



# Clinically significant radiographic parameter for thoracic myelopathy caused by ossification of the ligamentum flavum

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## Abstract

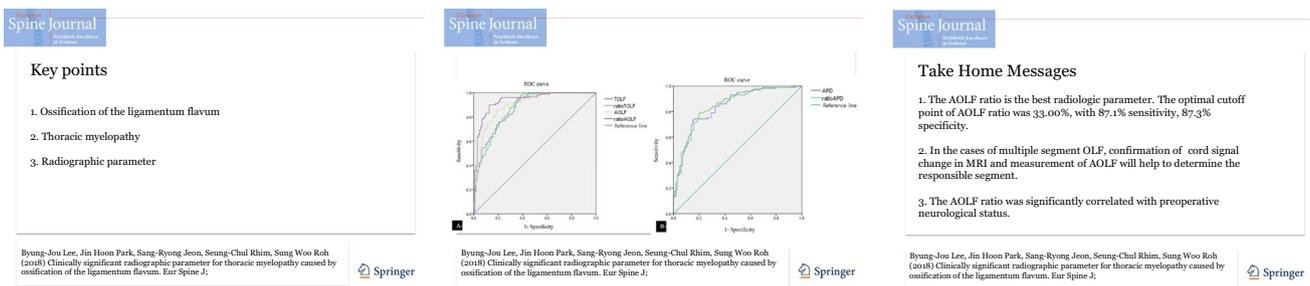
**Purpose** To investigate radiographic parameters to improve the accuracy of radiologic diagnosis for ossification of ligamentum flavum (OLF)-induced thoracic myelopathy and thereby establish a useful diagnostic method for identifying the responsible segment.

**Methods** We classified 101 patients who underwent surgical treatment for OLF-induced thoracic myelopathy as the myelopathy group and 102 patients who had incidental OLF and were hospitalized with compression fracture as the non-myelopathy group between January 2009 and December 2016. We measured the thickness of OLF (TOLF), cross-sectional area of OLF (AOLF), anteroposterior canal diameter, and the ratio of each of these parameters.

**Results** Most OLF cases with lateral-type axial morphology were in the non-myelopathy group and most with fused and tuberosus type in the myelopathy group. Most grade-I and grade-II cases were also in the non-myelopathy group, whereas grade-IV cases were mostly observed in the myelopathy group. The AOLF ratio was found to be the best radiologic parameter. The optimal cutoff point of the AOLF ratio was 33.00%, with 87.1% sensitivity and 87.3% specificity. The AOLF ratio was significantly correlated with preoperative neurological status.

**Conclusions** An AOLF ratio greater than 33% is the most accurate diagnostic indicator of OLF-induced thoracic myelopathy. In cases of multiple-segment OLF, confirmation of cord signal change on MRI and an AOLF measurement will help determine the responsible segment. AOLF measurement will also improve the accuracy of diagnosis of OLF-induced thoracic myelopathy in cases of grade III or extended-type axial morphology.

**Graphical abstract** These slides can be retrieved under Electronic Supplementary Material.



**Keywords** Ossification of ligamentum flavum · Thickness of ligamentum flavum · Area of ligamentum flavum · Thoracic myelopathy · Optimal cutoff point

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Extended author information available on the last page of the article

## Introduction

Thoracic ossification of the ligamentum flavum (OLF) is a commonly reported cause of thoracic myelopathy [1, 2]. Thickening of the OLF can compress the dural sac and nerve root, thereby reducing the diameter of the spinal canal and contributing to the progression of myelopathy [3, 4]. OLF accounts for 40–60% of the single-segment and 10–25% of the multi-segment cases [5]. We have found that 20% of surgically treated patients with OLF have multi-segment OLF. Hence, it is difficult to determine the segment responsible for the thoracic myelopathy in cases with multiple-segment stenosis. This diagnostic difficulty is also related to the surgical plan. It is necessary to establish a simple and accurate method of identifying the responsible segment in OLF-induced thoracic myelopathy. Here, we analyzed radiographic parameters to identify the exact causative segment in patients with OLF-induced thoracic myelopathy, and thereby established a useful diagnostic method for evaluating such cases.

## Materials and methods

### Patients

This study was registered at a single institute and our institutional review board approved the research protocol. We retrospectively analyzed 161 consecutive patients who underwent decompressive laminectomy for OLF with sensory and motor deficits, gait disturbance, or urinary symptoms due to OLF-induced myelopathy between January 2009 and December 2016. Patients were excluded if they met any one of the following criteria: (1) accompanying ventral compressive lesions, such as ossification of the posterior longitudinal ligament (OPLL) and thoracic disk herniation; (2) a history of surgical intervention for cervical myelopathy, or (3) accompanying lumbar spinal disease that required surgical treatment. A final cohort of 101 patients was enrolled as the myelopathy group. A modified Japanese Orthopedic Association (JOA) scoring system was used to preoperatively evaluate the neurological status of each patient (Table 1). A total of 456 patients diagnosed and hospitalized with thoracic- and lumbar-compression fracture during the same period were also retrospectively reviewed. From this population, we identified 102 patients with thoracic OLF but no definite neurological signs (JOA scores = 11) and enrolled these patients as the non-myelopathy group.

### Morphologic classification and canal compromise grading

Computed tomography (CT) and magnetic resonance imaging (MRI) scans with whole-spine T2-weighted sagittal images were available for review in the myelopathy

**Table 1** Modified Japanese Orthopedic Association (mJOA) scoring system for the assessment of thoracic myelopathy

Neurological status	Score
Lower-limb motor dysfunction	
No dysfunction	4
Lack of stability and smooth reciprocation of gait	3
Able to walk on flat floor with walking aid	2
Able to walk up-/downstairs with handrail	1
Unable to walk	0
Lower-limb sensory deficit	
No deficit	2
Mild sensory deficit	1
Severe sensory loss or pain	0
Trunk sensory deficit	
No deficit	2
Mild sensory deficit	1
Severe sensory loss or pain	0
Sphincter dysfunction	
No dysfunction	3
Minor difficulty in micturition	2
Marked difficulty in micturition	1
Unable to void	0
Total	11

group, whereas MRI and CT scans of only the thoracic spine were available in the non-myelopathy group. Two observers with more than 5 years of experience in the spine field independently assessed these data. The intra-examiner reproducibility and inter-examiner reliability were evaluated using the intraclass correlation coefficient.

Thoracic OLF was morphologically classified using a modified version of the Sato classification method (lateral/extended, enlarged, or fused/tuberous type) on axial CT images [3] and Kuh classification (beak or round type) on sagittal MR images, as previously described by Kang et al. [6] (Fig. 1).

The degree of spinal canal compromise was graded on axial T2-weighted MRI using the method of Feng et al. [7] as follows:

Grade I: OLF is present but the thecal sac has not yet been compressed or the OLF is only in contact with the thecal sac.

Grade II: the thecal sac is compressed and deformed but the OLF is not in contact with the spinal cord.

Grade III: the subarachnoid space is partially occluded and the OLF is in contact with the spinal cord, but the spinal cord is not yet deformed.

Grade IV: the spinal cord is obviously compressed and deformed.



**Fig. 1** Morphological classifications of thoracic ossification of the ligamentum flavum. **A–E** Sato classification, **A** lateral type, **B** extended type, **C** enlarged type, **D** fused type, **E** tuberous type. Kuh's classification, **F, G** Kuh's classification, **F** beak type, **G** round type

The location of the OLF was determined as being around the joint capsules of the facet joints and/or the medial lamina.

### Radiographic parameters and measurements

Six radiographic parameters were measured on CT, as follows; thickness of OLF (TOLF), TOLF ratio, area of OLF (AOLF), AOLF ratio, anteroposterior canal diameter (APD), and APD ratio.

#### 1. TOLF and TOLF ratio

Measurements were made in the axial area of the thickest part of the OLF, regardless of the shape of the OLF. The TOLF was measured by drawing a line along the side of the ligament facing the spinal canal and along the laminal side of the curve of the ligament and by recording the thickest point [8]. The TOLF ratio was calculated as follows: TOLF of affected segment/normal APD (average of normal APD just above and below the affected segment where there is no ossification but the distance between the pedicles is the widest)  $\times 100$  (Fig. 2).

#### 2. AOLF and AOLF ratio

The AOLF was measured as the cross-sectional area of the OLF at the thickest point in the axial view; the AOLF ratio (%) was measured as AOLF/normal canal area  $\times 100$ . The normal canal area is the average normal canal area just above and below the affected segment where there is no ossification but where the distance between the pedicles is the widest (Fig. 3).

#### 3. APD and APD ratio

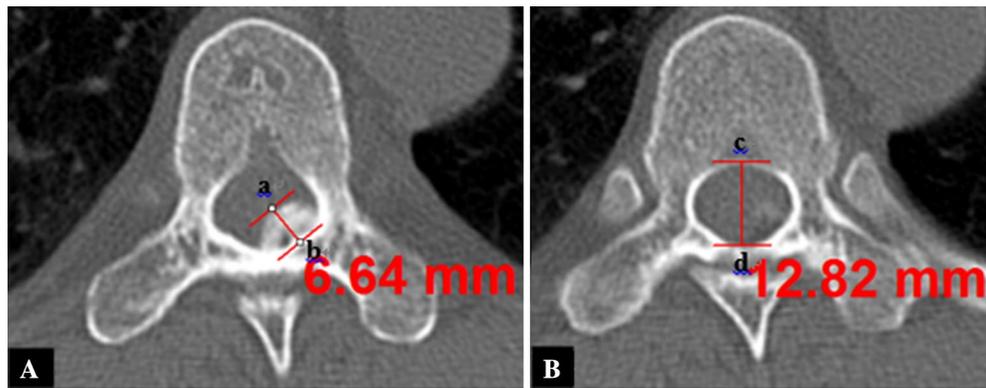
We measured the APD using the paramedian diameter described by Feng et al. [7]. The paramedian diameter is the spinal diameter between the midline and the boundary of the canal at the maximally stenosed level. The APD ratio was calculated as follows: APD/normal anteroposterior diameter  $\times 100$  (Fig. 4).

### Statistical analysis

We compared the clinical and radiologic data for the myelopathy and non-myelopathy groups. The receiver operating characteristic (ROC) curve was used to determine the best cutoff value of the parameters for diagnosing OLF-induced thoracic myelopathy. Pearson's correlation coefficients were used to analyze the association between radiographic parameters for thoracic myelopathy and the preoperative neurological status (determined by the JOA score). SPSS version 20 software (IBM Corporation, Armonk, NY) was used for these statistical analyses.

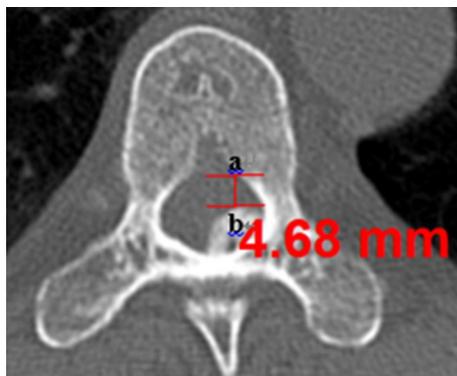
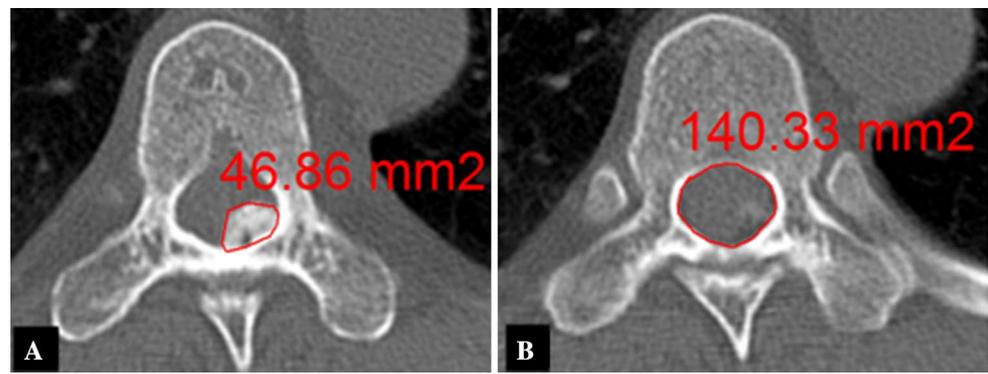
### Results

There were 43 (42.6%) men and 58 (57.4%) women with a mean age of  $62.52 \pm 11.20$  years (range, 24–86 years) in the myelopathy group and 48 (47.1%) men and 54 (52.9%) women with a mean age of  $63.07 \pm 12.03$  years (range, 25–90 years) in the non-myelopathy group. No significant variation in age ( $p = 0.73$ ) or sex ( $p = 0.52$ ) distribution was observed between these two groups. The mean



**Fig. 2** Measurements of the thickness of ossification of the ligamentum flavum (TOLF). **A** In the axial view, the TOLF is indicated by *a–b*. **B** The normal anteroposterior canal diameter is indicated by *c–d*

**Fig. 3** Measurement of the cross-sectional area of ossification of the ligamentum flavum (AOLF). **A** In the axial view, the AOLF is at the thickest point. **B** In the axial view, the normal canal area is just above and below the affected segment



**Fig. 4** Measurement of the anteroposterior canal diameter (APD). *a–b* indicate the APD

preoperative modified JOA score was  $7.45 \pm 1.48$  in the myelopathy group. The intra- and inter-examiner reliabilities showed strong agreement in the parameter measurements (intraclass, and interclass correlation coefficient, 0.88, and 0.85).

### Comparison of morphologic classification and canal grading between groups

The most commonly affected segment was T10-11, with 37.6% and 42.2% in the myelopathy and non-myelopathy groups, respectively. In the myelopathy group, 98 patients (97.0%) had cord signal change on T2-weighted MRI. The most common morphologic configuration in the axial view was the enlarged type in the myelopathy group and the lateral type in the non-myelopathy group. The configuration in the sagittal view did not differ between the two groups. In the myelopathy group, there were no grade-I cases, while there were four grade-II occupation on T2-weighted MRI cases (4.0%), 49 grade-III cases (48.0%), and 48 grade-IV cases (47.5%). In the non-myelopathy group, there were 50 grade-I cases (49.0%), 27 grade-II cases (26.5%), 23 grade-III cases (22.5%) and two grade-IV cases (2.0%). There were statistically significant differences in cord signal change, configuration (axial), and grade between the two groups ( $p < 0.01$ ), but not in age, sex, location, or configuration (sagittal) (Table 2).

## The AOLF ratio can most accurately diagnose OLF-induced thoracic myelopathy

The average TOLF and TOLF ratio were  $3.94 \pm 1.03$  mm and  $30.7 \pm 8.26\%$  in the non-myelopathy group and  $5.84 \pm 1.54$  mm and  $45.17 \pm 10.10\%$  in the myelopathy group, respectively. The average AOLF and AOLF ratio were  $33.85 \pm 16.05$  mm<sup>2</sup> and  $21.73 \pm 10.36\%$  in the non-myelopathy group and  $65.93 \pm 24.14$  mm<sup>2</sup> and  $43.12 \pm 10.72\%$  in the myelopathy group, respectively. The mean APD and APD ratio were  $5.94 \pm 1.48$  mm and  $46.09 \pm 10.81\%$  in the non-myelopathy group and  $4.09 \pm 1.23$  mm and  $31.88 \pm 9.46\%$  in the myelopathy group, respectively. There were statistically significant differences in all parameters between the

**Table 2** Comparison of morphologic classification and canal grading between the myelopathy and non-myelopathy study groups

Variable	Non-myelopathy group	Myelopathy group	<i>p</i> value
Location of OLF			0.47
T1-2	0	0	
T2-3	3	4	
T3-4	5	2	
T4-5	3	2	
T5-6	3	0	
T6-7	0	0	
T7-8	1	2	
T8-9	4	3	
T9-10	7	13	
T10-11	43	38	
T11-12	33	35	
T12-L1	0	2	
Cord signal change on MRI			<0.01
No	94	3	
Yes	8	98	
Morphologic classification			
Axial			<0.01
Lateral	60	1	
Extended	25	13	
Enlarged	16	68	
Fused	1	9	
Tuberous	0	10	
Sagittal			0.87
Beak	17	16	
Round	85	85	
Canal compromise grade			<0.01
Grade I	50	0	
Grade II	27	4	
Grade III	23	49	
Grade IV	2	48	

OLF ossification of the ligamentum flavum

two groups (Table 3). The ROC curves indicated that the AOLF ratio is the most accurate parameter for diagnosing OLF-induced thoracic myelopathy with an AUC of 0.934 (95% CI, 0.899–0.969) (Fig. 5). The optimal cutoff point of the AOLF ratio was measured at 33.00%, with 87.1% sensitivity and 87.3% specificity (Table 4). Pearson correlation coefficients indicated that AOLF ratio was significantly correlated with the preoperative neurological status ( $r = -0.72$ ,  $p < 0.001$ ). Results from the analysis of preoperative myelopathy severity and the AOLF ratio are presented in Table 5.

## Discussion

In multi-segmental OLF, not every segment will cause thoracic myelopathy, and it is therefore difficult to identify in these patients the segment responsible for spinal-cord injury. If the segment causing the cord injury can be accurately identified, however, errors at the surgical level and in the range of decompression would likely be reduced.

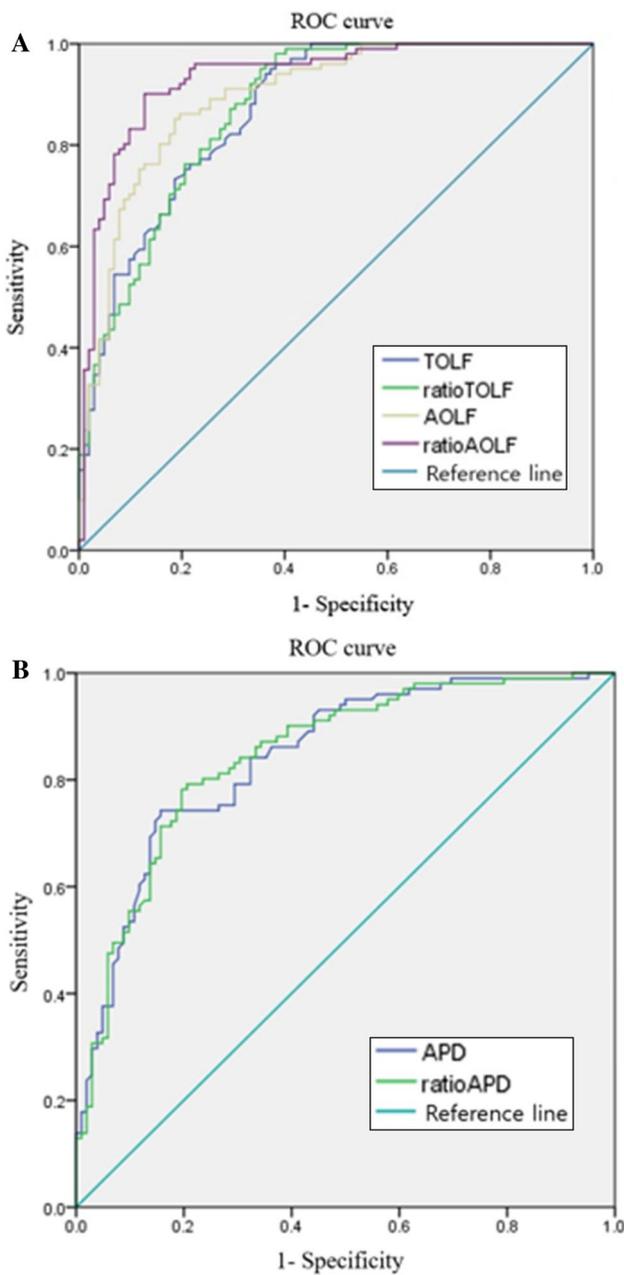
Previously, several studies showed that electrophysiological examination could be also helpful for determining the necessary decompression level for thoracic myelopathy surgery [9–11]. Other studies reported that MRI is the most important modality for detecting OLF-induced thoracic myelopathy [12]. Thoracic myelopathy can be identified by cord signal change on T2-weighted images [13]. Here, 97% of the patients with thoracic myelopathy showed cord signal change on MRI. However, in patients with a continuous multiple-segment OLF, the cord signal change extends over several levels. It can thus be difficult in these cases to determine which segment has caused the change and to decide the level of surgical decompression (Fig. 6). In such instances, however, we speculated that confirmation of cord signal change on MRI and subsequent measurement of a reliable radiologic parameter would improve the accuracy of an OLF-induced

**Table 3** Comparison of radiographic parameters between the myelopathy and non-myelopathy study groups

Variable	Non-myelopathy group	Myelopathy group	<i>p</i> value
TOLF (mm)	$3.94 \pm 1.03$	$5.84 \pm 1.54$	<0.01
Ratio of TOLF (%)	$30.71 \pm 8.26$	$45.17 \pm 10.10$	<0.01
AOLF (mm <sup>2</sup> )	$33.85 \pm 16.05$	$65.93 \pm 24.14$	<0.01
Ratio of AOLF (%)	$21.73 \pm 10.36$	$43.12 \pm 10.72$	<0.01
APD (mm)	$5.94 \pm 1.48$	$4.09 \pm 1.23$	<0.01
Ratio of APD (%)	$46.09 \pm 10.81$	$31.88 \pm 9.46$	<0.01

Data presented as means  $\pm$  standard deviations

TOLF thickness of the ossification of the ligamentum flavum, AOLF cross-sectional area of the ossification of the ligamentum flavum, APD anteroposterior canal diameter



**Fig. 5** Receiver operating characteristic (ROC) curve of the measurements. **A** Thickness of ossification of the ligamentum flavum (TOLF), TOLF ratio, cross-sectional area of ossification of the ligamentum flavum (AOLF), and AOLF ratio. **B** Anteroposterior canal diameter (APD), and APD ratio

thoracic myelopathy diagnosis. Here, most lateral types of axial morphology were evident in the non-myelopathy group and most fused, tuberos, and enlarged types were evident in the myelopathy group. However, the myelopathy group included 13 patients with the extended type, whereas the non-myelopathy group included 25 of these patients. This result indicated that diagnostic accuracy for myelopathy is poor in the extended type. Here also, all grade-I cases were

**Table 4** Cutoff values for the study parameters

Measurements	Sensitivity (%)	Specificity (%)
<b>TOLF (mm)</b>		
4.82*	73.3	81.4
4.84	71.3	81.4
4.87	70.3	81.4
<b>Ratio of TOLF (%)</b>		
36.73*	79.2	76.5
36.81	78.2	76.5
36.97	77.2	76.5
<b>AOLF (mm<sup>2</sup>)</b>		
47.42	82.2	81.4
47.73*	82.2	82.4
48.09	81.2	82.4
<b>Ratio of AOLF (%)</b>		
33.00*	87.1	87.3
33.12	86.1	87.3
33.29	85.1	87.3
<b>APD (mm)</b>		
5.17*	79.2	70.6
5.21	79.2	69.6
5.23	79.2	68.6
<b>Ratio of APD (%)</b>		
39.77	79.2	76.5
39.89*	80.2	76.5

TOLF thickness of the ossification of the ligamentum flavum, AOLF cross-sectional area of the ossification of the ligamentum flavum, APD anteroposterior canal diameter

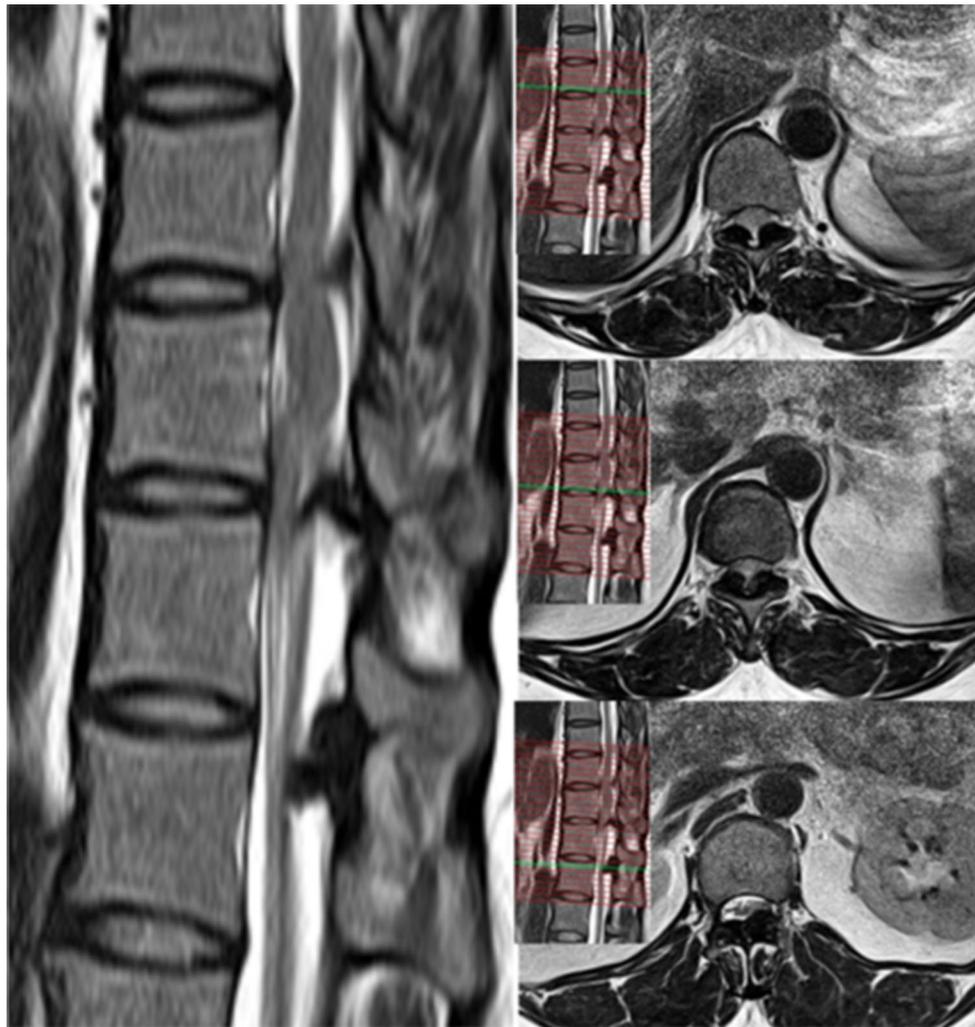
\*The best cutoff point on the receiver operating characteristic curve

**Table 5** Relationship between ratio of AOLF and severity of preoperative myelopathy

Preoperative myelopathy severity	No. of patients	JOA score (mean)	Ratio of AOLF
≥ 8	55	8.54 ± 0.57	37.25 ± 6.50%
5–7	39	6.56 ± 0.64	47.35 ± 8.61%
≤ 4	7	3.85 ± 0.37	65.68 ± 6.26%
<i>p</i> value			< 0.01

AOLF cross-sectional area of the ossification of the ligamentum flavum, JOA Japanese Orthopedic Association

in the non-myelopathy group and there were 27 grade-II cases in the non-myelopathy group but only four grade-II cases in the myelopathy group. In contrast, there were 48 grade-IV cases in the myelopathy group but only two of these cases in the non-myelopathy group. Hence, most of the grade-I and grade-II cases were in the non-myelopathy group, whereas grade IV was much more prominent in the myelopathy group. In terms of grade-III cases, there were



**Fig. 6** Continuous multiple-segment ossification of the ligamentum flavum

49 in the myelopathy group and 23 in the non-myelopathy group. The 23 grade-III cases in the non-myelopathy group showed obvious cord compression but no neurological signs. These results indicated that the MRI grading system alone can be inaccurate in determining the exact segment responsible for OLF-induced thoracic myelopathy in grade-III cases and that the interpretation of grade III depends on the experience and subjective judgement of the treating physician. In addition, MRI examination may be impossible in some patients with embedded metal medical devices or in economically disadvantaged countries. However, we showed the validation of CT-based measurement in this study and believed that the CT scan could in the future be used as the only imaging modality required for making a decision.

Measurement of the APD (paramedian) that has been compromised by OLF has been proposed as a method of diagnosing OLF-induced myelopathy [7]. It was also previously reported that a canal diameter (paramedian) of < 60%

on axial CT scan can serve as a critical diagnostic indicator of OLF-induced myelopathy with 95.5% sensitivity and 95.5% specificity [7]. According to the OLF growth pattern, ossification usually begins in the capsular portion, grows into the lamina portion, and finally enlarges anteriorly toward the spinal cord [14]. Hence, measurements of the APD between the middle line and lateral boundary of the spinal canal have been presented. However, if ossification shows bilateral growth, it is then unclear which side to measure. When ossification shows dominant growth in the middle line or lateral side and compresses the cord, a paramedian measurement does not reflect the degree of cord compression. Munns et al. [15] demonstrated differences between the medial and lateral thicknesses of the LF and emphasized that single measurements ignore possible differences in the location and laterality of stenosis. Additionally, enlargement of the LF is sometimes unilateral due to asymmetrical mechanical stress [16–19]. Thus, measurement errors could

occur at any time in these patients. Here, the AOLF had higher sensitivity and specificity than any other parameter in diagnosing OLF-induced thoracic myelopathy. Therefore, the AOLF can directly reflect the degree of compression and has the highest correlation and diagnostic value in cases of OLF-induced thoracic myelopathy.

OLF that only compresses the dural sac can also cause myelopathy because the static pressure of the OLF caused by the flow wave of the CSF acts on the spinal cord. The flowing fluid can press through the narrowed segment caused by the OLF. Additionally, OLF can intermittently press the spinal cord via various external forces such as flexion and extension [20]. Cases with an AOLF ratio greater than 33% may have reached the threshold for myelopathy due to this biomechanical mechanism, even if there is no definite cord compression. We also analyzed the relationship between various parameters and preoperative neurological deficits. Sanghvi et al. [1] previously reported that the preoperative dural canal diameter significantly correlates with preoperative neurological status ( $r$  coefficient = 0.41,  $p < 0.039$ ) in OPLL cases. Here, AOLF also showed a correlation with preoperative neurological status. We found that the extent of the lesion is related to the preoperative state.

A tuberos type of axial morphology or grade-IV compression is reportedly causative of thoracic myelopathy, and surgical treatment should be considered in these patients. However, in the case of grade III or extended-type axial morphology, measurement of the AOLF will improve the accuracy of diagnosing OLF-induced thoracic myelopathy. In cases with continuous multiple-segment OLF, a confirmation of cord signal change on MRI and an AOLF measurement will also help determine the responsible segment.

Our study had limitations. First, as the incidence of OLF is low, we only had access to a small sample. Second, there may have been errors associated with parameter measurements on MRI or CT due to differences in cutting angles and levels, possibly owing to technical problems or individual anatomical variations. Third, the evaluation of the entire spine was not clear in the non-myelopathy group because whole-spine MRIs were not available. Thus, cord compression lesions at other segments may not have been included. Fourth, the prevalence of OLF is higher among Asian populations. Our results were only drawn from patients at the single institute located in a single Asian country. Because of ethnicity-related anatomical variations, our results cannot be applied worldwide. Additionally, our results do not apply to individuals with different canal sizes, as seen in achondroplasia, ankylosing spondylitis, or acromegaly. Fifth, this study has the methodological limitation of having recruited non-comparable patient groups. Because asymptomatic individuals do not ordinarily undergo MRI examination, we inevitably collected MRI data of patients who had stable compression fracture. We believe that it is necessary to

perform a similar well-designed prospective analysis based on our retrospective results to validate our findings.

## Conclusions

An AOLF ratio greater than 33% is the most relevant parameter on axial CT scan for the diagnosis of OLF-induced thoracic myelopathy. In cases of multiple-segment OLF, confirmation of cord signal change on MRI and AOLF measurements will help determine the responsible segment. Measuring the AOLF will also improve diagnostic accuracy in cases of grade-III OLF-induced thoracic myelopathy or of an extended type of axial morphology.

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## Compliance with ethical standards

**Conflict of interest** The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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