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

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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 ≥ 3 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

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Introduction

Cervical sagittal alignment has been investigated as a crucial determinant of surgical and radiological outcomes after cervical spine surgery[1-3]. C7 slope behaves as an important marker of the sagittal spinal alignment, linking the occipitocervical and thoracolumbar spine[4]. To adjust cervical sagittal alignment or horizontal gaze, lordotic change of C2-C7 angle occurs when C7 slope increases[5-8]. 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[8-10]. It has been reported that SL preserves the compen-

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satory mechanism of cervical lordosis after surgery for cervical spondylotic myelopathy (CSM) and ossification of the posterior longitudinal ligament (OPLL), segmental type (OPLL-S)[8].

OPLL is a hyperostotic condition resulting from the ectopic calcification of the posterior longitudinal ligament[11]. The OPLL patients with kyphotic cervical spine, or postoperative changes in cervical alignment from lordotic to straight, tend to have poor surgical outcomes after laminoplasty[12]. 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, segmental, mixed, and localized[13]. In the current study, based on the motion preservation at the intervertebral level, we divided 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 patients with CSM, OPLL-S, and OPLL-O, and evaluate the influence of the compensatory mechanism on functional outcomes.

Materials and Methods

Subjects

Between January 2010 and March 2017, 891 consecutive patients underwent SL for CCM at a single academic institution. SL was not performed for patients who had 1) a local kyphosis of >20°, 2) spondylolisthesis of >3.5 mm[14], or 3) an OPLL occupancy ratio of >60%[15]. Patients who presented with radiculopathy without myelopathy patients who had undergone foraminotomy or previous surgery for cervical spine, and patients who had undergone treatment for spinal tumors, trauma, or infection were excluded. Preoperatively, 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 ≥ 3 consecutive laminae (CLs) were selected. The most cranial laminectomy level was C3 and the most caudal level was C7. The study involved 235 CCM patients 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[7-10]. 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 fragments of the split C4, C5, C6, and C7 spinous processes were sutured together.

Prior to surgery, cervical myelogram-CT with the patients' necks in neutral and extended positions was performed, and the results were assessed. We determined the decompression laminae through the obstruction of the subarachnoid 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[7,8]. Normally, the mean laminectomy width was 15-19 mm. Bilateral facet joints were never exposed during surgery.

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 Association (JOA) score system for cervical myelopathy at the preoperative stage and final follow-up (at least one year after surgery). The recovery rate (RR) of the JOA score was calculated using the Hirabayashi's method[16].

Radiological assessments

Standing plain radiographs (anteroposterior, neutral lateral, flexion, and extension) of the cervical spine were obtained at the preoperative stage and final follow-up. A neutral lateral radiograph was obtained with patients in a comfortable 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 superior end plate of C7 and a horizontal line. Due to difficulties measuring the T1 slope in many patients, we used the C7 slope instead[7,8,17,18]. 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 factor (i.e., vertebral disk, bony spur, or OPLL) and the nearest point of the anterior margin of the spinal cord on postoperative T2-weighted mid-sagittal MRI. The presence of postoperative 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[19]. 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[13]. 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).

Table 2. Patients' Radiological Parameters.

	CSM	OPLL-S	OPLL-O	*p*-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)	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

Radiological parameters of patients in CSM, OPLL-S, and OPLL-O groups

Patients in the CSM group had a greater lordotic C2-C5 angle than did those in the OPLL-S group pre- ($p = 0.024$) and postoperatively ($p = 0.019$). Although a greater postoperative C7 slope was observed in the OPLL-O than in the CSM group ($p = 0.032$), the postoperative C2-C7 angle was comparable among the three groups ($p = 0.383$). A greater C7 slope minus C2-C7 angle was observed in the OPLL-O group than in CSM group pre- ($p = 0.041$) and postoperatively ($p = 0.002$). Preoperative C2-C7 SVA was greater in the OPLL-O group than in the CSM group ($p = 0.019$). Postoperative C2-C7 SVA was greater in the OPLL-O group than in the CSM and OPLL-S groups ($p = 0.001$ and $p = 0.017$, respectively). Cervical ROM was worse in the OPLL-O group than in CSM group pre- ($p = 0.022$) and postoperatively ($p = 0.010$). PSCC was narrower in the OPLL-O group than in the CSM and OPLL-S groups ($p < 0.001$ and $p = 0.002$, 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) ($p < 0.001$; 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 ($r = -0.305$, $p < 0.001$). The pre- and postoperative C7 slope minus C2-C7 angle were correlated with PSCC ($r = -0.207$, $p = 0.001$ and $r = -0.238$, $p < 0.001$, 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 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 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[7,20-22]. A higher T1 (C7) slope minus C2-C7 angle, therefore, demonstrates uncompensated cervical alignment or cervical kyphosis[7,21,22]. 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.

Table 4. Correlation of RR of JOA Score and C7 Slope Minus C2-C7 Angle with Postoperative Decompression Factors.

	r	*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

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[23-25]. 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[26]. 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

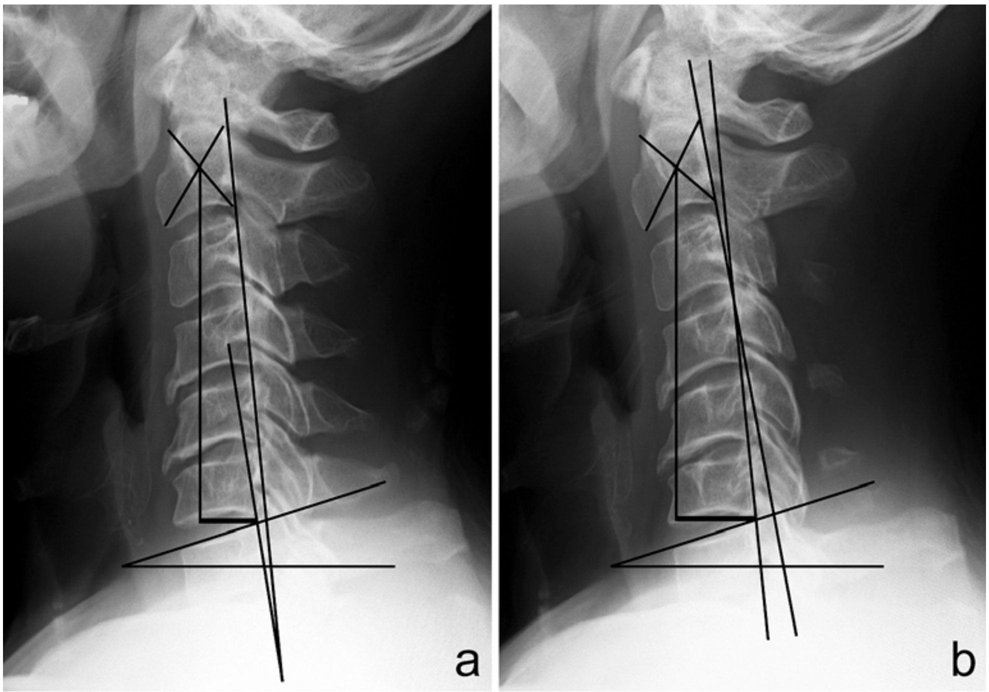

Figure 1. Case presentation.
A 42-year-old man (of the OPLL-O group) underwent a C3-C6 SL. The preoperative JOA score, postoperative JOA score, and RR of JOA score were 13, 13, and 0%. a: The preoperative C2-C7 angle, C7 slope, C7 slope minus C2-C7 angle, and C2-C7 SVA were 4.2°, 18.0°, 13.8°, and 20.6 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.

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