ABSTRACT

Objective: Ossification of the posterior longitudinal ligament (OPLL) can progress even after cervical spine surgery and may cause neurological injury as a result of minor trauma. The purpose of this study was to investigate the preventive factors associated with OPLL progression after anterior cervical discectomy and fusion (ACDF), a procedure commonly performed in clinical practice.

Methods: We retrospectively investigated 295 male soldiers who underwent ACDF surgery between 2012 and 2017. Patients who were followed up for >12 months using dynamic radiography and computed tomography (CT) were included in the study. Radiological parameters investigated included OPLL progression, C2-C7 angles on dynamic radiography, segmental angles, C2-C7 cervical sagittal vertical axis (C2-C7 SV A), and the T1 slope. These parameters were measured preoperatively and 1 year postoperatively.

Results: A total of 49 patients were enrolled, and 10 patients were confirmed to have OPLL progression. Comparison between the OPLL progression and non-progression groups showed no statistically significant differences in pre- and postoperative cervical range of motion. However, statistically significant differences were observed in the postoperative neutral C2-C7 angle (progression −3.9°±6.4° vs. non-progression −13.4°±7.9°, p=0.001) and the SV A change (progression 5.8±7.9 mm vs. non-progression −3.7±6.3 mm, p=0.00). The cutoff values were −8.01° for the postoperative neutral C2-C7 angle and 1.4 mm for SV A changes.

Conclusion: Increased SV A (>1.4 mm) and a small postoperative neutral C2-C7 angle (<−8.01°) 1 year after ACDF were associated with OPLL progression. It is important to be mindful of these factors during follow-up after ACDF, because additional surgical treatment may be necessary for OPLL progression due to neurological injury caused by minor trauma.

Keywords: Spine; Cervical vertebrae; Lordosis; Ossification of posterior longitudinal ligament; Disease progression
INTRODUCTION

Ossification of the posterior longitudinal ligament (OPLL) is a condition of abnormal ectopic calcification of the posterior longitudinal ligament (PLL).\(^5\) The incidence of OPLL is 2.4% in Asians and occurs predominantly in the cervical spine, mostly between the C2 and C4 vertebrae.\(^{39}\) Cervical OPLL can cause spinal canal stenosis and spinal cord compression by gradually increasing calcium deposition in the PLL in the transverse or longitudinal direction, which can lead to neurological damage such as myelopathy.\(^{49}\) This can also lead to the unexpected development of new symptoms from even minor trauma such as fall onto the ground level.\(^{20}\)

Anterior decompression with or without fusion and posterior decompression, such as laminectomy or laminoplasty, has been reported for the treatment of cervical OPLL.\(^{8}\) Laminoplasty is the favored treatment for posterior decompression\(^{22,24}\) as radiographic progression of OPLL after laminoplasty in long-term follow-up has been demonstrated\(^{17}\) with several studies suggesting that OPLL progression after laminoplasty can be attributed to its ability to preserve ROM in the cervical spine.\(^{12,16,17,26,40}\)

Also, OPLL progression is associated with younger age (<40 years), multiple vertebral level involvement, mixed-type and continuous-type OPLL, and excessive range of motion.\(^{4,6,11,12}\)

Although postoperative OPLL progression in anterior decompression with fusion (ADF) is lower than that in laminoplasty,\(^{6,34}\) it can progress after ADF. Due to its low incidence, only a few cases have been reported, and most studies have reported corpectomy or hybrid (corpectomy and fusion) cases compared to laminoplasty.\(^{15,31,34}\) There is no literature that analyzes the risk factors for OPLL progression after anterior cervical discectomy and fusion (ACDF) alone, as it is one of the methods of ADF.

Therefore, the purpose of this study is to find preventive factors for the OPLL progression after ACDF in terms of preventing the progression of myelopathy in advance, in association with the changes of cervical motion range and posture.

MATERIALS AND METHODS

After obtaining approval from the Institutional Review Board (IRB) of the Armed Forces Capital Hospital (2022-01-005-001), we retrospectively reviewed the medical records of patients who underwent ACDF between June 2012 and December 2017 at our institution.

The impact of the data used in our study presented minimal risk to the study participants. It was also difficult to obtain complete consent from all participants to conduct the research. The analysis of only those participants who consented was judged to have a serious effect on the validity of the study, and exemption was obtained from the IRB.

Patient enrollment
We performed a retrospective survey of 295 patients who underwent ACDF.

The ACDF indications were as follows: 1) radiculopathy with intractable axial pain, 2) progressive motor weakness, and 3) myelopathy with herniated intervertebral disc confirmed by MRI or with OPLL resulting in central stenosis.
The inclusion criteria were as follows: 1) patients who underwent ACDF, 2) follow-up of >12 months, 3) preoperative and 12-month postoperative dynamic cervical radiography, and 4) postoperative follow-up computed tomography (CT) taken after >24 months.

The exclusion criteria were as follows: 1) follow-up loss within 12 months, 2) no cervical dynamic X-ray preoperative or 12-month postoperative, 3) invisible C7 on cervical dynamic radiography, and 4) no follow-up CT after 24 months postoperative.

Among 295 patients, 49 were enrolled in the study. The enrolled patients were divided into 2 groups: 10 and 39 patients in the OPLL progression and non-progression groups, respectively.

**Surgical procedure and postoperative management**
ACDF was performed using the Smith-Robinson approach. The symptomatic discs, osteophytes, and OPLL were removed to achieve sufficient decompression. After discectomy, cervical implants were inserted into the intervertebral disc space; C7 cage (polyetheretherketone; Medyssey Co. Ltd., Dongducheon, Korea), or Cornerstone cage (polyetheretherketone; Medtronic Sofamor-Danek, Memphis, TN, USA), or Cervios ChronOS cervical cage (polyetheretherketone; Synthes, West Chester, PA, USA) were used and filled with allobone chips and demineralized bone matrix (DBM).

After implantation, vertebral bodies were fixed with plates and screws; a skyline anterior cervical plate and screw (Johnson and Johnson Professional, Inc., Raynham, MA, USA) and Atlantis Cervical Plate System (Medtronic, Memphis, TN, USA) were used.

All patients started walking after wearing a cervical orthosis on postoperative day 1. Pain control was achieved with nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, and tramadol postoperatively. A cervical orthosis was applied to all patients after ACDF, and the average duration of application was 5.7±2.4 months.

**Radiologic evaluation**
All patients were evaluated using preoperative static and dynamic cervical radiography and CT. Static and dynamic cervical radiographs were obtained 12 months postoperatively, and follow-up cervical CT was performed >24 months postoperatively.

OPLL was evaluated using preoperative and postoperative CT according to the conventional classification. The definition of OPLL progression was divided into two groups: vertical length and thickness. Vertical growth >2 mm and thickness growth >1 mm were defined as vertical and thickness progression, respectively.

The levels of OPLL progression were classified into index levels, upper than index levels, and lower than index level. The index level was defined as the posterior space behind the vertebral body and intervertebral disc space of the surgical site.

The cervical sagittal alignments were measured before surgery and >12 months postoperatively on static and dynamic radiographs for changes in the cervical spine; T1 slope (T1S), C2-C7 sagittal vertical alignment (SVA), C2-C7 angle in neutral, flexion, and extension positions, and C2-C7 segmental angles in neutral, flexion, and extension positions (FIGURE 1). The T1S was defined as the angle between the T1 upper endplate and the horizontal reference line through the midpoint of the T1 upper endplate. C2-C7 SVA is
measured by the distance between the plumb line from the C2 centroid and the posterior C7 upper-end plate. To be clear, lordosis was measured as a negative number and kyphosis was measured as a positive number in this study.

Clinical outcomes
To compare the clinical outcomes of the OPLL progression and non-progression groups, we used immediate preoperative and 24-month postoperative visual analog scale (VAS) scores. While patients showed one or more neurological symptoms of radiculopathy, myelopathy, and motor weakness, all also complained of cervical pain. Only one case showed motor weakness without cervical pain.

Statistical analysis
Data obtained by radiological analysis were analyzed for statistical significance using the Student’s \( t \)-test or Mann-Whitney \( U \) test. Descriptive variables were analyzed using the \( \chi^2 \) test or Fisher’s exact test. The results are presented as the mean±standard deviation. Univariate analyses were performed to determine the association between radiological parameters and OPLL progression after ACDF, using the independent Student’s \( t \)-test for continuous variables. Variables with \( p<0.05 \) in the univariate analysis were used in the multivariate analysis. Adjusted odds ratios (ORs) with 95% confidence intervals are presented with \( p<0.05 \) considered significantly different. We used receiver operating characteristic (ROC) curves to assess the predictability cutoff values.

Interclass and intraclass correlations
All measurements were performed twice at intervals of >2 weeks by one neurosurgeon (JMK), and twice by another neurosurgeon (SHH) blinded to the information of the patients to assess their reliability. The intraobserver and interobserver intraclass correlation coefficients were calculated for mean values.

**FIGURE 1.** Schematic drawings of radiographic parameters to define SVA, T1S, C2-C7 angle. SVA: sagittal vertical axis, T1S: T1 slope.
RESULTS

The incidence of OPLL progression in patients who underwent ACDF surgery during this period (from June 2012 to December 2017) was 3.4% (10/295). Of the 295 patients surveyed, 49 who satisfied the inclusion and exclusion criteria were enrolled for risk factor analysis. The OPLL progression and non-progression groups included 10 and 39 patients, respectively. The mean age of the OPLL progression and non-progression groups was 46.8±5.5 and 46.1±6.3 years \((p=0.75)\), respectively. The body mass index values of both groups were 26.1±2.6 and 25.8±2.8 kg/m\(^2\) \((p=0.79)\), respectively. The mean follow-up period of dynamic X-ray images were 13.7±1.9 months for OPLL progression group and 13.6±1.7 months for non-progression group \((p=0.89)\). There were 8 and 29 smokers in both groups \((p=0.72)\) with no significant differences in demographic data.

OPLL progression occurred at the index level in 6 cases, above the index level in 3 cases, and below the index level in 1 case (TABLE 1).

Radiological measurements

There were no significant differences in the preoperative neutral C2-C7 angle, preoperative T1S, postoperative SVA, or postoperative T1S between the groups. But there were significant differences in the presence of OPLL before surgery (10/10 vs. 25/39, \(p=0.025\)), preoperative SVA (14.0±5.6 mm vs. 20.5±9.2 mm, \(p=0.037\)), preoperative flexion C2-C7 angle (27.0°±6.3° vs. 20.1°±9.5°, \(p=0.034\)), preoperative extension C2-C7 angle (-16.5°±8.4° vs. -25.1°±10.5°, \(p=0.021\)), postoperative neutral C2-C7 angle (-3.9°±6.4° vs. -13.4°±7.9°, \(p=0.001\)), postoperative flexion C2-C7 angle (17.1°±5.2° vs. 9.5°±5.8°, \(p=0.00\)) and postoperative extension C2-C7 angle (-13.0°±10.0° vs. -23.2°±8.2°, \(p=0.001\)) in the OPLL progression and non-progression groups, respectively (TABLE 2).

There was no difference between the two groups in pre-and postoperative cervical range of motion (flexion angle minus extension angle in C2-C7), flexion range of motion (flexion angle minus neutral angle in C2-C7), and extension range of motion (neutral angle minus extension angle in C2-7). In addition, postoperative cervical range of motion changes, flexion

### TABLE 1. Characteristics of patients undergone ACDF with/without OPLL progression after ACDF

| Characteristics                  | OPLL Progression | OPLL Non-progression | p-value |
|----------------------------------|------------------|----------------------|---------|
| Total number of patients         | 10               | 39                   |         |
| Age (yr)                         | 46.8±5.5         | 46.1±6.3             | 0.75    |
| BMI (kg/m\(^2\))                 | 26.1±2.6         | 25.8±2.8             | 0.79    |
| Dynamic X-ray follow-up (months) | 13.7±3.9         | 13.6±1.7             | 0.89    |
| CT follow-up (mon)               | 49.0±18.1        | 41.8±14.5            | 0.19    |
| Smoking (yes/total)              | 8/10             | 29/39                | 0.72    |
| Level of operation               |                  |                      |         |
| C34                              | 2                | 1                    |         |
| C45                              | 6                | 6                    |         |
| C56                              | 7                | 30                   |         |
| C67                              | 3                | 16                   |         |
| C7T1                             | 1                |                      |         |
| Level of progression             |                  |                      |         |
| Index level                      | 6                |                      |         |
| Upper than index level           | 3                |                      |         |
| Lower than index level           | 1                |                      |         |

Values are presented as number or mean±standard deviation. ACDF: anterior cervical discectomy and fusion, OPLL: ossification of the posterior longitudinal ligament, BMI: body mass index, CT: computed tomography.
range of motion changes, extension range of motion changes, and neutral C2-C7 angle changes were not different between the two groups. However, postoperative SVA changes (postoperative SVA minus preoperative SVA) (5.8±7.9 mm vs. −3.7±6.3 mm, p=0.00) were significantly different between the OPLL progression and non-progression groups (TABLE 3).

Clinical outcomes
Most patients suffer from some degree of cervical pain accompanied by one or more radiculopathy, myelopathy, and motor weakness. Average preoperative neck VAS scores were 4.5±0.8 and 4.6±0.8 and arm VAS scores were 5.8±0.4 and 5.7±0.7 in OPLL progression and non-progression group, respectively. 24-month follow-up VAS scores were 1.9±0.7 and 1.7±0.8 in OPLL progression and non-progression group, respectively.

All patients with preoperative neck and arm pain showed improved VAS scores after ACDF, and the preoperative and 24-month postoperative VAS scores did not differ significantly between the 2 groups (TABLE 4).

---

**TABLE 2.** Comparison of radiographic parameters between OPLL progression and non-progression group in pre- and post-operative cervical X-rays

| Parameters                                | OPLL Progression | OPLL Non-progression | p-value |
|-------------------------------------------|------------------|----------------------|---------|
| Presence of OPLL before surgery (yes/total) | 10/10            | 25/39                | 0.025   |
| Pre-operative neutral C2-C7 angle (°)     | −3.8±8.7         | −9.4±9.5             | 0.10    |
| Pre-operative SVA (mm)                    | 14.0±5.6         | 20.5±9.2             | 0.037   |
| Pre-operative T1S (°)                     | 24.9±4.1         | 27.0±5.5             | 0.47    |
| Pre-operative extension C2-C7 angle (°)   | −16.5±8.4        | −25.1±10.5           | 0.021   |
| Post-operative neutral C2-C7 angle (°)    | −3.9±6.4         | −13.4±7.9            | 0.001   |
| Post-operative SVA (mm)                   | 19.7±7.3         | 16.8±6.8             | 0.24    |
| Post-operative T1S (°)                    | 24.6±4.6         | 27.5±6.0             | 0.32    |
| Post-operative flexion C2-C7 angle (°)    | 17±5.2           | 9.5±5.8              | 0.00    |
| Post-operative extension C2-C7 angle (°)  | −13.0±10.0       | −23.2±8.2            | 0.001   |

Types of OPLL were classified into segmental, continuous, and mixed types. All except 2 patients in the OPLL progression group were segmental types, and there was no statistical difference between the 2 groups. Values are presented as number or mean±standard deviation. OPLL: ossification of the posterior longitudinal ligament, SVA: sagittal vertical axis, T1S: T1 slope.

**TABLE 3.** Comparison of range of motions and SVA between OPLL progression and non-progression group in pre- and post-operative cervical X-rays

| Parameters                                | OPLL Progression | OPLL Non-progression | p-value |
|-------------------------------------------|------------------|----------------------|---------|
| Pre-operative cervical range of motion (°) | 43.5±11.0        | 45.3±12.8            | 0.72    |
| Pre-operative flexion range of motion (°) | 30.9±11.3        | 29.5±9.2             | 0.69    |
| Pre-operative extension range of motion (°) | 12.7±7.2        | 15.7±8.7             | 0.32    |
| Post-operative cervical range of motion (°) | 30.1±10.2      | 33.1±9.3             | 0.39    |
| Post-operative flexion range of motion (°) | 21.0±5.7         | 22.8±9.0             | 0.55    |
| Post-operative extension range of motion (°) | 9.1±8.3          | 9.8±7.5              | 0.81    |
| Post-operative cervical range of motion changes (°) | −13.4±10.7  | −12.0±13.6           | 0.78    |
| Post-operative flexion range of motion changes (°) | −9.8±9.5        | −6.7±11.0            | 0.42    |
| Post-operative extension range of motion changes (°) | −3.6±3.7        | −5.9±10.0            | 0.24    |
| Post-operative neutral C2-C7 angle changes (°) | −0.1±7.0        | −4.1±10.0            | 0.24    |
| Post-operative SVA changes (mm)           | 5.8±7.9          | −3.7±6.3             | 0.00    |

Values are presented as mean±standard deviation. SVA: sagittal vertical axis, OPLL: ossification of the posterior longitudinal ligament.
Univariate and multivariate regression analyses
Univariate analyses were initially performed for the factors investigated to determine the relationship between the progression of OPLL after ACDF and changes in cervical motion range and posture.

Postoperative neutral C2–C7 angle, SVA, cervical range of motion changes, flexion range of motion changes, extension range of motion changes, neutral C2–C7 angle changes, and SVA changes were included in the univariate and multivariate logistic regression analyses. Multivariate analysis showed that the postoperative neutral C2–C7 angle (OR, 1.192; \( p = 0.034 \)) and postoperative SVA changes (OR, 1.416; \( p = 0.015 \)) were related to OPLL progression after ACDF (TABLE 5).

ROC curve and cutoff values
Multivariate analysis revealed that the significant predictive factors for OPLL progression after ACDF were postoperative neutral C2–C7 angle and SVA changes. The area under the ROC curve (AUC) of the postoperative neutral C2–C7 angle was 0.828 and that of the SVA changes was 0.867.

The AUCs for these two factors were significant. When the cutoff value of the postoperative neutral C2–C7 angle was calculated at \(-8.01^\circ\), and the sensitivity and specificity were 70.0% and 71.8%, respectively. Finally, when the cutoff value of the SVA change was calculated at 1.4 mm, the sensitivity and specificity were 80.0% and 79.5%, respectively (FIGURE 2).

Intraobserver and interobserver reliabilities
For all radiological parameters, the intraobserver correlation coefficient was greater than 0.89 and the interobserver correlation coefficient was greater than 0.80. Therefore, the mean values of the 4 measurements were used in the present study.

| TABLE 5. Univariate and multivariate analysis of OPLL progression after ACDF |
|----------------|----------------|----------------|
| Variables                | Univariate analysis | Multivariate analysis |
|                          | OR (95% CI) | p-value | OR (95% CI) | p-value |
| Post-operative neutral C2–C7 angle (°) | 1.200 (1.056–1.363) | 0.005 | 1.192 (1.014–1.402) | 0.034 |
| Post-operative SVA (mm) | 1.067 (0.959–1.187) | 0.236 |               |       |
| Post-operative cervical range of motion changes (°) | 0.992 (0.939–1.047) | 0.765 |               |       |
| Post-operative flexion range of motion changes (°) | 0.972 (0.910–1.040) | 0.412 |               |       |
| Post-operative extension range of motion changes (°) | 1.032 (0.949–1.122) | 0.459 |               |       |
| Post-operative neutral C2–C7 angle changes (°) | 1.050 (0.968–1.138) | 0.241 |               |       |
| Post-operative SVA changes (mm) | 1.298 (1.073–1.571) | 0.007 | 1.416 (1.070–1.872) | 0.015 |

OPLL: ossification of the posterior longitudinal ligament, ACDF: anterior cervical discectomy and fusion, OR: odds ratio, CI: confidence interval, SVA: sagittal vertical axis.
DISCUSSION

OPLL is a pathological condition that can cause spinal cord compression and neurological deterioration like myelopathy, and even minor trauma can lead to neurological damage. Since neurological deterioration can be caused by OPLL, surgical decompression might be needed, and various surgical approaches can be considered according to the type, number of involved segments, location, and sagittal balance of the cervical spine. Although its pathophysiology remains unknown, OPLL progression has been observed after surgical treatment in several studies. Most of these studies, in terms of surgical methods, were related to laminoplasty, ADF-related studies were rare, and ACDF, as one of the methods of ADF, was much rarer. The overall prevalence of OPLL progression after ADF has been reported to be 5%–14%, and the risk factors for OPLL progression after ADF have been reported as follows: 1) the ADF technique involves floating the ossification of the OPLL, 2) OPLL type, and 3) mechanical stress caused by segmental motion. In addition to the rarity of OPLL progression after ADF, these studies were mainly related to corpectomy or hybrid surgery (corpectomy with fusion). In terms of ACDF cases alone, there is no literature proposing any risk factors for OPLL progression after ACDF.

Although this prevalence is very low compared to the 45-70% prevalence of OPLL progression after laminoplasty, a case has been reported that required additional surgery due to OPLL progression after ACDF.

In our study, the prevalence of OPLL progression after ACDF was 3.4%, and there was one patient who underwent laminoplasty 70 months after ACDF because of OPLL progression (Figure 3). Even after ACDF, spinal cord compression may worsen and cause neurological damage due to OPLL progression. Since even a minor trauma can cause neurological symptoms in patients with OPLL, additional surgery may be required in the future; thus, risk factors should be predicted and prevented.
In our study, it was found that 6 cases were progressed at index level, 3 cases at upper than index level, and 1 case at lower than index level. The OPLL progression at index level was the most common, and it was all located behind the vertebral bodies, and not behind the intervertebral disc space. These OPLL lesions were either not present or could not have been removed at the time of surgery, so these were distinguished from the ectopic bone formation or any bone formation of fusion process. Also, OPLL remaining at index level after surgery may grow due to micro-motion and tensile stress at the operated segment.\(^1,38\)

Although the pathophysiology of OPLL progression is not clear, previous studies have proposed that increased cervical mechanical stress is one of the OPLL progression factors after surgery.\(^9,37\) Matsunaga et al.\(^26\) also proposed that excessive cervical ROM causes increased mechanical stress on PLL. These studies suggest that OPLL progression contributes to excessive cervical ROM after laminoplasty and several studies support this conclusion.\(^12,16,17,26,40\)

However, this conclusion can be understood as the increased mechanical stress triggered by excessive cervical ROM causing OPLL progression rather than cervical ROM itself. This study showed that changes in pre- and postoperative cervical ROM were not significantly different between the OPLL progression and non-progression groups. This was a different result from previous studies that claimed that preservation of ROM was the main cause of OPLL progression after laminoplasty. Therefore, other causes that trigger increased mechanical stress should be investigated.

Rather than cervical ROM, changes in cervical posture over time showed a significant difference between the 2 groups. In the progression group, the SVA gradually increased, whereas in the non-progression group, the SVA decreased. As postoperative cervical kyphotic changes were reported to increase the SVA by moving the center of gravity of C2 forward, more lordotic forces were needed to obtain the horizontal line of the site.\(^29\) In addition, as the SVA increased, the force applied to the neck by the weight of the head increased.
which means that the loading on the cervical spine increased according to the posture (FIGURE 4).

In military, physical activities with heavy tactical equipment, especially on head, can add more weight on the cervical spine. This loading on cervical spine probably make micromovement on adjacent region of surgical level before entirely fused, and these conditions probably lead to OPLL progression. On the other hand, cervical injuries can be followed. Jones et al.\textsuperscript{15} surveyed descriptive epidemiology in the U.S. military. The reason for hospitalization from injuries accounted for 17\% (n=11,591) and conditions treated in outpatient clinics showed that injuries were the most common health problem, at 27\% of all outpatients (n=1,143,846). Cervical spine injuries accounted for 10.2\% of all hospitalizations, and 6\% of all outpatients. As axial loading, also referred to as vertical compression, is one of the mechanism of injuries,\textsuperscript{31} accumulation of cervical injuries can lead to increased axial loading and OPLL progression, even after surgery.

In our study, loss of postoperative cervical lordosis angle and increased SVA were statistically significant in the OPLL progression group. Cervical lordosis represents how efficiently muscles apply the force necessary to support the weight of the head,\textsuperscript{2} and loss of cervical lordosis increases axial loading on the cervical spine.\textsuperscript{29} So cervical loading can be increased according to posture and can lead to OPLL progression as a result of bone reformation based on Wolff’s Law.\textsuperscript{27,32}

In summary, 2 factors showed a significant association with OPLL progression after ACDF: SVA changes before and after ACDF, and postoperative neutral C2-C7 lordotic angle.

As we can see in the ROC curve, increased SVA of >1.4 mm after ACDF and postoperative C2-C7 lordotic angle >−8.1° can be risk factors for OPLL progression after ACDF.

In previous literature, the progression of OPLL after cervical surgery was more frequent in patients with existing OPLL.\textsuperscript{10} Similarly, the presence of OPLL before ACDF was associated with OPLL progression in the univariate analysis in this study. However, it was not statistically
significant in the multivariate analysis. However, because all patients in the OPLL progression group had OPLL before surgery, the presence of OPLL before ACDF seems to be correlated.

Limitations
The present study has several limitations. First, this was a retrospective study involving a small number of patients, which may have affected the results of the statistical analysis. Second, this study included only male patients who were soldiers and officers on active military duty under the age of 60 (range: 34–57), and the design of the present study meant that there was a chance of selection bias. Third, for the OPLL type referred to as the OPLL progression risk factors, all patients in the OPLL progression group were of the segment type, except that 2 patients who were of the mixed type. There was no statistical difference between the 2 groups; therefore, there was insufficient data to prove the risk factor in terms of the OPLL types. Lastly, it seems that the follow-up period might be too short for OPLL to grow enough to cause neurological symptoms. Long-term follow-up is needed to determine whether additional surgical treatment is required.

Despite these limitations, the present study demonstrated that OPLL progression following ACDF is associated with postural changes and the postoperative cervical lordotic angle.

CONCLUSION
The prevalence of OPLL progression after ACDF was 3.4%. In OPLL progression after ACDF, cervical ROM was not statistically significant, but SVA changes and postoperative C2-C7 angle in the neutral position were significant. OPLL progression should be suspected when the SVA increases by >1.4 mm at 1 year after ACDF or when the postoperative C2-C7 angle in neutral position at 1 year is >−8.1°. This is thought to be more likely in the presence of OPLL than in its non-presence of OPLL.

Therefore, it is necessary to periodically explain and emphasize on education and posture correction for cervical posture, as well as caution for even a minor trauma, after ACDF in patients with OPLL.

REFERENCES

1. Aizawa T, Sato T, Sasaki H, Kusakabe T, Morozumi N, Kokubun S. Thoracic myelopathy caused by ossification of the ligamentum flavum: clinical features and surgical results in the Japanese population. J Neurosurg Spine 5:514-519, 2006

2. Brasil AV, Fraett da Costa PR, Vial AD, Barcellos GD, Zauk EB, Worm PV, et al. Cervicothoracic lordosis can influence outcome after posterior cervical spine surgery. Open Orthop J 12:91-98, 2018

3. Cai HX, Yayama T, Uchida K, Nakajima H, Sugita D, Guerrero AR, et al. Cyclic tensile strain facilitates the ossification of ligamentum flavum through β-catenin signaling pathway: in vitro analysis. Spine (Phila Pa 1976) 37:E639-E646, 2012

4. Chiba K, Yamamoto I, Hiranayashi H, Iwasaki M, Goto H, Yonenobu K, et al. Multicenter study investigating the postoperative progression of ossification of the posterior longitudinal ligament in the cervical spine: a new computer-assisted measurement. J Neurosurg Spine 3:17-23, 2005
5. Choi BW, Song KJ, Chang H. Ossification of the posterior longitudinal ligament: a review of literature. *Asian Spine J* 5:267-276, 2011

6. Choi BW, Baek DH, Sheffler LC, Chang H. Analysis of progression of cervical OPLL using computerized tomography: typical sign of maturation of OPLL mass. *J Neurosurg Spine* 23:539-543, 2015

7. Dru AM, Lockney DT, Vaziri S, Decker M, Polifka AJ, Fox WC, et al. Cervical spine deformity correction techniques. *Neurospine* 16:470-482, 2019

8. Feng F, Ruan W, Liu Z, Li Y, Cai L. Anterior versus posterior approach for the treatment of cervical compressive myelopathy due to ossification of the posterior longitudinal ligament: a systematic review and meta-analysis. *Int J Surg* 27:26-33, 2016

9. Furukawa K. Current topics in pharmacological research on bone metabolism: molecular basis of ectopic bone formation induced by mechanical stress. *J Pharmacol Sci* 100:201-204, 2006

10. Ham JS, Kim JH, Yoon JH, Hwang SH, Yoon SH. Progression of ossification of the posterior longitudinal ligament after cervical total disc replacement. *Korean J Neurotrauma* 15:135-142, 2019

11. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. *Spine (Phila Pa 1976)* 6:354-364, 1981

12. Hori T, Kawaguchi Y, Kimura T. How does the ossification area of the posterior longitudinal ligament progress after cervical laminoplasty? *Spine (Phila Pa 1976)* 31:2807-2812, 2006

13. Hou Y, Liang L, Shi GD, Xu P, Xu GH, Shi JG, et al. Comparing effects of cervical anterior approach and laminoplasty in surgical management of cervical ossification of posterior longitudinal ligament by a prospective nonrandomized controlled study. *Orthop Traumatol Surg Res* 103:733-740, 2017

14. Iwasaki M, Kawaguchi Y, Kimura T, Yonenobu K. Long-term results of expansive laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine: more than 10 years follow up. *J Neurosurg* 96:180-189, 2002

15. Jones BH, Canham-Chervak M, Canada S, Mitchener TA, Moore S. Medical surveillance of injuries in the U.S. military descriptive epidemiology and recommendations for improvement. *Am J Prev Med* 38:S42-S60, 2010

16. Katsumi K, Izumi T, Ito T, Hirano T, Watanabe K, Ohashi M. 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. *Eur Spine J* 25:1634-1640, 2016

17. Kawaguchi Y, Kanamori M, Ishihara H, Nakamura H, Sugimori K, Tsuji H, et al. Progression of ossification of the posterior longitudinal ligament following en bloc cervical laminoplasty. *J Bone Joint Surg Am* 83:1798-1802, 2001

18. Lee CH, Jahng TA, Hyun SJ, Kim KJ, Kim HJ. Expansive laminoplasty versus laminectomy alone versus laminectomy and fusion for cervical ossification of the posterior longitudinal ligament. *Clin Spine Surg* 29:E9-E15, 2016

19. Lee JS, Son DW, Lee SH, Kim DH, Lee SW, Song GS. The predictable factors of the postoperative kyphotic change of sagittal alignment of the cervical spine after the laminoplasty. *J Korean Neurosurg Soc* 60:577-583, 2017

20. Lee SE, Jahng TA, Kim HJ. Adverse effect of trauma on neurologic recovery for patients with cervical ossification of the posterior longitudinal ligament. *Global Spine J* 5:124-129, 2015

21. Lee SH, Hyun SJ, Jain A. Cervical sagittal alignment: literature review and future directions. *Neurospine* 17:478-496, 2020
22. Lee SH, Son DW, Shin JJ, Ha Y, Song GS, Lee JS, et al. Preoperative radiological parameters to predict clinical and radiological outcomes after laminoplasty. J Korean Neurosurg Soc 64:677-692, 2021
PUBMED | CROSSREF
23. Maeno T, Okuda S, Yamashita T, Matsumoto T, Yamasaki R, Oda T, et al. Age-related surgical outcomes of laminoplasty for cervical spondylotic myelopathy. Global Spine J 5:118-123, 2015
PUBMED | CROSSREF
24. Matsumoto M, Chiba K, Toyama Y. Surgical treatment of ossification of the posterior longitudinal ligament and its outcomes: posterior surgery by laminoplasty. Spine (Phil a Pa 1976) 37:E303-E308, 2012
PUBMED | CROSSREF
25. Matsunaga S, Sakou T, Taketomi E, Yamaguchi M, Okano T. The natural course of myelopathy caused by ossification of the posterior longitudinal ligament in the cervical spine. Clin Orthop Relat Res 305:168-177, 1994
PUBMED | CROSSREF
26. Matsunaga S, Kukita M, Hayashi K, Shinkura R, Koriyama C, Sakou T, et al. Pathogenesis of myelopathy in patients with ossification of the posterior longitudinal ligament. J Neurosurg 96:168-172, 2002
PUBMED | CROSSREF
27. Mehdi SK, Alentado VJ, Lee BS, Mroz TE, Benzel EC, Steinmetz MP. Comparison of clinical outcomes in decompression and fusion versus decompression only in patients with ossification of the posterior longitudinal ligament: a meta-analysis. Neurosurg Focus 40:E9, 2016
PUBMED | CROSSREF
28. Nakajima H, Watanabe S, Honjoh K, Kitade I, Sugita D, Matsumine A. Long-term outcome of anterior cervical decompression with fusion for cervical ossification of posterior longitudinal ligament including postsurgical remnant ossified spinal lesion. Spine (Phil a Pa 1976) 44:E1452-E1460, 2019
PUBMED | CROSSREF
29. Oktenoğlu T, Özer AF, Ferrara LA, Andalkar N, Sarioğlu AÇ, Benzel EC. Effects of cervical spine posture on axial load bearing ability: a biomechanical study. J Neurosurg 94:108-114, 2001
PUBMED | CROSSREF
30. Park S, Lee DH, Ahn J, Cho JH, Lee SK, Kim KJ, et al. How does ossification of posterior longitudinal ligament progress in conservatively managed patients? Spine (Phil a Pa 1976) 45:234-243, 2020
PUBMED | CROSSREF
31. Raniga SB, Menon V, Al Muzahmi KS, Butt S. MDCT of acute subaxial cervical spine trauma: a mechanism-based approach. Insights Imaging 5:321-338, 2014
PUBMED | CROSSREF
32. Rubin CT, Hausman MR. The cellular basis of Wolff’s law. Transduction of physical stimuli to skeletal adaptation. Rheum Dis Clin North Am 14:503-517, 1988
PUBMED | CROSSREF
33. Rustagi T, Alonso F, Schmidt C, Oskouian RJ, Chapman JR, Tubbs RS, et al. Rapid progression of ossification of the posterior longitudinal ligament after anterior cervical discectomy and fusion. World Neurosurg 110:11-16, 2018
PUBMED | CROSSREF
34. Sakai K, Okawa A, Takahashi M, Arai Y, Kawabata S, Enomoto M, et al. Five-year follow-up evaluation of surgical treatment for cervical myelopathy caused by ossification of the posterior longitudinal ligament: a prospective comparative study of anterior decompression and fusion with floating method versus laminoplasty. Spine (Phil a Pa 1976) 37:367-376, 2012
PUBMED | CROSSREF
35. Sato R, Uchida K, Kobayashi S, Yayama T, Kokubo Y, Nakajima H, et al. Ossification of the posterior longitudinal ligament of the cervical spine: histopathological findings around the calcification and ossification front. J Neurosurg Spine 7:174-183, 2007
PUBMED | CROSSREF
36. Sugita D, Yayama T, Uchida K, Kokubo Y, Nakajima H, Yamagishi A, et al. Indian hedgehog signaling promotes chondrocyte differentiation in enchondral ossification in human cervical ossification of the posterior longitudinal ligament. Spine (Phil a Pa 1976) 38:E1380-E1396, 2013
PUBMED | CROSSREF
37. Takatsu T, Ishida Y, Suzuki K, Inoue H. Radiological study of cervical ossification of the posterior longitudinal ligament. J Spinal Disord 12:272-273, 1999
PUBMED | CROSSREF
38. Trivedi P, Behari S, Paul L, Banerji D, Jain VK, Chhabra DK. Thoracic myelopathy secondary to ossified ligamentum flavum. Acta Neurochir (Wien) 143:775-782, 2001
PUBMED | CROSSREF
39. Tsuyama N. Ossification of the posterior longitudinal ligament of the spine. Clin Orthop Relat Res (184):71-84, 1984
PUBMED | CROSSREF

40. Vaziri S, Lockney DT, Dru AB, Politka AJ, Fox WC, Hoh DI. Does ossification of the posterior longitudinal ligament progress after fusion? Neurospine 16:483-491, 2019
PUBMED | CROSSREF

41. Yamaura I, Kurosa Y, Matuoka T, Shindo S. Anterior floating method for cervical myelopathy caused by ossification of the posterior longitudinal ligament. Clin Orthop Relat Res 359:27-34, 1999
PUBMED | CROSSREF