JK, Smith JS, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery. 2012;71(3):662-9.
2. Oe S, Togawa D, Nakai K, et al. The influence of age and sex on cervical spinal alignment among volunteers aged over 50. Spine. 2015;40(19):1487-94.
3. Protopsaltis TS, Scheer JK, Terran JS, et al. How the neck affects the back: changes in regional cervical sagittal alignment correlate to HRQOL improvement in adult thoracolumbar deformity patients at 2-year follow-up. J Neurosurg Spine. 2015;23(2):153-8.
4. Nunez-Pereira S, Hitzl W, Bullmann V, et al. Sagittal balance of the cervical spine: an analysis of occipitocervical and spinopelvic interdependence, with C-7 slope as a marker of cervical and spinopelvic alignment. J Neurosurg Spine. 2015;23(1):16-23.
5. Ames CP, Blondel B, Scheer JK, et al. Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. Spine. 2013;38(22 Suppl 1):S149-60.
6. Chen Y, Luo J, Pan Z, et al. The change of cervical spine alignment along with aging in asymptomatic population: a preliminary analysis. Eur Spine J. 2017.
7. Nori S, Shiraishi T, Aoyama R, et al. Extremely high preoperative C7 slope limits compensatory cervical lordosis after muscle-preserving selective laminectomy. Eur Spine J. 2018;27(8):2029-
8. Nori S, Shiraiishi T, Aoyama R, et al. Muscle-Preserving selective laminectomy maintained the compensatory mechanism of cervical lordosis after surgery. Spine. 2018;43(8):542-9.
9. Shiraiishi T, Kato M, Yato Y, et al. New techniques for exposure of posterior cervical spine through intermuscular planes and their surgical application. Spine. 2012;37(5):E826-96.
10. Shiraiishi T, Fukuda K, Yato Y, et al. Results of skip laminectomy-minimum 2-year follow-up study compared with open-door laminoplasty. Spine. 2003;28(24):2667-72.
11. Matsunaga S, Sakou T. Ossification of the posterior longitudinal ligament of the cervical spine: etiology and natural history. Spine. 2012;37(5):E309-14.
12. Iwasaki M, Kawaguchi Y, Kimura T, et al. 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. 2002;96(2 Suppl):180-9.
13. Tsuyama N. Ossification of the posterior longitudinal ligament of the spine. Clin Orthop Relat Res. 1984;184:71-84.
14. White AA, 3rd, Johnson RM, Panjabi MM, et al. Biomechanical analysis of clinical stability in the cervical spine. Clin Orthop Relat Res. 1975;109:85-96.
15. Fujimori T, Iwasaki M, Okuda S, et al. Long-term results of cervical myelopathy due to ossification of the posterior longitudinal ligament of the cervical spine: more than 20 years follow up. J Neurosurg. 2008;108(2 Suppl):180-9.
16. Hirabayashi K, Miyakawa J, Satomi K, et al. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine. 1981;6(4):354-64.
17. Sakai K, Yoshii T, Hirai T, et al. Cervical sagittal imbalance is a predictor of kyphotic deformity after laminoplasty in cervical spondylotic myelopathy patients without preoperative kyphotic alignment. Spine. 2016;41(4):299-305.
18. Sakai K, Yoshii T, Hirai T, et al. Impact of the surgical treatment for degenerative cervical myelopathy on the preoperative cervical sagittal balance: a review of prospective comparative cohort between anterior decompression with fusion and laminoplasty. Eur Spine J. 2017;26(1):104-12.
19. Fujimori T, Le H, Hu SS, et al. Ossification of the posterior longitudinal ligament of the cervical spine in 3161 patients: a CT-based study. Spine. 2015;40(7):E394-403.
20. Lee CK, Shin DA, Yi S, et al. Correlation between cervical spine sagittal alignment and clinical outcome after cervical laminoplasty for ossification of the posterior longitudinal ligament. J Neurosurg Spine. 2016;24(1):100-7.
21. Kim B, Yoon DH, Ha Y, et al. Relationship between T1 slope and loss of lordosis after laminoplasty in patients with cervical ossification of the posterior longitudinal ligament. The spine journal: official journal of the North American Spine Society. 2016;16(2):219-25.
22. Ames CP, Smith JS, Eastlack R, et al. Reliability assessment of a novel cervical spine deformity classification system. J Neurosurg Spine. 2015;23(6):673-83.
23. Hosono N, Sakaura H, Mukai Y, et al. C3-6 laminoplasty takes over C3-7 laminoplasty with significantly lower incidence of axial neck pain. Eur Spine J. 2006;15(9):1375-9.
24. Ono A, Tonosaki Y, Yokoyama T, et al. Surgical anatomy of the nuchal muscles in the posterior cervicothoracic junction: significance of the preservation of the C7 spinous process in cervical laminoplasty. Spine. 2008;33(11):E439-54.
25. Takeuchi T, Shono Y. Importance of preserving the C7 spinous process and attached nuchal ligament in French-door laminoplasty to reduce postoperative axial symptoms. Eur Spine J. 2007;16(9):1417-22.
26. Sakaura H, Hosono N, Mukai Y, et al. Preservation of the nuchal ligament plays an important role in preventing unfavorable radiologic changes after laminoplasty. J Spinal Disord Tech. 2008;21(5):338-43.