The influence of ossification morphology on surgery outcomes in patients with thoracic ossification of ligamentum flavum (TOLF)

Peiyu Du†, Lei Ma† and Wenyuan Ding* "© The Author(s) 2022.

RESEARCH ARTICLE

Open Access

The influence of ossification morphology on surgery outcomes in patients with thoracic ossification of ligamentum flavum (TOLF)

Peiyu Du†, Lei Ma† and Wenyuan Ding*© The Author(s) 2022.

Abstract

Background: To determine whether there is a correlation between the type of ossification and radiological parameters, modified thoracic JOA scores, and complications in patients with thoracic ossification of ligamentum flavum treated by posterior thoracic surgery.

Methods: This retrospective cohort study included 48 patients with thoracic myelopathy caused by single-level thoracic ossification of ligamentum flavum who underwent thoracic posterior approach surgery in our Hospital between December 2013 to December 2018. Patients were divided into unilateral, bilateral, and bridged groups in axial position, and beak and round groups in sagittal position. The differences were analyzed according to the ossification morphology.

Results: In axial myelopathy, there was no significant difference in preop and postop JOA scores and RR among the three groups in axial position (P = 0.884). In sagittal view, there was no significant difference in preoperative JOA score between the two groups (P = 0.710), while the postop JOA score and the recovery rate in the beak group were significantly lower than that of the round group (P = 0.010, P = 0.034). Two-way ANOVA showed that sagittal morphology had a significant effect on postop JOA score (P = 0.028), but axial morphology don't (P = 0.431); there was no interaction between them (P = 0.444). For the recovery rate, sagittal morphology also had a significant effect (P = 0.043), but axial ossification don't (P = 0.998); there was no interaction between them (P = 0.479).

Conclusion: Sagittal morphology had a significant adverse effect on postop JOA score and surgical outcome, while axial morphology had no effect on surgical outcome, and there was no interaction between sagittal morphology and axial morphology.

Keywords: Ossification morphology, TOLF, Surgical outcomes, Spine surgery, Thoracic spine

Background

Thoracic ossification of ligamentum flavum (TOLF) is one of the ectopic ossification diseases of the spinal ligament. It can lead to thoracic spinal canal stenosis and is the most common cause of thoracic myelopathy. Ligamentum flavum is attached to the lower half in front of the upper lamina and the back and upper margin of the lower lamina, while the lateral attachment of the ligamentum extends to the intervertebral capsule and medially to the place where bilateral lamina forms the spinous process, which is one of the supporting structures of the posterior column of the spine. When the ligamentum flavum is replaced by mature bone, the ossified ligament compresses the posterior column. The ossified ligaments initially press against the posterior column, producing symptoms of walking...
instability similar to posterior cord syndrome. As the disease progresses, it develops into spastic motor paralysis or even paralysis [2].

Previous studies have shown that the incidence of ossification of ligamentum flavum (OLF) is very low [3], which may be related to the absence of obvious symptoms in the early stage. A large-scale epidemiological study showed that the incidence of OLF in thoracic vertebrae was 63.9%, and some of these affected individuals were adolescents [4]. Also, the highest prevalence of TOLF has been found in the Japanese population, followed by South Korea [5] and China [6]. Only a few cases were found even outside Asia [2].

In the past, OLF was often thought to be mainly related to genetic and dietary factors. However, following the reports of worldwide OLF cases, biomechanical factors came to be seen as the main cause of OLF [7]. Kuh et al. [8] classified ligamentum flavum into beak type and round type in sagittal position, and unilateral type, bilateral type, and bridged type in axial position according to different ossification morphology. Once diagnosed with the OLF, conservative treatment is often ineffective, and surgery is required. According to previous studies, the prognosis of patients is affected by various factors, such as the number of ossified segments, canal occupation rate, an intramedullary signal change, etc. However, for the type of TOLF, different studies have drawn different conclusions, and no study has specifically researched the relationship between surgery outcomes and ossification morphology.

The aim of this study was to conduct a retrospective cohort analysis to determine whether there is a correlation between the type of ossification and radiological parameters, modified thoracic JOA scores, and complications in patients with thoracic myelopathy due to single-level TOLF treated by posterior thoracic surgery.
round groups in the sagittal position (Figs. 1, 2). The ethics review committee of our Hospital approved the study.

**Operation method**

All patients were treated by experienced spinal surgeons with posterior laminectomy and resection of the ligamentum flavum of the ossified segment. The following were the key procedures: (1) intraoperative x-rays were used to locate the OLF segment and expose the posterior spine through a midline incision at the posterior part of the ossified segment; (2) the spinous process was excised, and the lamina and articular process were excised by rongeurs and high-speed drill; (3) the epidural fat and dura were dissected under the ossified mass; (4) the ossified mass was carefully removed with rongeurs. For increase stability, posterior internal fixation was performed by pedicle screws. (5) Sutures were made layer by layer, and the subfascial drain was placed for posterior wounds.

**Definition and measurement methods**

1. D1 and D2 were the maximum distances measured from the bilateral ossification mass to the inner edge of the lamina, where the larger one was Dmax. D is the perpendicular distance from the intersection of the canal occupation rate (APD) and the posterior vertebral wall to X1 or X2. Canal occupation rate (COR) was calculated using the following formula \[ \text{COR} = \frac{(D1 + D2)}{2D} \times 100\% \]. Considering that some patients only have unilateral ossification or unilateral ossification mass compresses the spinal cord much more than the contralateral, we used unilateral maximum canal occupation rate (umCOR) to indicate the percentage of the larger side ossified mass area to half of the spinal canal area. Unilateral maximum canal occupation rate (umCOR) = Dmax/D*100%.

2. The intramedullary hypersignal was observed at the sagittal position of MRIT2-weighted image before surgery.

3. Preoperative and postoperative neurological status were assessed by using modified Japanese Orthopaedic Association (JOA) Scores [10]. Recovery rate = Postoperative JOA - Preoperative JOA / (11 - Preoperative JOA) * 100%

**Statistical analysis**

SPSS 25.0 (IBM, Armonk, NY, USA) was used for the analysis. The measurement data between the two groups were compared using the independent sample T-test or Mann–Whitney test, according to the normal distribution and homogeneity of variance. ANOVA test or Kruskal–Wallis test was used to compare the measurement data among the three groups according to whether they were in accordance with normal distribution and homogeneity of variance. According to the expected value, counting data were compared between the two groups using Pearson test or continuous corrected Chi-square test. Counting data were compared between the three groups using Pearson’s test or Fisher’s exact probability method according to the expected value. \( P < 0.05 \) was considered to be statistically significant (Table 1).
Results
A total of 48 patients, 29 males and 19 females, with a mean age of 58.35 years (range 31–77 years) with thoracic myelopathy due to single-level TOLF were included in the study. Table 2 shows the descriptive characteristics of patients grouped by axial position, i.e., Unilateral (n = 14), Bilateral (n = 18), and Bridged (n = 16), and descriptive features of patients grouped by sagittal location as Beak (n = 19) and Round (n = 29). It can be seen that there was no significant difference in the number of patients with the three ossification types in the axial view (P > 0.05), while in the sagittal view, there were more

| Table 1 | Revised Japanese orthopaedic association scoring system |
|---------|--------------------------------------------------------|
| Motor function: lower extremity | Unable to stand up and walk by any means 0 |
| | Able to stand up but unable to walk 0.5 |
| | Unable to walk without a cane or other support on a level 1 |
| | Able to walk without support but with a clumsy gait 1.5 |
| | Walks independently on a level but needs support on stairs 2 |
| | Able to walk independently when going upstairs, but needs support when going downstairs 2.5 |
| | Capable of fast but clumsy walking 3 |
| Normal | |
| Sensory function: lower extremity | Complete loss of touch and pain sensation 0 |
| | 50% or less normal sensation and/or severe pain or numbness 0.5 |
| | More than 60% normal sensation and/or moderate pain or numbness 1 |
| | Subjective numbness of slight degree without any objective sensory deficit 1.5 |
| Normal | |
| Sensory function: trunk | Complete loss of touch and pain sensation 0 |
| | 50% or less normal sensation and/or severe pain or numbness 0.5 |
| | More than 60% normal sensation and/or moderate pain or numbness 1 |
| | Subjective numbness of slight degree without any objective sensory deficit 1.5 |
| Normal | |
| Bladder function | Urinary retention and/or incontinence 0 |
| | Sense of retention and/or dribbling and/or thin stream and/or incomplete continence 1 |
| | Urinary retardation and/or polyuria 2 |
| Normal | |
| Total score | 11 |

| Table 2 | Characteristics of patients divided by axial ossification type and sagittal ossification type |
|---------|-----------------------------------------------------------------------------------------|
| | Unilateral | Bilateral | Bridged | P value | Beak | Round | P value |
| No. of patients | 14 | 18 | 16 | … | 19 | 29 | … |
| Sex | | | | | | | |
| Male | 8 | 12 | 9 | 0.789 | 10 | 19 | 0.372 |
| Female | 6 | 6 | 7 | | 9 | 10 | |
| Age, mean ± SD, years | 60.5 ± 11.26 | 56.83 ± 7.12 | 58.19 ± 9.91 | 0.552 | 61.47 ± 7.63 | 56.31 ± 9.89 | 0.060 |
| Symptom duration, Q50 (Q25, Q75), month | 6.5 (1.875, 36) | 10 (2, 36) | 6 (2.25, 22.75) | 0.719 | 12 (2, 36) | 6 (2, 18) | 0.380 |
| Heart disease, no. (%) | 4 (28.6) | 5 (27.8) | 5 (31.3) | 1.000 | 6 (31.6) | 8 (27.6) | 0.766 |
| Diabetes, no. (%) | 2 (14.3) | 2 (11.1) | 1 (6.3) | 0.850 | 3 (15.8) | 2 (6.9) | 0.615 |
| Hypertension, no. (%) | 6 (42.9) | 7 (38.9) | 4 (25.0) | 0.551 | 7 (36.8) | 10 (34.5) | 0.867 |
| Bowel or bladder symptoms, no. (%) | 5 (35.7) | 9 (50.0) | 6 (37.5) | 0.659 | 9 (47.4) | 11 (37.9) | 0.517 |

SD = standard deviation
patients with round type than beak type \( (P < 0.05) \). Statistical comparisons showed that the descriptive characteristics of patients with various ossification types were similar \( (P > 0.05) \). In terms of comorbidities, there were no significant differences among patients with different ossification types \( (P > 0.05) \).

**Surgical methods and imaging parameters**

Table 3 shows the comparison of axial parameters of different ossification types. In terms of COR, the unilateral group was \( 22.68\% \pm 5.54\% \), the bilateral group \( 38.42\% \pm 9.69\% \), and the bridge group \( 41.63\% \pm 9.13\% \); there were significant differences among the three groups \( (P < 0.001) \). For umCOR, there was no difference as \( 45.36\% \pm 11.09\% \) in the unilateral group, \( 47.41\% \pm 13.60\% \) in the bilateral group and \( 51.23\% \pm 14.57\% \) in the bridge group \( (P = 0.470) \).

In order to clarify intra-group differences, pairwise comparisons were made between the three groups in terms of COR, umCOR, and surgical methods (Table 4), revealing significant differences in spinal canal occupancy between the unilateral group and bilateral group \( (P < 0.001) \) and bridged group \( (P < 0.001) \), while there was no significant difference between bilateral group and bridged group \( (P = 0.278) \), or in umCOR among the three groups. In the unilateral group, 1 case was located in the upper thoracic vertebrae (T1–T4), 2 in the middle thoracic vertebrae (T5–T9), and 11 in the lower thoracic vertebrae (T10–T12). In the bilateral group and the bridged group, the data were 3, 1, 14, and 4, 4, 8, respectively. There were no significant differences in ossification levels among the three groups \( (P = 0.323) \). There were also no significant differences \( (P > 0.05) \) between the three ossification types in the presence of a high signal on MRIT2-weighted image and the presence of dural ossification on CT.

As for the choice of surgical methods, most patients from the unilateral group chose laminectomy alone \( (n = 8, 57.14\%) \), while the bridged group had the highest proportion of laminectomy and internal fixations \( (n = 13, 81.25\%) \). Although there was no difference between the three groups \( (P = 0.88) \), there was a significant difference between the unilateral group and the bridge group \( (P = 0.029) \) (Table 4).

---

**Table 3** Surgical data of patients divided by axial ossification type and sagittal ossification type

|                  | Unilateral \( (n = 14) \) | Bilateral \( (n = 18) \) | Bridged \( (n = 16) \) | \( P \) value | Beak \( (n = 19) \) | Round \( (n = 29) \) | \( P \) value |
|------------------|--------------------------|--------------------------|------------------------|---------------|----------------|----------------|---------------|
| COR, mean ± SD, %| 22.68 ± 5.54             | 38.42 ± 9.69             | 41.63 ± 9.13           | \( <0.001 \)* | 31.66 ± 10.06 | 37.02 ± 12.15 | 0.117         |
| umCOR, mean ± SD, %| 45.36 ± 11.09           | 47.41 ± 13.60           | 51.23 ± 14.57          | 0.470         | 47.12 ± 13.72 | 48.72 ± 13.06 | 0.685         |
| OLF level        |                          |                          |                        |               |                 |                 |               |
| T1–T4, no. (%)  | 1 (7.1)                  | 3 (14.7)                 | 4 (25.0)               | 0.323         | 2 (10.5)       | 4 (13.8)       | 0.906         |
| T5–T9, no. (%)  | 2 (14.3)                 | 1 (5.56)                 | 4 (25.0)               | 3 (15.8)      | 6 (20.7)       |                 |               |
| T10–T12, no. (%)| 11 (78.6)                | 14 (77.8)                | 8 (50.0)               | 14 (73.7)     | 19 (65.5)      |                 |               |
| Intramedullary signal change on T2WI, no. (%) | 7 (50.0) | 12 (66.7) | 11 (68.8) | 0.513 | 13 (68.4) | 17 (58.6) | 0.493 |
| DO, no. (%)      | 2 (14.3)                 | 5 (27.8)                 | 5 (31.3)               | 0.545         | 4 (21.1)       | 7 (24.1)       | 0.804         |
| Surgical methods |                          |                          |                        |               |                 |                 |               |
| Posterior decompression, no. (%) | 8 (57.1) | 6 (33.3) | 3 (18.8) | 0.880 | 8 (42.11) | 9 (31.0) | 0.433 |
| Posterior decompression with fusion, no. (%) | 6 (42.9) | 12 (66.7) | 13 (81.3) | – | 11 (57.9) | 20 (69.0) | – |

COR: canal occupation rate, umCOR: unilateral maximum of canal occupation, DO: dural ossification, SD: standard deviation

**Table 4** Pairwise comparison of partial surgical data of patients divided by axial ossification type

|                  | The \( P \) value for the unilateral group and bilateral group | The \( P \) value for the unilateral group and bridged group | The \( P \) value for the bilateral group and bridged group |
|------------------|-------------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|
| COR              | 0.667                                                       | 0.233                                                    | 0.407                                                    |
| umCOR            | \(<0.001*\)                                                 | \(<0.001*\)                                              | 0.278                                                    |
| Surgical methods |                                                              |                                                          |                                                          |
| Posterior decompression | 0.178                                                        | 0.029*                                                   | 0.448                                                    |

COR: canal occupation rate, umCOR: unilateral maximum of canal occupation

*Statistically significant difference \( (P < 0.05) \)
On the sagittal plane (Table 3), there was no difference between the beak group and the round group in terms of COR and umCOR (P=0.117) (P=0.685), and no significant difference in the ossification segment, which was the same as in the axial position (P=0.906). Also, ossification mostly occurred in the lower thoracic vertebrae. There was no significant difference between the two groups on imaging with high signal and dural ossification. In terms of selecting surgical methods, most patients from the two groups chose laminectomy and internal fixation; however, no significant difference was found (P > 0.05).

In terms of the axial position (Table 5), there was no significant difference in preoperative and postoperative JOA scores among the three groups, but after surgical treatment, the unilateral group improved from 6.11 ±2.22 points before surgery to 7.93 ±2.29 points (P<0.001); a bilateral group from 6.92 ±1.22 to 8.83 ±1.06 (P<0.001); the bridge group improved from 6.63 ±1.77 to 8.50 ±1.75 (P<0.001), but there was no difference in the improvement rate among them (P=0.884). In the sagittal position (Table 5), the JOA score in the beak group changed from 6.03 ±1.84 to 7.74 ±1.91 (P<0.001), while in a round group it changed significantly from 6.95 ±1.59 to 8.93 ±1.43 (P<0.001). There was no significant difference in preoperative JOA score between the two groups (P=0.710), while a significant difference was observed in postoperative JOA score and recovery rate between the two groups (P=0.017) (P=0.034).

The effect of sagittal and axial ossification types on preoperative and postoperative JOA score and the recovery rate was analyzed by two-factor ANOVA. Neither sagittal nor axial ossification type had any effect on preoperative JOA score (P=0.098, P=0.476, respectively), and there was no interaction between them (P=0.383) (Table 6). However, sagittal ossification had a significant effect on postoperative JOA score (P=0.028) (Table 7). Sagittal ossification also had a significant effect on the recovery rate (P=0.043), while axial ossification had no effect on the recovery rate (P=0.998), and there was no interaction between the two groups (P=0.479) (Table 8).

Postoperative complications observed in this study included hematoma, CSF leakage, immediate neurological deterioration, superficial infection, and deep infection (Table 5). Among the 44 patients, no postoperative

### Table 5  Surgery outcomes of patients divided by axial ossification type and sagittal ossification type

| JOA score          | Unilateral (n=14) | Bilateral (n=18) | Bridged (n=16) | P value | Beak (n=19) | Round (n=29) | P value |
|--------------------|-------------------|------------------|----------------|---------|-------------|--------------|---------|
| Preop JOA score, mean ± SD | 6.11 ±2.22        | 6.92 ±1.22       | 6.63 ±1.77     | 0.430   | 6.03 ±1.84  | 6.95 ±1.59   | 0.710   |
| Postop JOA score, mean ± SD | 7.93 ±2.29        | 8.83 ±1.06       | 8.50 ±1.75     | 0.342   | 7.74 ±1.91  | 8.93 ±1.43   | 0.017*  |
| RR, mean ± SD, %  | 44.63 ±22.70      | 47.88 ±19.40     | 48.91 ±30.27   | 0.884   | 38.27 ±18.52 | 53.18 ±25.55 | 0.034*  |
| Hematoma, no. (%)   | 0                 | 0                | 0              | …       | 0(0)        | 0(0)         | …       |
| CSF leakage, no. (%) | 1(7.1)            | 2(11.1)          | 2(12.5)        | 0.773   | 2(10.5)     | 3(10.3)      | 1.000   |
| Immediate neurologic deterioration, no. (%) | 0(0)              | 0                 | 0              | …       | 0(0)        | 0(0)         | …       |

**RR** recovery rate, **CSF** Cerebrospinal Fluid, **SD** standard deviation

*Statistically significant difference (P < 0.05)

### Table 6  Preop JOA score influenced by sagittal and axial ossification type

| SS      | df  | MS  | F     | P    |
|---------|-----|-----|-------|------|
| Sagittal ossification type | 8.353 | 1   | 8.353 | 2.857 | 0.098 |
| Axial ossification type    | 4.416 | 2   | 2.208 | 0.755 | 0.476 |
| Sagittal ossification type* | 5.741 | 2   | 2.871 | 0.982 | 0.383 |
| Axial ossification type     | 5.158 | 2   | 2.581 | 0.829 | 0.444 |
| Error                        | 122.798 | 42  | 2.924 |
| Corrected Total             | 141.167 | 47  | …    |

**SS** sum of squares, **df** degree of freedom, **MS** mean square, **F** test; **P** P value

### Table 7  Postop JOA score influenced by sagittal and axial ossification type

| SS      | df  | MS  | F     | P    |
|---------|-----|-----|-------|------|
| Sagittal ossification type | 14.158 | 1   | 14.158 | 5.158 | 0.028* |
| Axial ossification type    | 4.720 | 1   | 2.360 | 0.860 | 0.431 |
| Sagittal ossification type* | 4.550 | 2   | 2.275 | 0.829 | 0.444 |
| Axial ossification type     | 139.417 | 47  | …    |

**SS** sum of squares, **df** degree of freedom, **MS** mean square, **F** test; **P** P value
hematoma or deep infection was observed. There was no significant difference in other complications in sagittal and axial positions. There were 5 cases of CSF leakage, which were divided into beak group (2 cases) and round group (3 cases) in sagittal position. In axial grouping, there were 2 cases in the bilateral group and 2 cases in the bridged group. There were 3 cases with immediate neurologic deterioration after the operation, all of which were located in the round group in sagittal position, 2 cases in the axial bilateral group, and 1 case in the bridged group in axial position. There were 2 cases of postoperative superficial infection and self-recovery without surgical treatment.

**Discussion**

In the past, many studies have investigated the factors influencing the surgical results of TOLF, achieving relatively consistent views on the factors affecting patients’ prognosis with TOLF, such as the intramedullary signal change and the long duration of preoperative symptoms and similar. However, different studies have different views on the influence of ossification morphology on the surgical prognosis in patients with TOLF. According to some studies, sagittal morphology does not affect the prognosis [10]. Some other studies suggest that the beak type in the sagittal position has a poor prognosis [8], while others argue that the beak type in the sagittal position has a better prognosis [3]. Some studies have also suggested that the types of axial ossification impact the surgical results [11]. Following the popularization of testing technology and population growth, the number of patients with TOLF has been steadily increasing year by year [6], so it is particularly important to clarify the influence of the ossification morphology on surgical prognosis.

In the present study, there was no correlation between ossification morphology and demographic characteristics such as gender, age, and symptom duration and so on (Table 2). In the comparison of surgical parameters, COR values of the three significantly differed in axial classification, unlike umCOR values, which is inconsistent with our clinical experience. Therefore, pairwise comparison of the three types showed no difference in COR values among the three types, while the umCOR values of unilateral type were significantly different between bilateral type and bridged type, which demonstrated that unilateral type, although smaller in COR than bilateral and bridged type, occupied more space in the unilateral spinal cord than bilateral and bridged type (Table 3). Still, the proportion of patients with unilateral type with intramedullary signal changes was lower than that of patients with bilateral type and bridged type, thus showing that COR could assess spinal cord injury more accurately than umCOR. It is possible that the spinal cord can shift to the opposite side due to unilateral ossification compression, thus alleviating the injury (Table 5). In terms of surgical methods, we also conducted a pairwise comparison and found significant differences between unilateral and bridged types of surgical methods. In unilateral type, more patients chose simple laminectomy, while in bridged type, more patients chose laminectomy and internal fixation, which is related to the fact that the bridged type requires a larger decompression area that easily destroys local stability and requires internal fixation to increase stability. In sagittal classification, there was no significant difference in surgical parameters among groups (Table 4).

In terms of surgical prognosis and complications, postoperative JOA scores in the three axial groups were significantly higher compared to those before surgery, while RR in the three groups showed no significant difference, indicating that the type of axial ligamentum flavum had no significant difference in prognosis, and there was no significant difference among the three groups in postoperative hematoma, CSF leakage and other related complications (Table 5). At the sagittal level, postoperative JOA scores were also significantly higher in both groups, suggesting that surgical treatment could be used as a palliative approach for any type of ossification. Prior research has shown that the sagittal morphology of TOLF tends to affect the prognosis of surgery, as the beak-type ossification morphology is difficult to remove, eventually leading to a poor surgical prognosis [3, 8]. This is in line with our results, considering that the preop JOA score in the beak group and round group revealed no obvious difference, while the postop JOA score and RR were significantly different.

Given that the TOLF is multidimensional interaction for compression of the spinal cord and can only be one-sided in relation to the separate analysis of the sagittal

### Table 8 Recovery rate influenced by sagittal and axial ossification type

|                        | SS   | df | MS   | F     | P     |
|------------------------|------|----|------|-------|-------|
| Sagittal ossification type | 0.251 | 1  | 0.251 | 4.377 | 0.043*|
| Axial ossification type  | <0.001 | 2  | <0.001 | 0.002 | 0.998 |
| Sagittal ossification type*axial ossification type | 0.089 | 2  | 0.045 | 0.750 | 0.479 |
| Error                  | 2.412 | 42 | 0.057 | ...   | ...   |
| Corrected total        | 2.700 | 47 | ...   | ...   | ...   |

SS sum of squares, df degree of freedom, MS mean square, F test, P P value

*Statistically significant difference (P < 0.05)
and axial position, we analyzed one more time these two types of ossification morphology by two-way ANOVA (Tables 6, 7, 8). The obtained results revealed that postop JOR score, recovery rate, and sagittal morphology were obviously significant, unlike axial morphology. Also, there was no significant interaction between sagittal and axial typing.

The present study has some limitations: (1) this was a single-center retrospective study, and due to the low incidence of single-level TOLF, the sample size was small, which should be addressed by further multi-center prospective large sample size studies; (2) the maximum duration of neurological function recovery after TOLF was unclear, and follow-up time of 2 years may be insufficient.

Conclusion
In this study, COR was more effective than unCOR in assessing spinal cord compression, even though some ossified ligamentum flavum compressed only one side of the spinal cord in the axial position. Surgery can be an effective way to restore spinal cord function regardless of the type of ossification. In sagittal classification, beak-type ossification had a significant adverse effect on surgical prognosis, while axial classification had no effect, and there was no interaction between sagittal and axial ossification morphology.

Abbreviations
TOLF: Thoracic ossification of ligamentum flavum; CT: Computerized tomography; JDA: Japanese Orthopaedic Association.

Acknowledgements
None.

Author’s contributions
PYD, LM and WYD contributed to the study conception and design. All authors collected the data and performed the data analysis. All authors contributed to the interpretation of the data and the completion of figures and tables. All authors read and approved the final manuscript.

Funding
None.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval was given by the Ethics Committee of the Third Hospital of Hebei Medical University. All patients gave their written informed consent.

Consent for publication
Not applicable.

Competing interests
All the authors declare that they have no conflict of interest.

References
1. Feng FB, Sun CG, Chen ZQ. Progress on clinical characteristics and identification of location of thoracic ossification of the ligamentum flavum. Orthop Surg. 2015;7(2):87–96. https://doi.org/10.1111/os.12165.
2. Ahn DK, Lee S, Moon SH, Boo KH, Chang BK, Lee JL. Ossification of the ligamentum flavum. Asian Spine J. 2014;8(1):89–96. https://doi.org/10.4184/asj.2014.8.1.89.
3. Wang H, Wei F, Long H, Han G, Sribastav SS, Li Z, et al. Surgical outcome of thoracic myelopathy caused by ossification of ligamentum flavum. J Clin Neurosci. 2017;45:83–8. https://doi.org/10.1016/j.jocn.2017.07.008.
4. Lang N, Yuan HS, Wang HL, Liao J, Li M, Guo FX, et al. Epidemiological survey of ossification of the ligamentum flavum in thoracic spine: CT imaging observation of 993 cases. Eur Spine J. 2013;22(4):857–62. https://doi.org/10.1007/s00586-012-2492-8.
5. Kang KC, Lee CS, Shin SK, Park SJ, Chung CH, Chung SS. Ossification of the ligamentum flavum of the thoracic spine in the Korean population. J Neurosurg Spine. 2011;14(4):513–9. https://doi.org/10.3171/2010.11. jns010405.
6. Guo JJ, Lü KD, Karppinen J, Yang H, Cheung KM. Prevalence, distribution, and morphology of ossification of the ligamentum flavum: a population study of one thousand seven hundred thirty-six magnetic resonance imaging scans. Spine. 2010;35(15):S1–6. https://doi.org/10.1097/BRS.0b013e3181b3f779.
7. Fukuyama S, Nakamura T, Ikeda T, Takagi K. The effect of mechanical stress on hypertrophy of the lumbar ligamentum flavum. J Spinal Disord. 1995;8(2):126–30.
8. Kuh SU, Kim YS, Cho YE, Jin BH, Kim KS, Yoon YS, et al. Contributing factors affecting the prognosis surgical outcome for thoracic OLF. Eur Spine J. 2006;15(4):485–91. https://doi.org/10.1007/s00586-005-0903-9.
9. Zhou SY, Yuan B, Qian C, Chen XS, Jia LS. Evaluation of measuring methods of spinal canal occupation rate in thoracic ossification of ligamentum flavum. World Neurosurg. 2018;110:e1025–30. https://doi.org/10.1016/j. wneu.2017.11.164.
10. Sanghvi AV, Chhabra HS, Mascarenhas AA, Mittal VK, Sangondimath GM. Thoracic myelopathy due to ossification of ligamentum flavum: a retrospective analysis of predictors of surgical outcome and factors affecting preoperative neurological status. Eur Spine J. 2011;20(2):205–15. https://doi.org/10.1007/s00586-010-1423-9.
11. Li Z, Ren D, Zhao Y, Hou S, Li L, Yu S, et al. Clinical characteristics and surgical outcome of thoracic myelopathy caused by ossification of the ligamentum flavum: a retrospective analysis of 85 cases. Spinal Cord. 2016;54(3):188–96. https://doi.org/10.1038/sc.2015.139.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.