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ORIGINAL ARTICLE

Novel therapeutic strategy in the treatment of ossification of the ligamentum flavum associated with dural ossification

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Abstract

Purpose To investigate the imaging characteristics of thoracic ossification of ligamentum flavum (OLF) combined with dural ossification (DO) and the clinical efficacy of zoning laminectomy.

Method The clinical data of 48 patients with thoracic OLF combined with DO who underwent zoning laminectomy between June 2016 and May 2020 were retrospectively analyzed. The modified Japanese Orthopedic Association (mJOA) score was used to evaluate neurological function before and after surgery, and the clinical efficacy was evaluated according to the improvement rate.

Results The symptoms of all patients significantly improved after the operation, and the average follow-up time was 27.8 (10–47) months. In addition, the average mJOA score had increased from 5.0 (2–8) preoperatively to 8.7 (6–11) postoperatively ($t = 18.880$, $P < 0.05$). The average improvement rate was 62.6% (25–100%), with 16 patients graded as excellent, 21 as good, and 11 as fair. Cerebrospinal fluid leakage occurred in 12 cases (25.0%), and all of them healed well after treatment. No postoperative aggravation of neurological dysfunction, wound infection or hematoma occurred. At the last follow-up, there was no recurrence of symptoms and kyphosis.

Conclusion The Zoning laminectomy described here is both safe and effective.

Keywords Thoracic spinal stenosis · Zoning · Ligamentum flavum · Dural ossification · Laminectomy

Introduction

Ossification of the ligamentum flavum (OLF) is one of the main causes of thoracic spinal canal stenosis (TSS) [1]. Its main prevalence is concentrated in Asian countries, especially Japan, China, and Korea [2, 3]. The natural history of OLF may be related to the subject's BMI, smoking status, location, and morphology of OLF [4]. The progression of the disease is slow, and conservative treatments are not very effective. As a result, it often leads to severe thoracic myelopathy. Most studies suggest that early surgery to relieve spinal cord compression is the most effective treatment for thoracic OLF [5–7]. However, at present, the incidence of complications of OLF surgery remains high. Dural ossification (DO) is an important risk factor [8]. Ossification of the dura mater not only greatly increases the difficulty of surgery, but also increases the risk of dural tears, cerebrospinal fluid leakage (CFL), and spinal cord and nerve damage [9]. Therefore, the choice of surgical technique is very important to avoid unnecessary complications. Here we discuss the efficacy, imaging signs, and treatment strategies for common complications of zoning laminectomy for thoracic OLF with DO.

Qiangqiang Pan and Yanyu Zhu have contributed equally to this work.

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Materials and methods

Patient population

We retrospectively reviewed the records of patients who underwent zoning laminectomy for thoracic OLF with DO at our institution between June 2016 and May 2020. We set the inclusion criteria: (1) Patients were identified as OLF with DO. (2) complete imaging and clinical data. (3) Patients were treated with zoning laminectomy. The exclusion criteria were patients with OLF with thoracic trauma, infection, ossification of the posterior longitudinal ligament and deformity. A total of 48 patients were included in the study, comprising 23 males and 25 females. The average age was 51.7 years (range 38–74 years). The mean course of disease was 20.7 months (range 10–48 months). All experienced symptoms caused by the compression of the thoracic spinal cord or nerve roots, and had OLF that was identified by X-ray, magnetic resonance imaging (MRI), and computed tomography (CT) scanning. The initial symptoms included numbness and weakness of the lower limbs found in 37 cases (77.1%), sensory changes in 43 cases (89.6%), sphincter dysfunction in four cases (8.3%), and back or lower limb pain in 15 cases (31.3%) (Table 1).

Table 1 Demographics and clinical characteristics

Item	Value
Sex	
M	23 (47.9%)
F	25 (52.1%)
Age (years)	51.7 ± 8.0 (range 38–74)
Course of disease (months)	20.7 ± 9.2 (range 10–48)
Distribution of OLF	
Upper thoracic spine (T1–T4)	23 (24.2%)
Middle thoracic spine (T5–T8)	16 (16.8%)
Lower thoracic spine (T9–T12)	56 (58.9%)
The initial symptoms	
Numbness and weakness of the lower limbs	37 (77.1%)
Sensory changes	43 (89.6%)
Sphincter dysfunction	4 (8.3%)
Back or lower limb pain	15 (31.3%)

Data are shown as mean ± standard deviation or number (percentage) of patients

M indicates man; F, female; OLF, ossification of the ligamentum flavum

Imaging observations

All patients underwent thoracic X-ray, magnetic resonance imaging (MRI), and computed tomography (CT) before surgery. Preoperative imaging showed that 95 diseased segments were involved, of which 23 (24.2%) were located in the upper thoracic spine, 16 (16.8%) in the middle thoracic spine, and 56 (58.9%) in the lower thoracic spine (Table 1). CT showed that there were 56 segments with DO, mostly in T9–T12 (66.1%, 37/56) (Fig. 1). Among them, 48 (85.7%) showed the "Tram Track sign" (TTs) and eight (14.3%) showed the "Comma sign" (Cs) (Fig. 2). No such signs were found in the other segments. According to the Sato classification of OLF, the lesion was categorized as lateral type, extended type, enlarged type, fused type or tuberous type [10]. The incidence of DO in these five types was 0%, 28.6%, 41.7%, 56.3%, and 70.9%, respectively.

The zoning basis and principle

The anatomical features of the thoracic ligamentum flavum are as follows: The upper portion of the ligamentum flavum attaches to the anterior portion of the lower 2/3 of the upper lamina, and the lower portion of it attaches to the upper edge of the lower lamina. The characteristics of pathological ossification of thoracic ligamentum flavum are as follows: The ossification process usually originates from bilateral

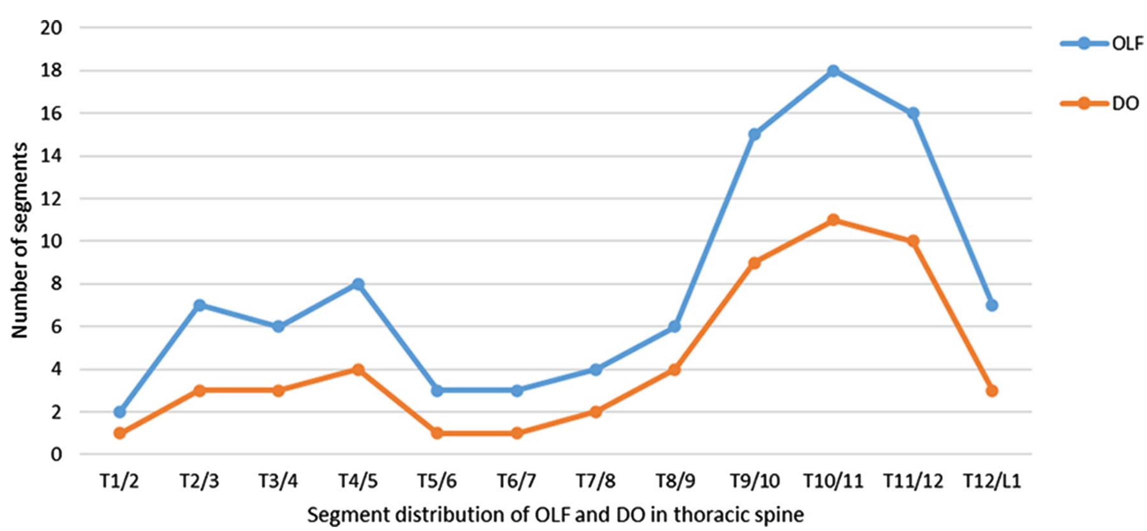

Fig. 1 Line chart of DO and OLF distributions in 48 patients

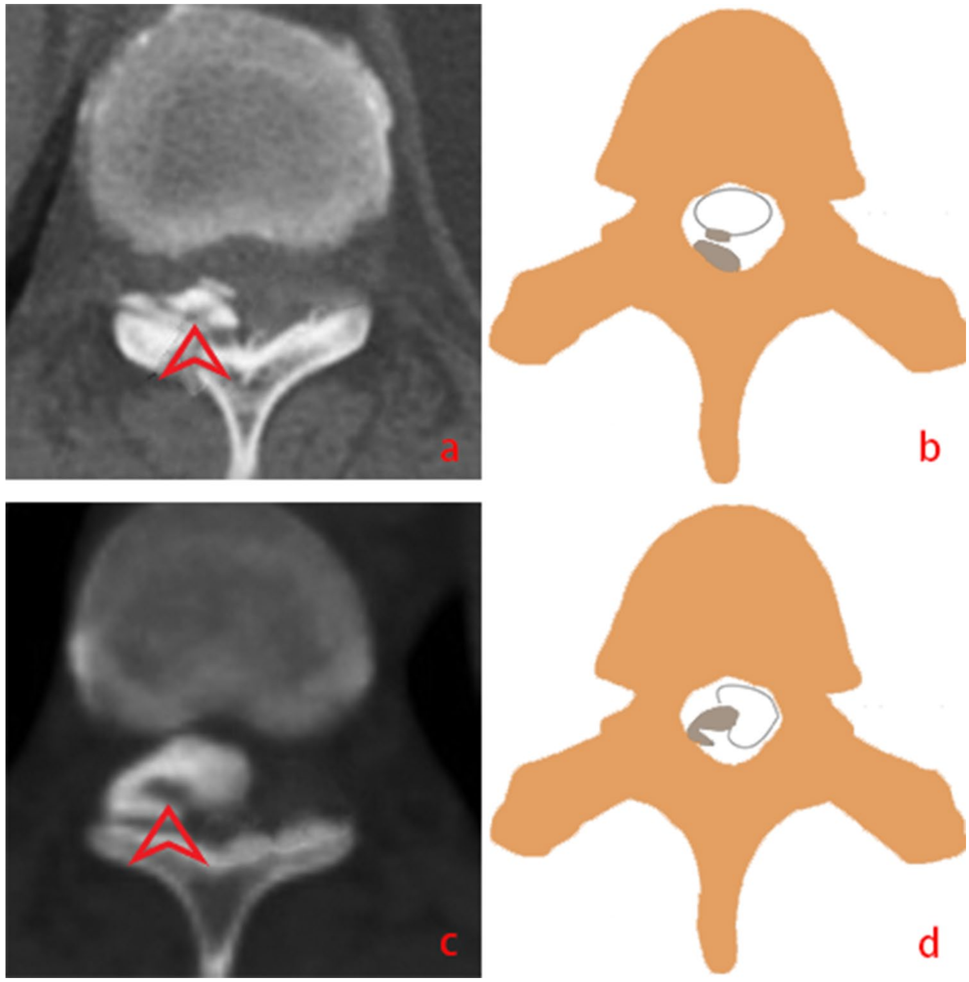

Fig. 2 Axial bone window CT indicating (**a**, **b**) the "tram track sign" (arrows point to a hyperdense bony excrescence with a hypodense center) and (**c**, **d**) the "comma sign" (arrows point to the ossification of one half of the circumference of the dura mater)

joint capsules and then spreads toward the center along the ligamentum flavum. Sometimes, bilateral ossified nodules fuse at the midline.

The lamina is divided into different zones according to the above characteristics of the ligamentum flavum. Zoning principles are as follows: (1) "first safe zone": the upper 1/3 of the lamina. (2) "second safe zone": the lateral side of the ossified ligamentum flavum. (3) "transition zone": the area between the "safe zone" and the "danger zone". (4) "danger zone": It is the area with the most severe ossification of the ligamentum flavum (Fig. 3).

Surgical technique

Under general anesthesia, the patient was placed in the prone position. Electrophysiologic monitoring was routinely used to monitor patients during surgery. The surgical segment was positioned by fluoroscopy before the operation. A posterior median incision was made, tissues were stripped to the bilateral articular processes; and then, pedicle screws and connecting rods were implanted both sides of the lesion segment. The "first safe zone" of the diseased segment was first removed using a high-speed drill (Fig. 4a). The inner edge of the "second safe zone" was probed and determined on both sides of the dura mater within the "first safe zone." The "transition zone" was then partially or completely resected and the boundary of the "danger zone" was explored using a nerve dissector (Fig. 4b). Finally, along the inner edges of both sides of the "second safe zone," two 2–3 mm wide longitudinal bone grooves were made to completely isolate the "danger zone" (Fig. 4c).

When dealing with DO, the lower edge of the ossified dura mater was first dissected with a sharp-pointed knife. A portion of the cerebrospinal fluid was released to cause the arachnoid membrane to subsidence. Then, a nerve probe was inserted between the dura mater and the arachnoid membrane to elevate the ossified nodule, and the sharp-pointed knife was used to completely cut the lower edge of the ossified dura mater. Finally, the ossified nodule was lifted with a vascular clamp instead of the nerve probe and removed completely along the medial surface of the ossified dura mater using a sharp knife (Fig. 4d). The dural defects were not repaired. A drainage tube was inserted; and then, the incision was tightly sutured layer by layer.

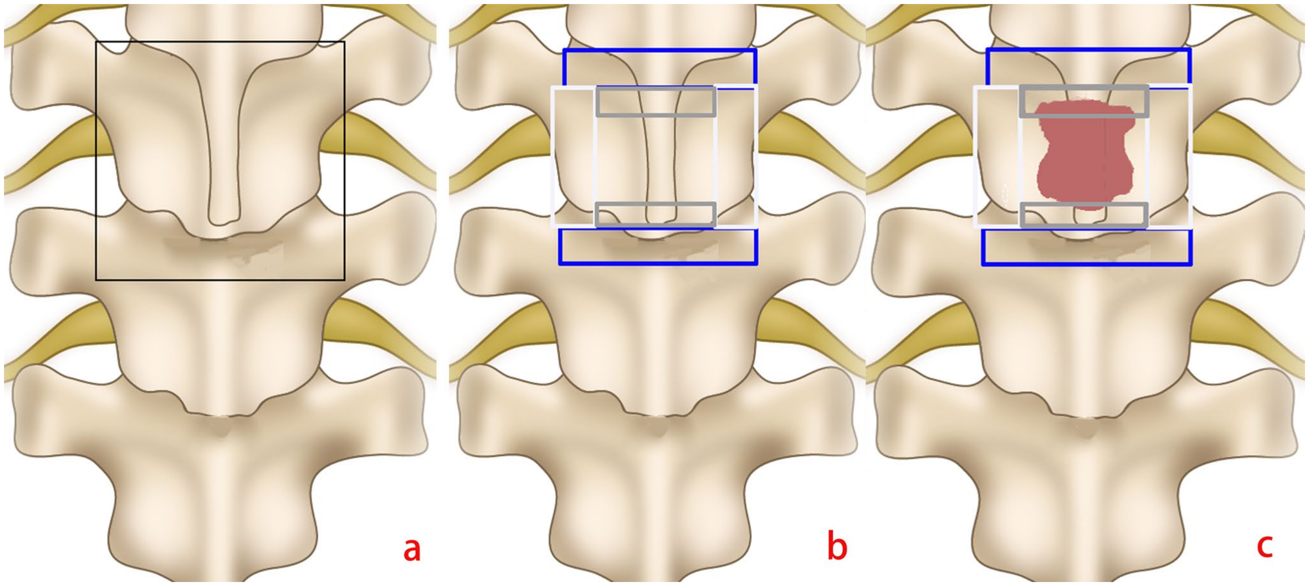

Fig. 3 Schematic diagram of zoning (**a**) the black box represents a decompressed segment, including the adjacent upper and lower laminas and the articular process. (**b**) The area in the blue box is the "first safe zone"; the area in the white box is the "second safe zone"; the area in the gray box is the "transition zone." (**c**) The red area represents the ossified ligamentum flavum, and the area in the middle of the box is the "danger zone"

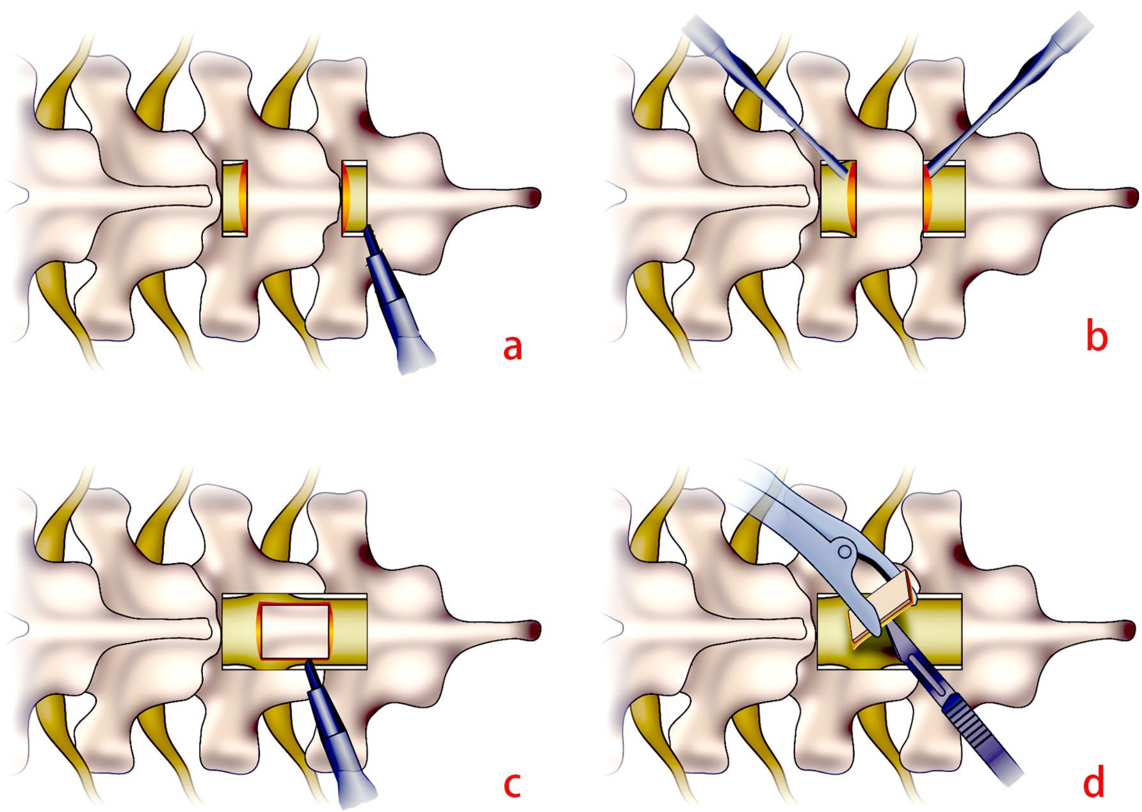

Fig. 4 Schematic diagram of zoning laminectomy (**a**) the "first safe zone" was removed. (**b**) The "transition zone" was partially resected, and the lateral and bottom edges of the "danger zone" were explored. (**c**) Along the inner edges of both sides of the "second safe zone," two 2–3 mm wide longitudinal bone grooves were made. (**d**) Ossified ligamentum flavum was elevated and resected with a sharp-pointed knife

Clinical assessment

Evaluations were carried out at the following times: preoperative, postoperative, 3 months, 6 months, and last follow-up. The patient's neurological function was evaluated according to the modified Japanese Orthopedic Association (mJOA) score (Table 2) [11]. The improvement rate (IR) was calculated as IR = (postoperative JOA score—preoperative JOA score/11—preoperative JOA score) × 100%. Surgical outcome was defined by the IR as follows: excellent (100–75%), good (74–50%), fair (49–25%), and poor (24–0%).

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 (SPSS Inc, Chicago, IL). Results are presented as mean ± standard deviation. A paired *t* test was used to compare the difference between preoperative and postoperative clinical outcomes, and $P < 0.05$ was considered statistically significant.

Results

Clinical results

A total of 90 segments were decompressed in 48 patients. DO was identified in 55 segments of all patients, accounting for 61.1% of all decompression segments. In addition, the average operation time was 171.9 min (range 105–362 min), and the average blood loss was 488.3 mL (range 300–750 mL). The mean hospital stay was 8.2 days (range, 5–11 days), and the average followed up was 27.8 months (range 10–47 months) (Table 3). The initial symptoms of all patients were significantly improved after the operation. The preoperative and postoperative mJOA scores, respectively, were 5.0 (2–8) and 8.7 (6–11) ($t = 18.880$, $P < 0.05$). The average improvement rate of neurological function was 62.6%, with 16 patients graded as excellent, 21 as good, and 11 as fair. Postoperative X-ray showed that the position of

Table 3 Clinical outcomes of the patient

Item	Value
Operation time (min)	171.9 ± 65.1 (range 105–362)
Blood loss (ml)	488.3 ± 121.0 (range 300–750)
Hospital stay (day)	8.2 ± 1.6 (range 5–11)
Follow-up (months)	27.8 ± 8.6 (range 10–47)
Radiographic results	
DO (n)	
TTs	45
Cs	8
Intraoperative determination	2
Intraoperative exclusion	3
Total	55
Complications	
Cerebrospinal fluid leakage	12 (25.0%)

Data are shown as mean ± standard deviation or number (percentage) of patients

DO indicates Dural Ossification; n, number; TTs, Tram Track sign; Cs, Comma sign

Table 2 Modified Japanese Orthopedic Association scoring system for thoracic myelopathy

Score	Neurological status
Motor dysfunction of lower extremities	
0	Unable to walk
1	Able to walk on flat floor with walking aid
2	Able to walk up and/or down stairs with handrail
3	Lack of stability and smooth reciprocation of gait
4	No dysfunction
Sensory deficit in lower extremities	
0	Severe sensory loss or pain
1	Mild sensory loss
2	No deficit
Sensory deficit in trunk	
0	Severe sensory loss or pain
1	Mild sensory loss
3	No deficit
Sphincter dysfunction	
0	Unable to void
1	Marked difficulty in micturition
2	Mild difficulty in micturition

instrumentation was in appropriate position. CT and MRI scanning showed that the ossified nodule was completely removed (Fig. 5).

Complications

Cerebrospinal fluid leakage was the main postoperative complication. It occurred in 12 of the 48 cases (25.0%). The dural defects were not repaired intraoperatively but were covered with gelatin sponge; and then, the paraspinal muscles, deep fascia, and skin were sutured tightly. After the operation, the drainage tube was pulled out when the

Fig. 5 A 56-year-old man developed numbness and weakness of the lower extremities for 16 months, accompanied by sphincter dysfunction for 6 days was treated with zoning laminectomy. (**a**, **b**) Preoperative X-ray images. (**c**) Preoperative MRI scan showed severe compression of the spinal cord compression at T8–11 levels. (**d**–**g**) Preoperative sagittal CT scans showed OLF in T8–T11, and axial CT scan showed the "Tram Track sign" in T8/9 segment, which indicated DO. (**h**, **i**) Postoperative 3 months X-ray images. (**j**) Postoperative MRI scan showed the spinal cord floating posteriorly and intramedullary signal back to normal. (**k**, **l**) The postoperative sagittal and axial CT scans showed the spinal cord was decompressed sufficiently

drainage volume was less than 50 ml/24 h. Transient CFL leakage stopped after 6–8 days conservative treatment with local pressure.

Discussion

TSS is usually caused by one or more pathological factors, among which OLF is a principal element. However, when DO occurs, the difficulty of surgery and the risk of intraoperative dural tears will be greatly increased. Some studies have reported that DO often coexists with severe OLF [12, 13]. Currently, the common methods used to identify DO are the signs of the "comma sign" (Cs) and the "tram track sign" (TTs) on CT images [14, 15]. In our study, preoperative CT scans showed a total of 56 segments with OLF combined with DO. However, the DO was confirmed intraoperatively in only 55 segments. Therefore, the presence of these radiological findings on CT does not necessarily confirm DO and their absence does not exclude DO. Recently, Chen et al. [16] reported a new imaging sign, termed the " banner cloud sign" (the OLF forms the peak, while the ossified dura mater appears as a flag-like cloud floating over the ossified ligamentum flavum) in sagittal CT scans, which can also be used to diagnose DO. In addition, Prasad et al. [17] reported an "MRI-T2 ring sign" (sagittal T2-weighted MRI shows an elongated circular area of hypointensity around the dura mater, which is the DO) for the diagnosis of DO. In this study, we found that DO occurred mainly in fused and tuberous cases of OLF, and the incidence rates were 56.3% and 70.9%, respectively. Therefore, we believe that the Sato classification of OLF has a certain reference value for the preoperative diagnosis of DO. If the OLF is classified as fused and tuberous, the probability of finding DO during operation will be high, which is consistent with the research conclusion of Sun et al. [18]. At present, there are many methods to diagnose DO. We believe that combining two or more imaging signs will help to improve the accuracy of the preoperative diagnosis of DO.

In this study, we adopted the technique of zoning laminectomy for the decompression of TSS caused by OLF with DO, which was determined by the anatomical and pathological characteristics of the thoracic ligamentum flavum described above. Zoning laminectomy provided a safe surgical method for the decompression of TSS. The "first safe zone" was not involved during the entire ossification process of the ligamentum flavum, and the volume of the spinal canal in this area was normal. Therefore, it was very safe to remove the lamina in this area. After removal of the "first safe zone," the exposed outer edge of the dura mater was used as a reference marker for decompression of the "second safe zone," so as to effectively control the depth of the instruments into the spinal canal and avoid direct injury to the spinal cord and nerves. Consequently, it was also safe to perform laminectomy in this area. The ligamentum flavum in the "transition zone" was partially ossified. A nerve dissector was used to probe along its side to determine the extent of the "danger zone" and ascertain whether there was dural ossification or adhesion.

If DO was identified after exploration, a small part of the lower edge of the ossified dura mater was first cut with a sharp-pointed knife. Then, the ossified dura mater and ligamentum flavum were gently lifted, and the lower, inner, upper and outer edges of the ossified dura mater were completely cut. Finally, the ossified nodule was removed completely. The advantages of this decompression operation are as follows: (1) It delineates the safe area of the lamina and allows decompression with a direct view of the most compressed part of the spinal cord and the ossified dura mater, thereby reducing the risk of spinal cord and nerve injury. (2) This regional and staged resection of the lamina results in a gradual reduction of tension in the epidural venous plexus, which reduces the risk of spinal cord edema and ischemia–reperfusion injury due to rapid decompression.

At present, the most commonly used surgical technique for OLF is posterior laminectomy. Although it can relieve the compression of the spinal cord, it still carries a high risk of spinal cord and nerve injury [19, 20]. In particular, when combined with DO, en bloc laminectomy may result in extensive dural tears and even severe CFL [21]. Therefore, this technique was not chosen in this study, but zoning laminectomy was performed. After 10–47 months of follow-up, the muscle strength and motor function of all the patients were significantly improved at the final evaluation. The average mJOA score had increased from 5.0 preoperatively to 8.7 postoperatively, and the average improvement rate was 62.6%. No patient had worsened neural symptoms, so the final result was ideal. Some studies have reported that excessive facet resection can change the biomechanical stability of the spine, easily leading to kyphosis and affecting the surgical outcome [22, 23]. In order to reduce the risk of complications, we performed internal fusion for patients with multilevel OLF to increase the stability of thoracic spine. Additionally, we agree that patients with single-level OLF can also obtain good stability without fusion, which has been reported in previous studies [24, 25]. Therefore, we did not perform internal fusion for patients with single-level OLF. In this study, none of the patients developed kyphosis.

Dura mater injury is the most common complication of OLF surgery [22, 26], especially in patients with DO, with an incidence of between 11 and 32% [10, 12, 27]. This study found that DO mainly occurred in OLF patients with severe spinal canal invasion and obvious clinical symptoms, and ossified dura mater and ligamentum flavum were often integrated and difficult to separate. Some studies have recommended abrading the ossification as thinly as possible and leaving it floating [28, 29]. However, when abrading the ossified tissue on the surface of the dura mater, the drill can easily injure it and even the spinal cord. Therefore, we advocate that DO should be excised as much as possible. All patients in this group showed good recovery of neurological function after resection of DO. Consequently, we believe that resection of DO has no obvious effect on the recovery of postoperative neurological function, which is consistent with the research conclusion of Sun et al. [18] In this study, all patients suffered different degrees of dura mater injury during the operation because irregular defects of the dura mater were inevitable after resection of DO. This also confirms the above conclusion that DO does increase the risk of dura mater injury during OLF surgery. It is worth noting that although the majority of current studies suggest that the dura mater injury should be actively repaired when it occurs during surgery [17]. However, in this study, we did not repair these defects. Because we found that the dural defects were irregular, and occurred mostly lateral to the dura mater. In addition, the limited surgical incision increased the difficulty of repair. These factors make it difficult or even impossible to do either a satisfactory water-tight primary suture or a good water-tight duraplasty. Therefore, in this case, we think that the most important thing is to suture tightly the deep fascia, paraspinal muscles, and skin. We observed postoperative CFL in 12 patients. Transient CFL leakage usually stopped after 6–8 days conservative treatment. No patients developed subarachnoid infection, pseudoduraocele or fistula. Our study showed that CFL can be cured by conservative treatment. Therefore, we think that the repair seems unnecessary. In addition, some previous studies have also confirmed that CFL can be cured by conservative treatment [8, 30].

Neurological deterioration is a serious complication after thoracic spine surgery. The known causes of early neurological deficits are dural tears, epidural hematoma, and spinal cord injury [19, 31]. Fortunately, no such complication was found in this study. We believe that this technique reduced intraoperative stimulation to the spinal cord by orderly decompression from the safe zone to the danger zone, consequently improving the safety of the operation.

Conclusions

Zoning laminectomy for the treatment of OLF with DO is safe and effective, and can achieve good clinical results.

Author contributions All authors contributed to the study conception and design. All operations were performed by Qingde Wang. Material preparation, data collection, and analysis were performed by Qiangqiang Pan, Yanyu Zhu, Zhenhui Zhang, and Wei Mei. The first draft of the manuscript was written by Qiangqiang Pan and all authors commented on previous versions of the manuscript. Qiangqiang Pan and Yanyu Zhu contributed equally. All authors read and approved the final manuscript.

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Data availability The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the Ethics Committee of Zheng zhou Orthopaedics Hospital.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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