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True Continuous Segment of Ossification of Posterior Longitudinal Ligament is Protective Against Postoperative Early Kyphosis Progression After Laminoplasty

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BACKGROUND AND OBJECTIVES: Ossification of the posterior longitudinal ligament (OPLL) is a potentially catastrophic disease. Laminoplasty (LP) is a common surgical intervention, but postoperative kyphosis progression is a major complication, for which various risk factors have been identified and used in surgical decision-making. Our focus is on the ability of OPLL with specific morphological traits, designated as the true continuous segment (TCS), to stabilize alignment and prevent postoperative kyphosis after LP.

METHODS: This retrospective case-control study included patients who underwent cervical LP for OPLL treatment with a minimum 1-year follow-up. Demographic, operative, and radiographic parameters were analyzed. TCS is defined as a continuous segment of OPLL that spans the disk space more than half of the adjacent vertebral body height without crack, or OPLL segment attached to both upper and lower adjacent vertebral bodies by bridging, or obvious interbody autofusion, and is identified from preoperative computed tomography. A subgroup analysis for preoperatively lordotic patients, divided into 2 groups based on cervical alignment at the final follow-up, was conducted to identify risk factors for kyphosis progression. Difference analysis, linear regression analysis for loss of lordosis (LoL), and logistic regression analysis for kyphosis progression were used.

RESULTS: A total of 84 patients were identified. Among them, 78 patients with preoperatively lordotic alignment were divided into 2 groups: those who maintained lordotic alignment (n = 60) and those who progressed to kyphosis (n = 18). Regression analyses revealed a significant protective effect of TCS count against LoL and postoperative kyphosis, with a TCS count of 3 or more conclusively preventing kyphosis (sensitivity 1.000, specificity 0.283, area under the curve 0.629).

CONCLUSION: For patients with OPLL, TCS was shown to protect against the LoL after LP. Therefore, TCS should be identified and considered when planning surgical treatment for OPLL.

KEY WORDS: Kyphosis, Laminoplasty, Ossification of posterior longitudinal ligament, True continuous segment

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Ossification of posterior longitudinal ligament (OPLL) can potentially induce irreversible myelopathy in severe cases. Surgical treatments include anterior method, such as anterior cervical discectomy or corpectomy with fusion, targeting the compressive lesion. By contrast, posterior methods such as laminoplasty (LP) or laminectomy, with or without fusion, aim for indirect spinal cord decompression. Numerous studies have compared these surgical modalities. One widely accepted concept is the superiority of the anterior approach for K-line negative OPLL due to the incompleteness of decompression from the posterior approach.[1] Laminectomy with fusion is occasionally advocated for its potential to halt OPLL growth by eliminating segmental motion.[2,3] Nonetheless, LP is often preferred for its unique advantages, such as surgical ease for long-level OPLL, avoidance of dural tear, preservation of cervical motion, and prevention of adjacent segment disease following loss of range of

ABBREVIATIONS: L to L, lordosis to lordosis; **L to K,** lordosis to kyphosis; **LP,** laminoplasty; **LoL,** loss of lordosis; **LoROM,** loss of range of motion; **mJOA,** modified Japanese Orthopedic Association; **OPLL,** ossification of posterior longitudinal ligament; **SVA,** sagittal vertical axis; **TCS,** true continuous segment.

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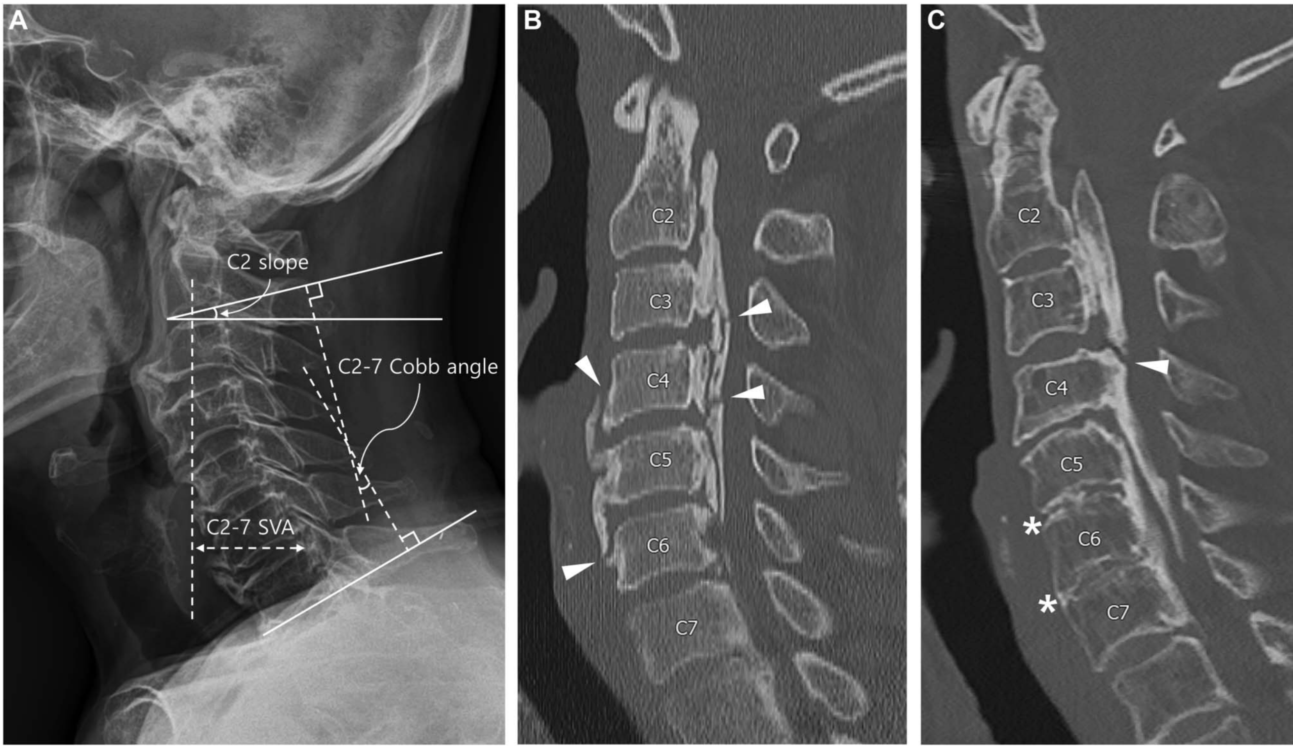

FIGURE 1. **A**, *A neutral sagittal cervical radiograph with the C2–7 Cobb angle, C2–7 SVA, and C2 slope parameters being expressed.* **B**, *OPLL with TCS observed only at the C2/3 level, for which continuous OPLL spans the disk space more than half of the height for C2 and C3 vertebral bodies with no bony crack. By contrast, the OPLL at the C3/4 and C4/5 disk levels has multiple bony cracks, with incomplete intervertebral autofusion demonstrated by bony defects at the C4/5 and C5/6 level osteophytes (arrowheads). These features render the OPLL ineligible for TCS. As per our definition for TCS, a bony bridge between the posterior vertebral body and OPLL is not a requirement.* **C**, *OPLL with 4 TCSs at C2/3, C4/5, C5/6, and C6/7. Note the segmental bony crack of OPLL only at the C3/4 level (arrowhead), along with the autofusion of C5/6/7 (asterisks). The stalagmite-shaped OPLL originates from C4 and extends down to the C6/7 disk level. OPLL, ossification of posterior longitudinal ligament; SVA, sagittal vertical axis; TCS, true continuous segment.*

motion (LoROM) from fusion.[4-6] Therefore, understanding risks and protective factors associated with LP-related complications is essential for surgical decision-making.

We propose the true continuous segment (TCS) concept as a potential mechanism for stabilizing cervical alignment. We postulate that the TCS serves as a rigid tension band, provided the OPLL retains longitudinal integrity across the disk space, preventing postoperative kyphosis or loss of lordosis (LoL). This study aims to clarify the role of OPLL TCS in preventing postoperative kyphosis progression after cervical LP, marking the first investigation into the TCS concept and its impact on cervical alignment changes after LP.

METHODS

This retrospective case-control study was approved by our institution's Institutional Review Board, and the informed consent was waived. STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist as the research reporting guideline was implemented.

From our institution's electronic records, we identified patients who (1) underwent LP for OPLL treatment performed by 4 spinal surgeons between 2001 and 2021, (2) had at least 1-year follow-up, (3) had preoperative and postoperative neutral and dynamic cervical radiographs, and (4) had preoperative cervical computed tomography (CT) for precise morphological assessment. We excluded patients who (1) underwent LP for non-OPLL reasons, (2) previously underwent cervical spinal surgeries, and (3) received cervical spinal surgeries with LP.

All patients underwent a double-door type LP, with suture-securing of the interlaminar ligamentum flavum to the corresponding level's multifidus muscle. Autobone chips from trimmed spinous processes were applied at hinge sites to promote bone fusion. A hard neck collar was uniformly applied for 1 month postoperatively with no neck exercises recommended.

Data were collected on patients' demographic data, baseline medical conditions, follow-up duration, radiographic parameters, operative characteristics, and modified Japanese Orthopedic Association (mJOA) scores. Future revisional cervical operations were identified. K-line classification and cervical alignment parameters were assessed using radiographs. Several neutral cervical parameters are presented in Figure 1A. Neutral alignment was classified as either lordotic for a C2–7 Cobb angle over 0 or kyphotic otherwise. Preoperative cervical CTs were used to identify OPLL-specific characteristics, including morphological types,

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TABLE 1. Patient Demographics, Surgical Characteristics, Radiographic Parameters, and mJOA Score

	All cases (n = 84)
Demographics	
Male sex	72 (85.7%)
Age	59.7 (±11.4)
Body mass index (kg/m^2)	25.4 (±3.57)
Diabetes	19 (22.6%)
Smoking	22 (26.2%)
Follow-up (mo)	44.8 (±36.6)
Future revision	5 (6.0%)
Surgical characteristics	
Double door method	84 (100.0%)
LP level	3.38 (±0.77)
OPLL types	
Continuous	18 (21.4%)
Segmental	21 (25.0%)
Localized	10 (11.9%)
Mixed	35 (41.7%)
OPLL characteristics	
Thickness (mm)	5.42 (±1.69)
Occupying ratio (%)	44.7 (±14.3)
Cord signal change	71 (84.5%)
K-line negative	16 (19.0%)
TCS count	1.26 (±1.51)
0	40 (47.6%)
1	13 (15.4%)
2	11 (13.0%)
3	13 (15.4%)
4	3 (3.5%)
5	4 (4.7%)
Alignment change	
Lordosis to lordosis	60 (71.4%)
Lordosis to kyphosis	18 (21.4%)
Kyphosis to kyphosis	6 (7.1%)
Kyphosis to lordosis	0 (0.0%)

TABLE 1. Continued.

	All cases (n = 84)
Radiographic parameters	
Neutral C2–7 Cobb (pre) (°)	14.2 (±11.2)
Neutral C2–7 Cobb (final) (°)	4.20 (±11.4)
LoL (°)	9.99 (±8.24)
C2–7 SVA (pre) (mm)	12.7 (±8.67)
C2–7 SVA (final) (mm)	15.6 (±9.47)
C2 slope (pre) (°)	12.7 (±8.67)
C2 slope (final) (°)	15.6 (±9.47)
mJOA score	
Preoperative	13.5 (±3.69)
Final follow-up	15.8 (±2.98)
Recovery rate (%)	54.5 (±57.5)

final, final follow-up; LoL, loss of lordosis; LP, laminoplasty; mJOA, modified Japanese Orthopedic Association; OPLL, ossification of posterior longitudinal ligament; pre, preoperative; SVA, sagittal vertical axis; TCS, true continuous segment.
Continuous variables are presented as mean (SD), and categorical variables are presented as number (%).

maximal thickness, occupying ratio, and, most importantly, TCS counts. Preoperative MRIs facilitated cord signal change assessments. For preoperative and postoperative mJOA scores, medical records including scanned questionnaires were used. If final follow-up scores were unattainable, the first author directly called the patients and asked about all 4 domains. The recovery rate of the mJOA score was calculated using the formula [(final follow-up score − preoperative score)/(18 − preoperative score) * 100%], as described by Hirabayashi et al.[7] The radiographic data were assessed and gathered by coauthors, who are experienced spine surgeons. They were blinded to the primary hypothesis throughout the measurement process.

The definition for TCS was established between C2 and C7 as follows: (1) continuous type OPLL on disk space spanning the upper and lower adjacent vertebral bodies for more than half of their height without any bony crack regardless of bridge formation between vertebral bodies, (2) OPLL adherent to both upper and lower adjacent vertebral bodies by bridging, or (3) obvious interbody autofusion. Valid TCSs are counted per cases from preoperative CTs. Although facet joint fusions were noted from CTs, they were limited and invariably paired with vertebral body autofusion, falling under our TCS definition. Figure 1B and 1C presents 2 case examples of C2 to C7 continuous type OPLL with different TCS counts.

Statistical analyses were performed using R (version 4.2.2; www.r-project.org). Between-group differences were analyzed using the *t*-test for quantitative data and χ^2 test for binary data, considering P value <.05 as statistically significant. Factors associated with LoL were identified using linear regression analysis for all patients. A subgroup analysis was performed for

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TABLE 2. Linear Regression Analysis for the Relationship of Surgical, Preoperative Radiographic Factors, and OPLL Characteristics With LoL in all Cases

	Univariate analysis		Multivariate analysis	
	β coefficient	*P* value	β coefficient	*P* value
LP level count	−1.603	.171	0.643	.603
TCS count	−2.984	<.001[a]	−2.267	<.001[a]
Neutral C2–7 Cobb (pre)	0.247	.001[a]	0.480	<.001[a]
C2–7 SVA (pre)	−0.039	.589	−0.091	.486
C2 slope (pre)	−0.086	.412	0.273	.112
Flexion C2–7 Cobb (pre)	−0.013	.839	−0.009	.294
Extension C2–7 Cobb (pre)	0.079	.348	−0.190	.081
Maximum thickness of OPLL	−1.837	<.001[a]	−1.683	.135
Occupying ratio	−0.200	.001[a]	0.145	.315

LoL, loss of lordosis; LP, laminoplasty; OPLL, ossification of posterior longitudinal ligament; pre, preoperative; TCS, true continuous segment.
[a]Statistically significant, $P < .05$.

preoperatively lordotic patients, divided into 2 groups based on postoperative cervical alignment, resulting in a lordosis to lordosis (L to L) group and a lordosis to kyphosis (L to K) group. Logistic regression analysis was performed to identify factors associated with L to K complication and presented as adjusted odds ratio (OR), 95% CI, and *P* value. Finally, the receiver operating characteristic (ROC) curve identified the cut-off value of TCS count to best predict kyphosis progression through the maximum Youden index method.

RESULTS

Demographic Data, Surgical and Radiographic Parameters, and Modified Japanese Orthopedic Association Score

Initially, we identified 233 patients who underwent LP for OPLL. After excluding 119 patients with less than 1-year follow-up, 24 patients with previous cervical operation, and 6 patients who had concurrent cervical surgeries with LP, 84 patients were included (Table 1). The average age was 59.7 years, with 85.7% men. Average follow-up was 44.8 months with a SD of 33.6 months, with a range of 17–180 months. By the end, 6.0% had undergone cervical revisional surgeries. All underwent a double-door type LP, averaging 3.38 LP levels. Negative K-line was observed in 19.0% of cases. Average neutral C2–7 Cobb angle was 14.2° preoperatively and 4.2° at the final follow-up, with a LoL of 9.99°. Of 78 preoperatively lordotic patients, 60 maintained lordosis at the final follow-up, while the rest progressed to kyphosis. Only 7.1% had preoperatively kyphotic alignment, all of whom remained kyphotic at the final follow-up. Based on cervical CT, the most common OPLL type was mixed (41.6%), followed by segmental (25.0%), continuous (21.4%), and localized (11.9%). Average OPLL thickness was 5.42 mm with a 44.6% occupying ratio. TCS count ranged from 0 to 5, with an average count of 1.26. Most cases showed cord signal change from preoperative MRI (84.5%). All cases had suitable preoperative records for mJOA score, but 20 lacked appropriate documentation for postoperative scoring. A phone survey secured responses from 9 of these, leaving 11 without available scores due to various reasons such as death (2/11), change of contact number (5/11), and no response (4/11). The scores of the 2 deceased cases were classified as unavailable because of their nonmyelopathic causes (malignancies). Both simple and multiple linear regression analyses revealed that TCS count negatively correlated with LoL (Table 2).

Subgroup Analysis for Preoperatively Lordotic Patients

In the analysis of preoperatively lordotic patients, most remained lordotic (L to L, n = 60) postoperatively, while some transitioned to kyphotic (L to K, n = 18) (Table 3). No significant differences in demographics, surgical, or OPLL classification existed. However, the TCS count differed; the L to L group had an average TCS count of 1.37, with 28.3% having 3 or more TCSs. By contrast, the L to K group averaged a TCS count of 0.55, with none exceeding 2 TCSs. Several cervical alignment parameters differed between groups. The L to K group had smaller C2–7 Cobb angles both preoperatively and at the final follow-up, along with larger LoL and C2 slope. No differences were observed in ROM, LoROM, or mJOA scores.

A multivariate logistic regression revealed that each additional TCS reduced the likelihood of progression from lordosis to kyphosis by 75% (adjusted OR = 0.25, 95% CI 0.05-0.64, $P = .020$) (Table 4). A larger preoperative extension C2–7 Cobb angle also protected against kyphosis progression (adjusted OR = 0.84, 95% CI 0.71-0.96, $P = .024$). ROC curve analysis revealed that a TCS

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TABLE 3. **Subgroup Analysis for Preoperatively Lordotic Patients**

	L to L (n = 60)	L to K (n = 18)	*P* value
Demographics			
Male sex	51 (85.0%)	15 (83.3%)	1.000
Age	60.1 (±11.5)	61.0 (±10.4)	.755
Body mass index (kg/m^2)	25.0 (±3.77)	26.0 (±2.77)	.206
Diabetes	17 (28.3%)	2 (11.1%)	.211
Smoking	17 (28.3%)	4 (22.2%)	.766
Follow-up (mo)	45.0 (±38.2)	42.4 (±26.2)	.751
Future revision	4 (6.7%)	1 (5.6%)	1.000
Surgical characteristics			
Double door method	60 (100.0%)	18(100.0%)	1.000
LP level count	3.43 (±0.83)	3.28 (±0.57)	.373
C2 involved	5 (8.3%)	1 (5.6%)	1.000
C7 involved	5 (8.3%)	0 (0.0%)	.584
OPLL types			
Continuous	16 (26.7%)	1 (5.6%)	.100
Segmental	16 (26.7%)	4 (22.2%)	1.000
Localized	7 (11.7%)	2 (11.1%)	1.000
Mixed	21 (35.0%)	11 (61.1%)	.089
OPLL characteristics			
Thickness (mm)	5.53 (±1.74)	5.08 (±1.62)	.321
Occupying ratio (%)	44.6 (±15.0)	43.1 (±11.8)	.655
Cord signal change	50 (83.3%)	17 (94.4%)	.441
TCS count	1.37 (1.57)	0.55 (0.78)	.005[a]
0	28 (46.7%)	11 (61.1%)	.420
1	8 (13.3%)	4 (22.2%)	.457
2	7 (11.7%)	3 (16.7%)	.689
3	11 (18.3%)	0 (0.0%)	.059
4	3 (5.0%)	0 (0.0%)	1.000
5	3 (5.0%)	0 (0.0%)	1.000
3 or more	17 (28.3%)	0 (0.0%)	.008[a]
K-line negative	8 (13.3%)	4 (22.2%)	.457
Radiographic parameters			
Neutral C2–7 Cobb (pre) (°)	18.3 (±8.55)	8.76 (±5.25)	<.001[a]
Neutral C2–7 Cobb (final) (°)	10.0 (±6.65)	−8.05 (±4.62)	<.001[a]
LoL (°)	8.31 (±7.78)	16.8 (±6.31)	<.001[a]

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TABLE 3. Continued.

	L to L (n = 60)	L to K (n = 18)	*P* value
Flexion C2–7 Cobb (pre) (°)	−11.5 (±12.8)	−20.9 (±12.1)	.008[a]
Extension C2–7 Cobb (pre) (°)	24.4 (±8.56)	14.1 (±6.64)	<.001[a]
ROM (pre) (°)	35.4 (±13.9)	35.0 (±12.6)	.909
Flexion C2–7 Cobb (final) (°)	−5.80 (±10.6)	−18.9 (±6.21)	<.001[a]
Extension C2–7 Cobb (final) (°)	20.3 (±10.3)	4.39 (±8.52)	<.001[a]
ROM (final) (°)	25.7 (±13.7)	23.3 (±11.5)	.474
Loss of ROM (°)	9.69 (±11.0)	11.6 (±13.3)	.578
C2–7 SVA (pre) (mm)	22.9 (±12.0)	24.3 (±13.5)	.711
C2–7 SVA (final) (mm)	26.8 (±12.9)	30.3 (±17.7)	.445
C2 slope (pre) (°)	10.5 (±7.98)	16.2 (±7.13)	.007[a]
C2 slope (final) (°)	13.1 (±8.86)	21.8 (±9.26)	.001[a]
mJOA score			
Preoperative	13.4 (±3.77)	13.8 (±3.65)	.652
Final follow-up	15.8 (±3.01)	16.0 (±2.50)	.784
Recovery rate (%)	57.0 (±40.2)	41.7 (±96.9)	.545

final, final follow-up; LoL, loss of lordosis; LP, laminoplasty; L to L, lordosis to lordosis; L to K, lordosis to kyphosis; mJOA, modified Japanese Orthopedic Association; OPLL, ossification of posterior longitudinal ligament; pre, preoperative; ROM, range of motion; SVA, sagittal vertical axis; TCS, true continuous segment.
Continuous variables are presented as mean (SD), and categorical variables are presented as number (%).
[a]Statistically significant, $P < .05$.

count above the cutoff of 2.5 effectively excluded progression from lordosis to kyphosis (sensitivity 1.000, specificity 0.283, area under the curve 0.629) (Figure 2), consistent with no patients in the L to K group having 3 or more TCSs, compared with 28.3% in the L to L group.

DISCUSSION

OPLL, characterized by progressive bone formation replacing the ligament, occasionally requires surgical treatment either through an anterior or posterior approach. The anterior approach, while effective in directly removing OPLL, can lead to severe complications such as paraplegia or dural tear.[5] Among posterior approaches, both LP and laminectomy with posterior fixation are prevalent.[2,3,8] However, owing to the discomfort from long cervical fixation and significant pseudoarthrosis risks, LP is preferred for multilevel OPLL in many practices. Thus, identifying risk factors that lead to complications from LP is crucial in surgical decision-making.

Postoperative kyphosis progression is a recognized complication from LP, influenced by factors such as age, LP level, C2 or C7 involvement of LP, OPLL type, and preoperative alignment. Although there is debate on whether LoL negatively affects surgical outcomes, such as neck pain, neurological recovery, and revision rate,[9-13] cervical kyphosis is against the natural compensatory mechanism for global sagittal balance and associated with adjacent segment degenerations.[14,15] Therefore, many studies aim to reveal the risk factors specifically related to post-LP kyphosis or LoL.[16-19] However, the role of specific OPLL morphologies on cervical alignment is often neglected.[20,21] In addition, such effect of OPLL on cervical motion and alignment can vary by segment, making the widely accepted OPLL categorization (continuous, segmental, mixed, localized) based on general morphology unsuitable for assessing postoperative kyphosis progression risks.

We hypothesized that longitudinally intact OPLL segment, regardless of bridging, can stabilize the alignment, despite some segmental motion. This hypothesis was inspired by numerous biomechanical studies along with the observations from our patients. Several biomechanical studies suggest that longitudinal ligaments function as significant stabilizers of spine.[22,23] Nonetheless, other soft tissue structures, including disks, zygapophyseal joints, capsular ligaments, and posterior neck muscles, also contribute critically to spinal stability.[24-26] A limited number of clinical studies indicate that anterior decompression fusion, coupled with posterior decompression—similar to the procedure in patients with TCSs undergoing LP—can help maintaining cervical lordosis to some extent.[27] Collectively, these studies suggest that an anterior

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TABLE 4. Logistic Regression Analysis for the Relationship of Surgical, Preoperative Radiographic Factors, and OPLL Characteristics With Lordosis to Kyphosis Progression in Preoperatively Lordotic Patients

	Adjusted OR	95% CI	*P* value
LP level count	0.74	0.13–3.79	.716
TCS count	0.25	0.05–0.64	.020[a]
Neutral C2–7 Cobb (pre)	0.86	0.70–1.01	.101
C2–7 SVA (pre)	0.88	0.75–1.01	.101
C2 slope (pre)	1.15	0.95–1.47	.174
Flexion C2–7 Cobb (pre)	1.06	0.95–1.20	.274
Extension C2–7 Cobb (pre)	0.84	0.71–0.96	.024[a]
Maximum thickness of OPLL	0.80	0.22–2.94	.730
Occupying ratio	1.07	0.92–1.26	.366

LP, laminoplasty; OPLL, ossification of posterior longitudinal ligament, OR, odds ratio; pre, preoperative; SVA, sagittal vertical axis; TCS, true continuous segment.
[a]Statistically significant, $P < .05$.

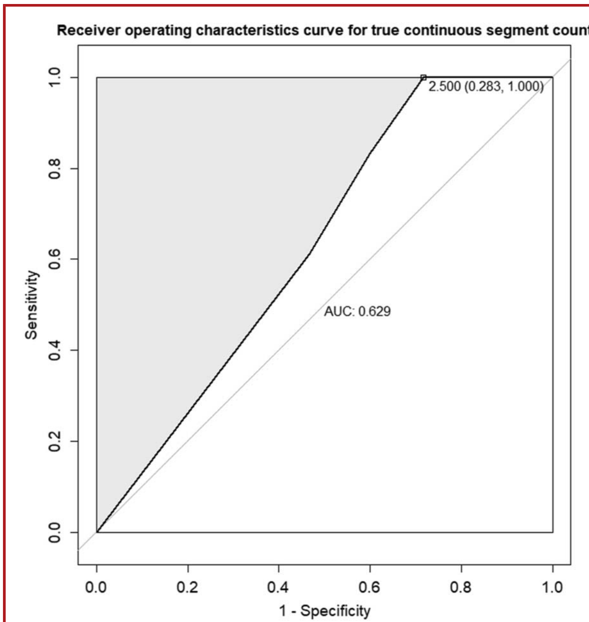

FIGURE 2. *The receiver operating characteristics curve for TCS count as a predictor of progression from lordosis to kyphosis after laminoplasty for ossification of posterior longitudinal ligament shows an optimal TCS count cutoff of 2.5 according to the maximum Youden index method. This cutoff results in a sensitivity of 1.000, specificity of 0.283, and AUC of 0.629. AUC, area under the curve; TCS, true continuous segment.*

tension band, in any form, possesses the capability to maintain alignment. TCS is defined not only for segments with an obvious bony bridge or interbody autofusion but also for those without a bony bridge, provided it does not crack across over half the vertebral height of intervertebral segments. This broad classification criterion accommodates diverse OPLL cases on a segmental basis. TCS can exist not only in continuous types but also in localized and mixed types, as this concept is applied to each segment. The maximum possible TCS count for each case is 5 from C2 to C7.

Our subgroup analysis revealed that the L to L group had significantly more TCSs, averaging 1.37, compared with 0.55 for the L to K group (Table 3). Regression analyses confirmed significantly negative correlation of TCS count with both LoL and kyphosis progression (Tables 2 and 4). This demonstrates that the TCS could reflect the inherent stability against sagittal alignment change postsurgery, suggesting its role as a protective factor against kyphosis. Interestingly, none of the cases with 3 or more TCSs progressed from lordosis to kyphosis. This is also evident from the ROC curve with the TCS count cutoff of 2.5, yielding sensitivity of 1.000. All 17 patients with 3 or more TCSs maintained lordosis with negligible LoL of 0.6° on average. We suggest that patients with TCS count of 3 or more can undergo LP treatment with reduced risk of kyphosis progression. However, it is important to underscore that our results do not imply that patients with a TCS count of 2 or less should be discouraged from LP, given the low specificity (0.283) and low area under the curve (0.629). Moreover, over 20 years of data from our center showed that more than half of OPLL cases (52.4%) had at least 1 TCS, demonstrating the broad applicability of this concept.

Figures 3 and 4 illustrate 2 patients with different TCSs and contrasting postoperative alignment outcomes. Despite the extensive cervical OPLL and osteophytes in both, the 50-year-old man with 2 TCSs progressed to kyphosis at 25 months postoperatively (Figure 3), while the 70-year-old man with 3 TCSs maintained lordosis even until 69 months postoperatively (Figure 4). Although preoperative cervical lordosis was positively correlated with LoL from linear regression analysis (Table 2), the latter case had more preoperative lordosis but much less LoL, which can partially be attributed to more TCSs.

It is worthwhile to mention other parameters being analyzed. Univariate linear regression analysis revealed that both OPLL thickness and occupying ratio significantly correlated with the LoL after LP (Table 2). We suspect that thicker OPLL might be associated with more TCSs, although the 2 do not precisely equate. No significant differences in ROM or LoROM were found (Table 3). Our subjects, characterized by autofusion promoted at hinge sites by bone chip application, hard cervical collar application for 1 month postoperatively without neck exercises, yielded an average LoROM of approximately 10.0°, while LoROM after LP is reported with a wide range of results in many studies.[28-30] Despite our low revision operation rate (6.0%) and moderate mJOA recovery rate (54.5%), the clinical significance of LoROM warrants further investigation.[31] Postoperatively, both subgroups exhibited increased C2–7 sagittal vertical axis and C2 slope, suggesting some deterioration in cervical sagittal balance. Especially, average C2 slope of 21.8° for L to K subgroup which is

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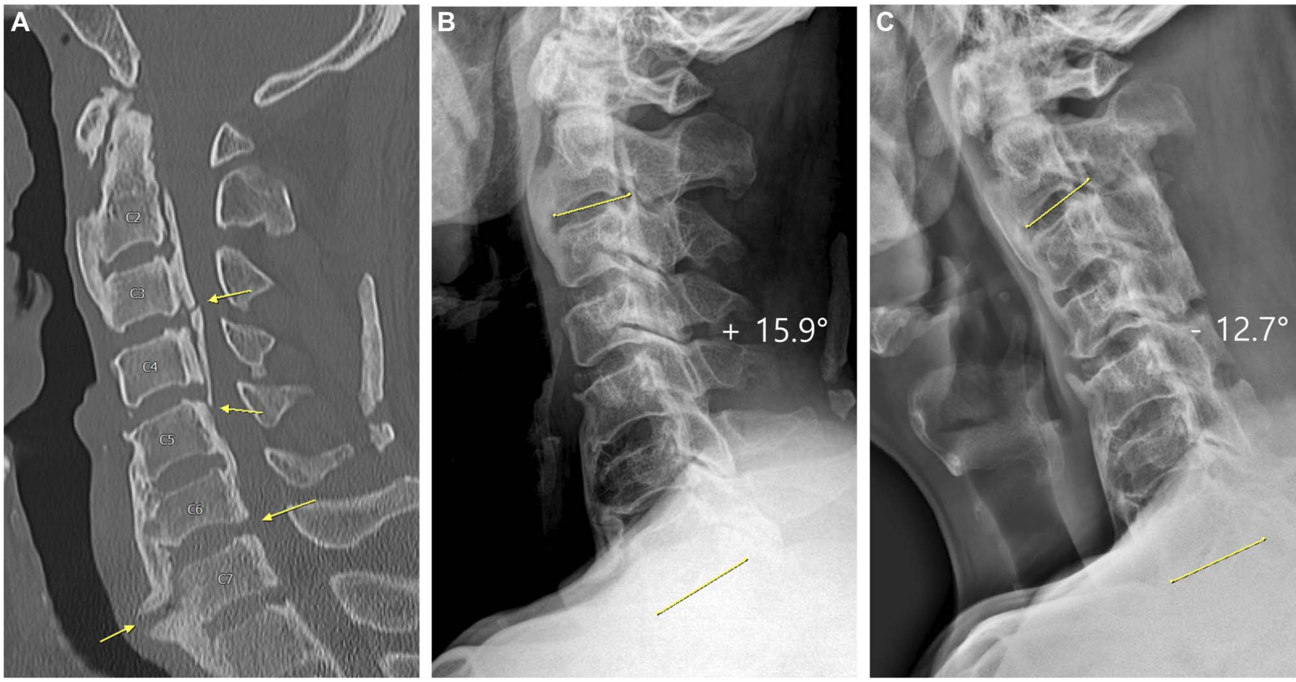

FIGURE 3. *Case of a 50-year-old man with OPLL containing 2 TCSs treated by C3 to C6 laminoplasty who eventually progressed from lordosis to kyphosis at the final follow-up.* **A**, *Preoperative sagittal computed tomography showing 2 TCSs at C2/3 and C5/6. Note the segmental bony cracks of the OPLL at C3/4, C4/5, and C6/7 levels with anterior osteophyte crack signifying incomplete autofusion at the C6/7 level (arrows).* **B**, *Preoperative sagittal radiograph with lordotic alignment of 15.9°.* **C**, *Sagittal radiograph at the final follow-up of 25 months postoperatively with kyphotic alignment of −12.7°. Modified Japanese Orthopedic Association score improved from 16 preoperatively to 17 at the final follow-up. OPLL, ossification of posterior longitudinal ligament; TCS, true continuous segment.*

significantly larger than L to L group well correlates with its representative role for cervical alignment.[32] However, mJOA scores and recovery rates between groups were not significantly different, consistent with other studies demonstrating a lack of correlation between post-LP cervical alignment and clinical outcomes.[12,33] Our analysis indicates a positive correlation between preoperative cervical lordosis and LoL, a result that invites further debate as it contrasts with previous studies suggesting a significant correlation between small preoperative cervical lordosis and postoperative kyphosis progression.[18,34-36] Furthermore, our logistic regression analysis revealed a negative correlation between preoperative extension C2–7 Cobb angle and kyphosis progression, reinforcing the widely accepted concept that extension capacity correlates negatively with LoL or kyphosis progression.[16,34,37]

Despite many advantages on LP, a balanced perspective is vital. Some report that mixed or continuous OPLL types are more prone to progression.[38,39] As continuous OPLL often involves more TCSs, they might face radiographic and potentially clinical deterioration, despite reduced post-LP kyphosis risk. Furthermore, LP might lead to OPLL progression due to retained cervical motion, unlike laminectomy with fusion which can slow or reverse OPLL progression.[40-42] Therefore, in certain situations, LP may present inherent risks, independent of kyphosis progression.

In summary, our research emphasizes that TCS is negatively correlated with LoL. Specifically, 3 or more TCSs offer a strong protective effect against post-LP kyphosis progression. This carries particular importance since LP is invariably perceived as a kyphosis progression factor. Consequently, many surgeons opt for decompression with fusion, anticipating unacceptable kyphosis progression if LP was the sole intervention. However, with 3 or more TCSs and effective cord decompression achievable through laminoplasty, LP has become our primary consideration choice, although a balanced view remains essential. Consequently, we propose that TCS should be identified and incorporated into the surgical decision-making and future OPLL research.

Limitations

Our study has several limitations. First, this retrospective study had a relatively small sample size, which affects the validation of our novel TCS concept. We anticipate other alignment studies incorporating the TCS concept given the ease of identification from CT and broad applicability to various types of OPLL.

Second, certain parameters were excluded from our study due to specific constraints. We could not include the T1 slope, frequently associated with LoL in cervical alignment studies involving LP,[16,34] due to challenges visualizing the T1 upper endplate in many cases.

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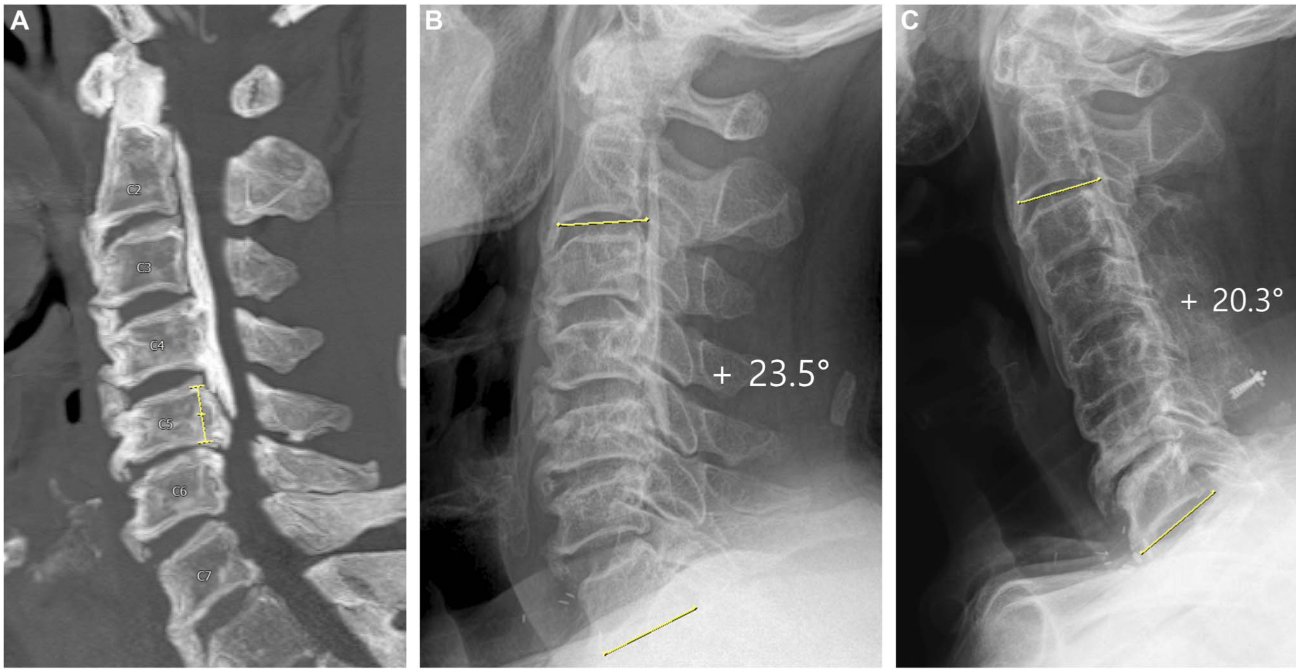

FIGURE 4. *Case of a 70-year-old man with OPLL containing 3 TCSs treated by C3 to C6 laminoplasty who maintained lordotic alignment at the final follow-up.* **A**, *Preoperative sagittal computed tomography showing 3 TCSs at C2/3, C3/4, and C4/5. Note that OPLL spans longitudinally down to more than half of C5 vertebral height, and bony bridge was present only at C4.* **B**, *Preoperative sagittal radiograph with lordotic alignment of 23.5°.* **C**, *Sagittal radiograph at the final follow-up of 69 months postoperatively with maintained lordotic alignment of 20.3°. Modified Japanese Orthopedic Association score improved from 11 preoperatively to 16 at the final follow-up. OPLL, ossification of posterior longitudinal ligament; TCS, true continuous segment.*

Given that C2 slope cannot be a direct substitute for T1 slope, this omission represents a study limitation. Although our institution typically obtains cervical radiographs in the standing position, some patients with difficulty standing due to myelopathy or other reasons were imaged seated, potentially affecting C2–7 sagittal vertical axis and C2 slope measurements. Similarly, the global sagittal spinal balance, shown to correlate significantly with postoperative cervical kyphosis progression post-LP,[43] could not be analyzed due to the lack of whole spine standing radiographs. The absence of whole spine radiographs also limits the definite detection of diffuse idiopathic skeletal hyperostosis, a condition relevant to cervical alignment and to our study. However, none of our cases exhibited the characteristic cervical spinal features of diffuse idiopathic skeletal hyperostosis, such as flowing anterior osteophyte formation with preserved disk space and the absence of facet joint ankylosis. Furthermore, the lack of postoperative MRIs in many instances limited our analysis concerning postoperative cervical muscle changes and kyphosis progression.

Third, as OPLL can both grow and fuse with adjacent bony structures, TCS count can vary accordingly at the final follow-up. Owing to the lack of long-term follow-up CT, we could not compare OPLL growth at TCS and non-TCS sites.

Finally, as indicated by our ROC curve analysis, despite a high sensitivity of 1.000, the specificity was low (0.283). This suggests that while a TCS count of 3 or above could effectively rule out postoperative kyphosis progression, a TCS count of 2 or below provides little predictive value for this complication. This highlights the multifactorial nature of post-LP kyphosis progression, which includes patient, radiographic, and surgical factors.

CONCLUSION

Our study introduced the concept of TCS in OPLL and explored its effects on cervical alignment changes after LP. TCS, the longitudinally intact continuous OPLL segment, can be found in a sizable proportion of OPLL cases and could serve as a marker of intrinsic stability and predictor for postoperative alignment changes. This finding paves the way for surgical decision-making and future research in OPLL management.

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Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

The authors have introduced a new rational biomechanical concept of a true continuous segment acting as a negative predictor factor for delayed cervical kyphosis following laminectomy. This concept is based upon the idea that if clinicians are able to predict which patients have intrinsic posterior column fusion to the extent that kyphosis is less likely, it may be reasonable to proceed with laminoplasty alone rather than laminectomy and fusion. The study was successful in demonstrating a negative correlation between true continuous segment and kyphosis progression. However, it is striking that this radiological difference has not yet translated into clinical benefit with mJOA scores and recovery rates being similar. Readers should also consider that other factors, such as paraspinal musculature cross-sectional area and length of the lever created by ossified posterior longitudinal fusion, are factors which also should be considered. Further randomized and prospective studies in this field are still required.

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