Heliyon 9 (2023) e18541

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Short shaft ratio: A novel predictor for dural ossification in patients with ossification of the ligamentum flavum

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ARTICLE INFO

Keywords:
Ossification of the ligamentum flavum
Dural ossification
Thoracic spine
Diagnosis accuracy

ABSTRACT

Background: Dural ossification (DO) is strongly correlated with an increased incidence of complications during the surgery for the patients with thoracic ossification of the ligamentum flavum (OLF). Some methods for predicting DO have emerged, but the accuracy remains to be improved. We aimed to find a more accurate way to predict the appearance of DO.
Methods: Retrospective study was adopted in this study. According to the intraoperative findings, ninety-one patients with thoracic OLF were ultimately included and divided into two groups based on the presence or absence of DO. Patient characteristics and radiographic data were recorded. The residual area ratio (RAR, residual area/cross-section area of normal spinal canal × 100%) and the short shaft ratio (SSR, the length of short shaft of the ellipse-like shape/the length of the spinal canal × 100%) were measured and calculated by 2 independent observers, followed by statistical analysis. The receiver operating characteristic curve was used to evaluate the accuracy of the SSR and RAR in predicting DO.
Results: No significant differences were found in sex, age and BMI between the DO group and the non-DO group. The mean RAR (and standard deviation) in the Non-DO group (62.6% ± 10.2%) was significantly higher ($p < 0.001$) than that in the DO group (46.1% ± 10.5%). The mean SSR (and standard deviation) in the Non-DO group (61.6% ± 6.0%) was significantly higher ($p < 0.001$) than that in the DO group (43.6% ± 9.2%). The receiver operating characteristic curve indicated that the SSR and RAR can be used as the efficient indicators to identify DO, and the SSR has a higher accuracy in indicating the presence of DO, with a cutoff value of < 48.71% (sensitivity of 100% and specificity of 85.0%).
Conclusion: The SSR can be used as a supplement parameter to traditional methods to predict DO, and it could be a better predictor. And, compared with bilateral and bridged type, unilateral type of OLF was more likely to develop DO with a larger SSR.

1. Background

Ossification of the ligamentum flavum (OLF) is one of the common causes of thoracic spinal stenosis, and the incidence is higher in the Japanese and other East Asian populations [1–5]. Kim et al. [6] reported that the average age of onset of OLF is 60.9 years, and the

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https://doi.org/10.1016/j.heliyon.2023.e18541
Received 6 March 2023; Received in revised form 18 July 2023; Accepted 20 July 2023
Available online 23 July 2023
2405-8440/

List of abbreviations

DO	Dural ossification
OLF	ossification of the ligamentum flavum
RAR	Residual area ratio
SSR	short shaft ratio

morbidity increases with aging. The neural function of patients gradually deteriorated due to ischemic pathological changes of spinal cord secondary to the posterior compression [7]. Due to the insidious feature of this disease, symptoms of the patients with OLF were usually severe when they went to hospital. Operation is the only effective treatment while laminectomy surgery for OLF is usually difficult and high risk especially when combined with dural ossification (DO) [8]. Because complications such as dural tears, cerebrospinal fluid leakage and spinal cord injury were disastrous and closely related to the appearance of DO [9–11], a definitive preoperative diagnosis of DO is essential. Recently, there have been fewer studies on dural ossification but the results were controversial. According to current research, DO is usually secondary to OLF. Lingjia Yu et al. [12] believed that DO occurred only when spinal canal stenosis became severe. In his study, the occupying ratio of the spinal canal was used to reflect the severity of spinal canal stenosis. Dural ossification could be certainly found only when the occupying ratio was more than 55%, whereas it could not be found when the occupying ratio was less than 45%. In our study, we found that the spinal cord had a limited compliance to deformation, and there would be cavity which was not filled with spinal cord in the space of canal was not occupied by OLF. There was no absolute linear relationship between the occupying ratio and the degree of spinal stenosis, and thus the morphology of OLF needs be considered as another factor that might affect dural ossification. It is well known that different morphologies of OLF with the same occupying ratio of the spinal canal could create different pressures on the dura matter. DO appeared on the point with the greatest pressure in contact with the OLF. Theoretically, the incidence of DO may be different when the occupying ratio was the same whereas the morphologies of

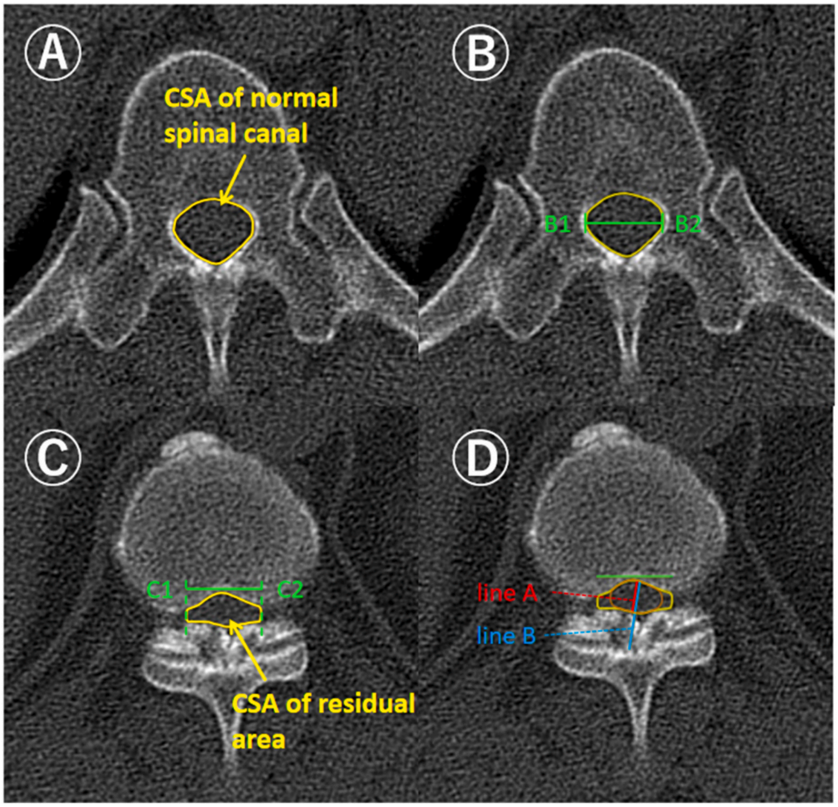

Fig. 1. Measurement method of bridged type OLF. A. The pedicle section adjacent to the narrowest section was considered as normal spinal canal, and the CSA of this section was measured. B. Maximum distance between bilateral pedicles at this region was measured and defined as the width (B1–B2) of canal. C. Residual area was measured at the narrowest section within the width (C1–C2) defined above (length of (B1–B2) = length of (C1–C2)). Residual area ratio = residual area/CSA of normal spinal canal × 100%. D. An ellipse-like shape was drawn in the residual area, and the short shaft (line A) of the ellipse-like shape was found. The length of the short shaft and the length of spinal canal along the short shaft (line B) were measured. Short shaft ratio = line A/line B × 100%.

OLF were different. Based on the above consideration, we put forward the new concept of short shaft of the elliptic-like shape aiming to find out a more sensitive and accurate radiographical parameter for the diagnosis of dural ossification.

2. Materials and methods

2.1. Study population

A retrospective study was performed. Patients with thoracic OLF who underwent posterior decompression surgery in the inpatient of our hospital from January 2021 to January 2023 were enrolled. Hospital and the patients of all participants provided written informed consents to participate. Inclusion criteria were that thoracic OLF patients with corresponding neurological symptoms and imaging features underwent laminectomy surgical treatment. Exclusion criteria were: 1) thoracic vertebral infection, 2) thoracic spinal tumor, 3) revision surgery, 4) ossification of the posterior longitudinal ligament (OPLL), 5) thoracic disk herniation (TDH) with or without ossification and 6) diffuse idiopathic skeletal hyperostosis. The demographic data, including sex, age, body mass index (BMI), comorbid disease and disease duration (months), were recorded. Patients with thoracic OLF who met the criterion were divided into two groups based on the presence or absence of DO during the operation. The thoracic segments with OLF of the enrolled patients were also divided into two groups based on whether combined with DO. The distribution (T1-4, T5-8, T9-12) and the morphology of OLF were recorded. The morphologies of OLF were as follows: unilateral, bilateral, and bridged in the axial position, and beak and round groups in the sagittal position [13].

2.2. Radiographic measurements

All the included patients underwent preoperative CT and MRI scan. CT images were mainly used for radiographic measurements because it was difficult to find the boundaries of the OLF in MRI images. Most of the patients had multi-segment OLF. Twenty-eight patients had single segment OLF, 32 patients had double segment OLF, and 31 patients had three or more segments OLF. The segments of maximum compression were chosen for radiographic measurements because DO mostly occurred only in the segment with

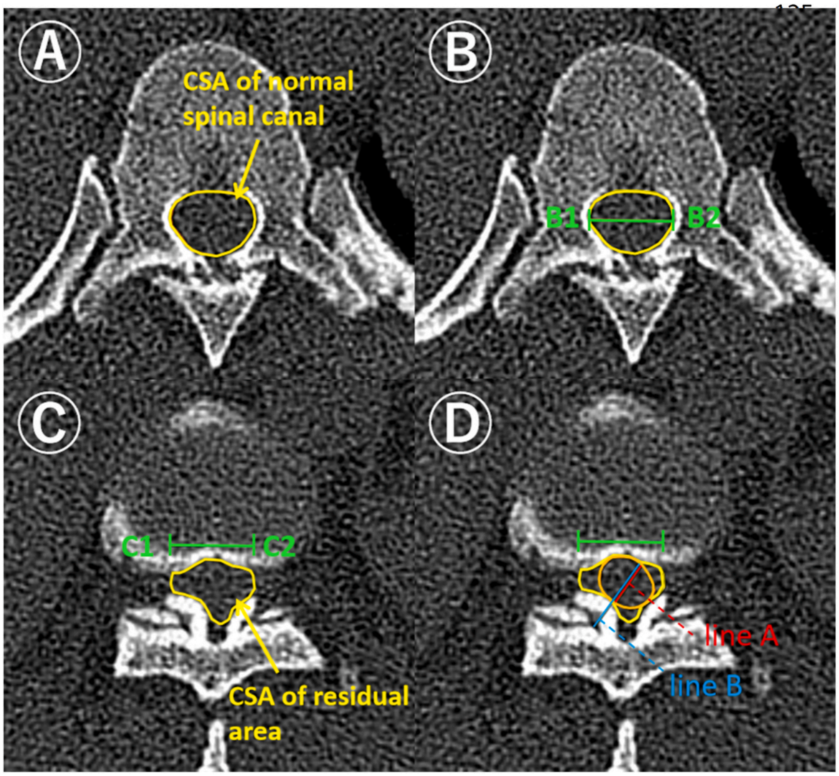

Fig. 2. Measurement method of bilateral type OLF. A. The pedicle section adjacent to the narrowest section was considered as normal spinal canal, and the CSA of this section was measured. B. Maximum distance between bilateral pedicles at this region was measured and defined as the width (B1–B2) of canal. C. Residual area was measured at the narrowest section within the width (C1–C2) defined above (length of (B1–B2) = length of (C1–C2)). Residual area ratio = residual area/CSA of normal spinal canal × 100%. D. An ellipse-like shape was drawn in the residual area, and the short shaft (line A) of the ellipse-like shape was found. The length of the short shaft and the length of spinal canal along the short shaft (line B) were measured. Short shaft ratio = line A/line B × 100%.

maximum compression [12]. We used the PACS software for radiographic measurements of the axial CT scans. The CT images of all OLF segments with or without DO were reviewed by two observers who were blinded to the patients' medical records. To improve the measurement precision, all OLF segments were measured twice by each observer, and the mean of the two measurements was adopted.

The narrowest axial planes in CT scans were chosen as the parameters of study. The normal cross-sectional area (CSA) of the spinal canal was defined as the CSA on the pedicle section adjacent to the OLF [12]. Region of interest (ROI) along the bone vertebral canal border was drawn, and the PACS software automatically calculated the CSA on the pedicle section (Figs. 1–3 A). Maximum distance between bilateral pedicles at this region was defined as the width (B1–B2) of canal (Figs. 1–3 B). On the narrowest axial plane, region of interest (ROI) was drawn for measuring the area which was not occupied by OLF within the width (C1–C2) and defined as residual area (Figs. 1–3 C, length of C1–C2 = length of B1–B2). Residual area ratio (RAR) was defined as the ratio of residual area to normal CSA. The MRI axial plane showed that the spinal cord did not fill all the residual area we measured above due to its limited compliance, therefore, the cavity existed in residual area [Fig. 4 (A, B)]. The largest ellipse-like shape that can fit in the residual area was drawn, which was roughly the same shape as the spinal cord in MRI plane. The ellipse-like shape roughly represented the real space where the spinal cord was. Based on general knowledge of mechanics, the length of the short shaft in ellipse-like shape could represent the degree of the maximum pressure. The length ratio of short shaft (Figss. 1–3 D, line A) to the length of canal (Figs. 1–3 D, line B) was adopted as a radiographical parameter in this study named short shaft ratio (SSR).

$$\text{Residual area ratio (RAR)} = \frac{\text{residual area}}{\text{CSA of normal spinal canal}} \times 100\%$$

$$\text{Short shaft ratio (SSR)} = \frac{\text{the length of short shaft of the ellipse} - \text{like shape}}{\text{the length of the spinal canal}} \times 100\%$$

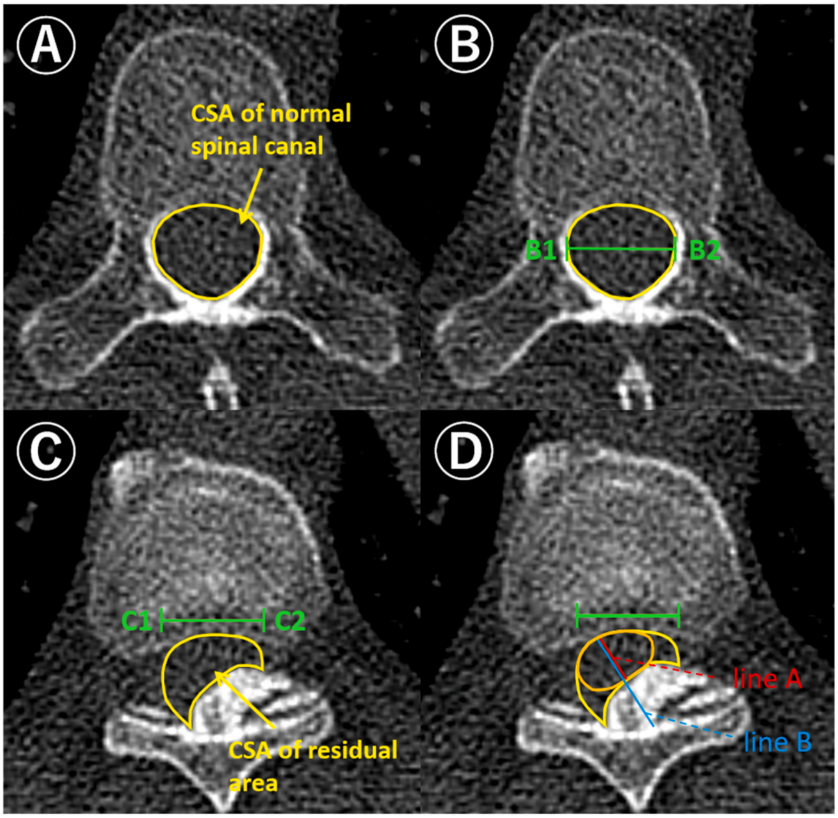

Fig. 3. Measurement method of unilateral type OLF. A. The pedicle section adjacent to the narrowest section was considered as normal spinal canal, and the CSA of this section was measured. B. Maximum distance between bilateral pedicles at this region was measured and defined as the width (B1–B2) of canal. C. Residual area was measured at the narrowest section within the width (C1–C2) defined above (length of (B1–B2) = length of (C1–C2)). Residual area ratio = residual area/CSA of normal spinal canal × 100%. D. An ellipse-like shape was drawn in the residual area, and the short shaft (line A) of the ellipse-like shape was found. The length of the short shaft and the length of spinal canal along the short shaft (line B) were measured. Short shaft ratio = line A/line B × 100%.

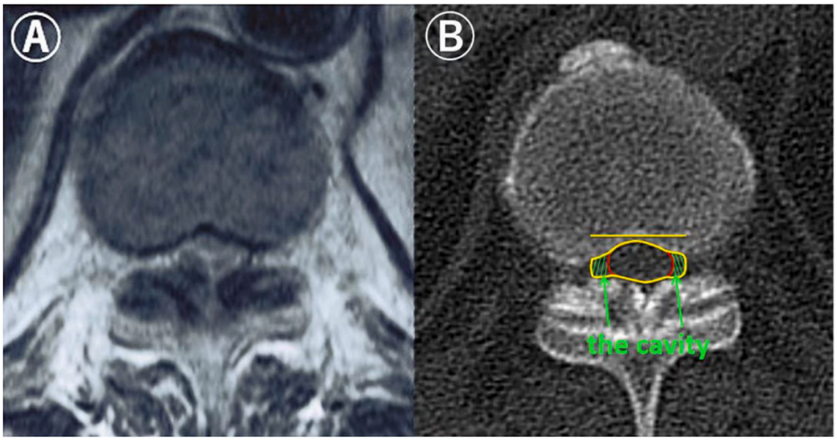

Fig. 4. Axial plane of the narrowest section. **A.** A typical MRI image of OLF segments. **B.** An ellipse-like shape was drawn on CT plane to represent the spinal cord according to the shape of the spinal cord in MRI plane. There were the cavities (green arrow) in the residual area which were not filled by spinal cord. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.3. Statistical analysis

The Statistical Package for Social Sciences 25.0 (SPSS Inc., Chicago, IL, USA) software was used for data analysis. Chi-square test is used for categorical variables, presented as frequency (percentage,%). T-test is used for data of continuous variables that conform to a normal distribution, presented as mean±standard, and the sum of ranks test is used for data of continuous variables that are not normally distributed, presented as M (Q1, Q3). Interclass correlation coefficients (ICCs) were calculated to assess interobserver reliability [14]. Receiver operating characteristic (ROC) curve was drawn, and the area under the curve (AUC) was used to determine the best cutoff value of the parameters for diagnosing DO. P value < 0.05 was considered statistically significant.

3. Results

3.1. Patient characteristics

Ninety-one consecutive patients with thoracic OLF (43 males and 48 females) were ultimately included in this study. There were 40 patients in group with DO and 51 patients in group without DO. There was no significant difference in sex ($p = 0.220$), age (DO group: 58.90 ± 7.03 years, Non-DO group: 55.43 ± 11.02 years, $p = 0.072$), the duration of symptoms (DO group: 8.5 months [3.0, 33.0], Non-DO group: 12 months [3.0, 60.0], $p = 0.730$), or BMI (DO group: 26.48 ± 2.83 kg/m^2, Non-DO group: 27.79 ± 3.97 kg/m^2, $p = 0.080$). No significant difference in the comorbid diseases was found between the 2 groups (hypertension ($p = 0.083$), diabetes mellitus ($p = 0.408$)) (Table 1).

3.2. Identifying dural ossification using the residual area ratio (RAR) and the short shaft ratio (SSR)

Ninety-one OLF segments were divided into two groups based on the presence or absence of DO during the operation (40 segments with DO, 51 segments without DO). No significant difference was found in distribution of OLF segments between the two groups ($p = 0.655$). There was no significant difference in the distribution of different OLF morphologies in axial plane ($p = 0.145$) and sagittal plane ($p = 0.055$) between the two groups (Table 2).

For the RAR, the ICC across the 91 cases for both observers was 0.975 (95% confidence interval [CI], 0.962 to 0.983). For SSR, the

Table 1
Demographic data of OLF patients with or without Dural ossification (DO).

	Group with DO	Group without DO	95%CI	t/Z/F Value	*P* Value
No. of patients	40	51			
Sex				1.506	0.220
Male	16 (40.0%)	27 (52.9%)			
Female	24 (60.0%)	24 (47.1%)			
Age (yr.)	58.90 ± 7.03	55.43 ± 11.02	−7.250, 0.312	−1.824	0.072
BMI (kg/m^2)	26.48 ± 2.83	27.79 ± 3.97	−0.074, 2.834	1.769	0.080
Disease duration (months)	8.5 (3.0, 33.0)	12 (3.0, 60.0)	−3.000, 8.000	−0.345	0.730
Hypertension	23 (57.5%)	20 (39.2%)			0.083
DM	9 (22.5%)	8 (15.7%)			0.408

ICC was 0.980 (95% CI, 0.969 to 0.984). These results indicated that the RAR and SSR are excellent reliability for identifying DO. The overall RAR in the Non-DO group (62.6% ± 10.2%) was significantly higher than that in the DO group (46.1% ± 10.5%) ($p < 0.001$). The overall SSR in the Non-DO group (61.6% ± 6.0%) was significantly higher than that in the DO group (43.6% ± 9.2%) ($p < 0.001$) (Table 2).

The accuracy of the RAR and SSR in identifying dural ossification was assessed. The ROC curve showed that RAR had a relatively high diagnostic value for DO (area under the curve [AUC], 0.864 [95% CI, 0.791 to 0.937], $p < 0.001$). The Youden index was used to determine the optimal cutoff value for dural ossification diagnosis. Cutoff value for this subgroup was < 55.77%, with sensitivity and specificity being 74.5% and 85.0%, respectively. The ROC curve showed that SSR had a much higher diagnostic value for the diagnosis of DO compared with RAR (area under the curve [AUC], 0.945 [95% CI, 0.889 to 1.000], $p < 0.001$), and the optimal cutoff value for this subgroup was < 48.71%, with sensitivity and specificity being 100% and 85.0%, respectively. [Fig. 5 (A, B) and Fig. 6 (A, B)] Cutoff value of <50% was also analyzed. A sensitivity of 96.1% and a specificity of 85% were found for <50%.

Cutoff values for the SSR in different OLF morphologies in axial position were also analysis. The Youden index was used to determine the optimal cutoff values for different OLF morphologies in axial position, respectively. Cutoff value for unilateral group was <55.54%, with sensitivity and specificity being 100% and 66.7%, respectively. Cutoff value for bilateral group was <48.22%, with sensitivity and specificity being 100% and 100%, respectively. Cutoff value for bridged group was <49.13%, with sensitivity and specificity being 100% and 92%, respectively. In the unilateral group, bilateral group and bridge group, the diagnostic coincidence rates of cutoff value < 50% were 82.61%, 95.24% and 93.75%, respectively (Table .3).

4. Discussion

Ossification of thoracic ligamentum flavum (OLF) is a common cause of thoracic spinal stenosis and neural dysfunction. Operation is the only effective treatment at present. Dural ossification (DO) is often accompanied by serious OLF and often associated with OLF to become an integral part. In clinical practice, complications of operation, such as dural tear, cerebrospinal fluid leakage and spinal cord injury, were more likely to occur when combined with dural ossification (DO). Therefore, preoperative diagnosis of DO is very helpful for avoiding complication. However, at present, there is no exact radiographical parameter for diagnosis of DO. Although the image features of DO, such as tram-track sign, comma sign [15], bridge sign [16], banner cloud sign [17], etc., often indicate the appearance of DO, the diagnostic accuracy needs to be improved. In a retrospective study of 91 segments of OLF, we found that the diagnostic accuracy was very limited by using the above-mentioned image features. Of the 40 segments with DO, only 27 showed the image features such as tram-track sign, comma sign, bridge sign or banner cloud sign. Moreover, the false positive was very high. In the segments without DO, 18 in 51 segments showed these typical image features. Although banner cloud sign had a high sensitivity, incidence of this image feature was very low (18/40 segments with DO showed the banner cloud sign).

It has been known that when the dura mater is compressed by ossification of ligamentum flavum, the relative movement between them causes local inflammation, which eventually contributes to the occurrence of DO [18]. The dural ossification is closely related to the degree of spinal stenosis, as confirmed by measuring the correlation between the occupancy rate of OLF and DO [12]. However, in our study, we found that the deformation of spinal cord after compression was limited to some extent, and there were the cavities in the area which was not filled by spinal cord. Moreover, although the total occupancy rate of ossified spinal canal was the same in the different forms of ossification, the incidence of DO was different. Furthermore, the spinal cord was compressed and deformed by OLF, and DO often occurred at the most compressed part in contact with OLF. In this study, ellipse-like shape was drawn in CT plane, which was reference to ellipse-like shape of spinal cord under compression in MRI planes. We found that the length of the shortest shaft of spinal cord could represent the severity of the compression. So, the ratio of the shortest shaft of ellipse-like shape to spinal canal length (SSR) could indicate the severity of the pressure applied to the dura. Satisfactory results have been obtained in this study. ROC curve analysis showed that SSR had a higher accuracy than RAR (SSR: AUC = 0. 945, RAR: AUC = 0. 864). Thus, SSR could be used as a new parameter to further identify whether OLF is accompanied by DO, and the cutoff value was less than 48.71%. Cutoff value of <50% was also analyzed. The results showed that SSR also had a high diagnostic coincidence rate for OLF with different morphologies in axial position when the cutoff value was < 50%. In clinical work, when SSR is approximate less than 50%, it is strongly suggest that there is

Table 2
Univariate analysis of related variables.

	Group with DO	Group without DO	t/Z/F Value	*P* Value
Residual area ratio	46.1% ± 10.5%	62.6% ± 10.2%	7.574	< 0.001
Short shaft ratio	43.6% ± 9.2%	61.6% ± 6.0%	11.281	< 0.001
Distribution of OLF			F = 0.845	0.655
T1-4	4 (10.0%)	7 (13.7%)		
T5-8	9 (22.5%)	8 (15.7%)		
T9-12	27 (67.5%)	36 (70.6%)		
Morphology in sagittal plane			F = 3.697	0.055
Round type	17 (42.5%)	32 (62.7%)		
Beak type	23 (57.5%)	19 (37.3%)		
Morphology in axial plane			F = 3.862	0.145
Unilateral type	9 (22.5%)	14 (27.5%)		
Bilateral type	6 (15.0%)	15 (29.4%)		
Bridged type	25 (62.5%)	22 (43.1%)		

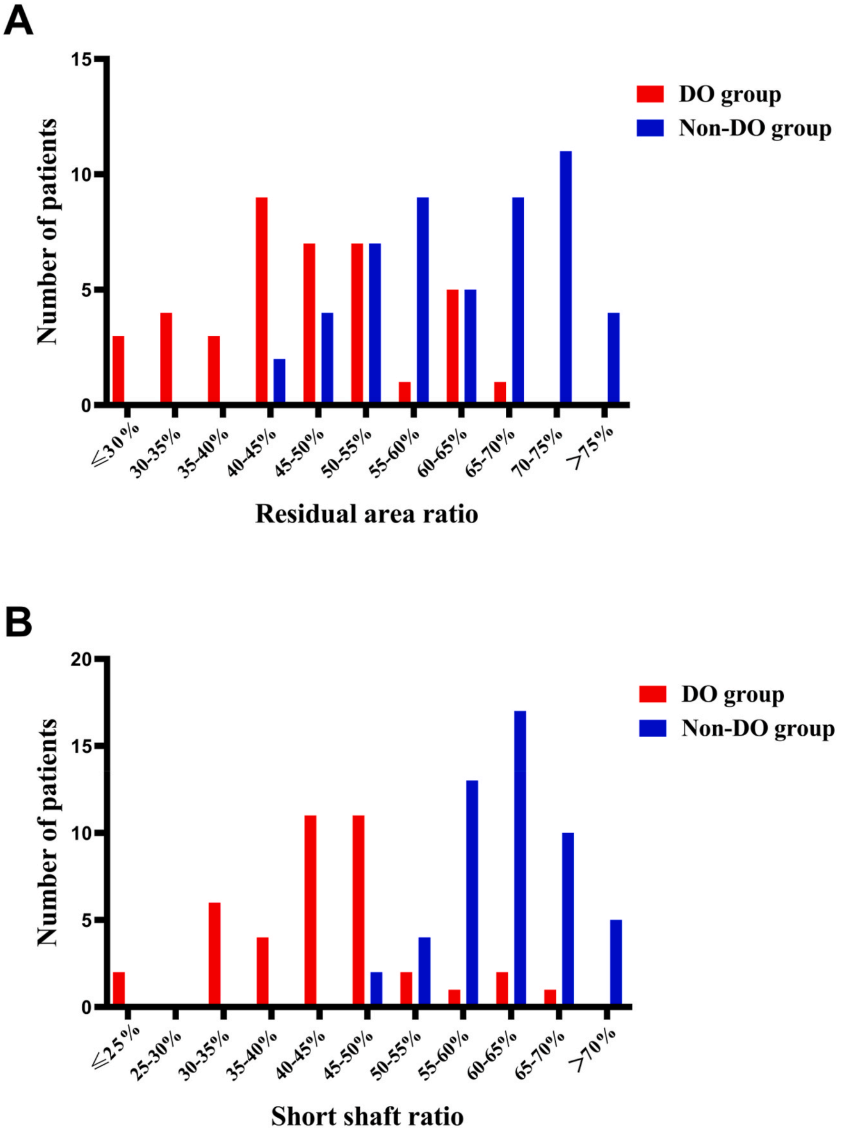

Fig. 5. A. Distribution (histograms) of the residual area ratio. B. Distribution (histograms) of the short shaft ratio.

DO.

It is worth noting that unilateral type of OLF is special. Four patients with DO in unilateral type of OLF caused obvious deviation for RAR more than 55.77%, one of which has a larger SSR more than 70%. Compared with bilateral and bridged type, unilateral type of OLF was more likely to develop DO with a larger SSR. We believed that unilateral OLF pushed the spinal cord just in one direction and the transposition of the cord was limited due to the traction of nerve root. So, this kind of OLF produced the greater pressure and friction on the area of dura even if the volume of OLF was not very big. Therefore, considering that unilateral type has certain particularity, OLF morphologies in axial position should be taken into account when using SSR to diagnose the presence of DO.

There was also a limitation in this study. The sample size is relatively small because of the low incidence of ossification of ligamentum flavum. In the future, a multicenter and prospective study is needed to further verify the results of this study.

Author contribution statement

Jiabao Chen: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.
Qingsong Yu: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Haidong Wang, Huangda An, Chenhao Dou: Performed the experiments.
Zhe Lu, Aoran Ding: Performed the experiments; Analyzed and interpreted the data.
Lei Ma: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

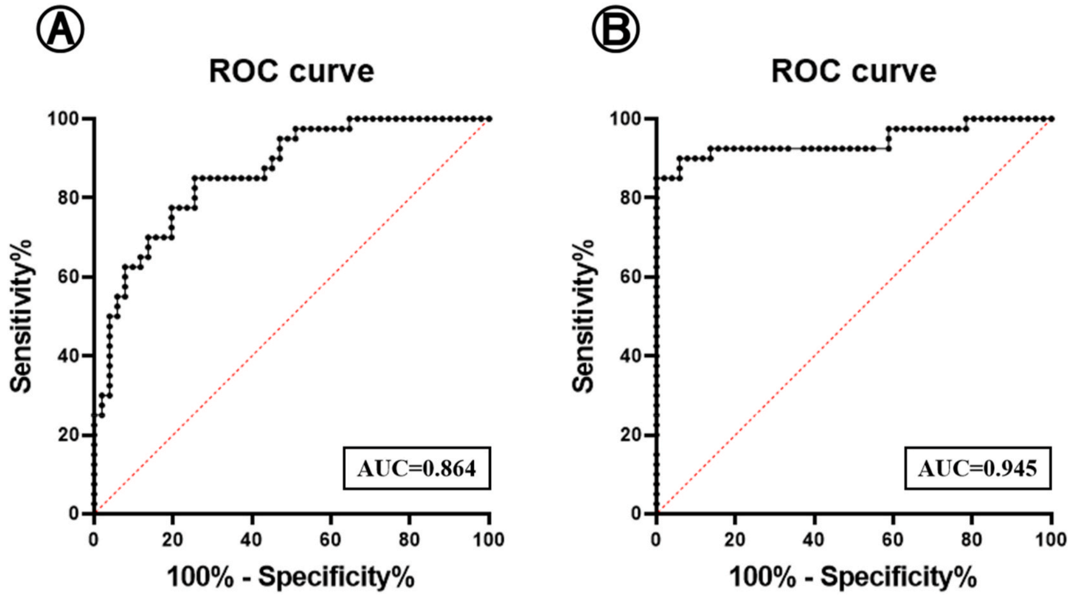

Fig. 6. A. The ROC curve indicates that residual area ratio (RAR) has a relatively high diagnostic value for DO (AUC, 0.864 [95% CI: 0.791 to 0.937]; $p < 0.001$). **B.** The ROC curve shows that short shaft ratio (SSR) has a much higher diagnostic value for the diagnosis of DO compared with RAR. (AUC, 0.945 [95% CI: 0.889 to 1.000], $p < 0.001$).

Table 3
Cutoff value for the SSR in different OLF morphologies in axial position.

OLF Morphologies in Axial Position	Optimal Cutoff Value	Sensitivity	Specificity	Diagnostic Coincidence Rate with Optimal Cutoff Value	Diagnostic Coincidence Rate with Cutoff Values of <50%
Unilateral (23)	<55.54%	100%	66.7%	86.96%	82.605%
Bilateral (21)	<48.22%	100%	100%	100%	95.238%
Bridged (47)	<49.13%	100%	92%	95.74%	93.75%
Total (91)	<48.71%	100%	85%	94.51%	91.21%

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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