ORIGINAL ARTICLE

Clinical characteristics and surgical outcome of thoracic myelopathy caused by ossification of the ligamentum flavum: a retrospective analysis of 85 cases

Z Li^{1,2,4}, D Ren^{1,4}, Y Zhao^{1,4}, S Hou¹, L Li¹, S Yu³ and T Hou³

Study design: A retrospective comparative study.

Objectives: To describe the clinical features and radiological findings, to assess the safety and effectiveness of posterior decompressive laminectomy and resection of the ossification of the ligamentum flavum (OLF), and to determine which presurgical and surgical variables were most closely related to postsurgical prognosis of thoracic myelopathy (TM) caused by OLF in China.

Methods: Eighty-five patients with the diagnosis of TM caused by OLF received surgical treatment from July 1998 to May 2012. Clinical data were collected from medical and operative records. Correlations between the surgical outcome and various factors were also analyzed.

Results: All cases were followed up for a mean of 49.2 months (range, 24–190 months) postoperatively. The mean Japanese Orthopaedic Association score was 3.8 points preoperatively and 8.2 points at the final follow-up, yielding a mean recovery rate of 63.0%. Postoperative complications included transient neurological deficits (9 cases), persistent neurological deficits (4 cases), dural tears (17 cases), cerebrospinal fluid leakage (9 cases), wound dehiscence (2 cases) and wound infection (3 cases). The OLF level (middle thoracic), preoperative duration of symptoms, intramedullary signal change on T2WI and preoperative severity of myelopathy were important predictors of surgical outcome.

Conclusions: Biomechanical and anatomical factors may have a key role in thoracic OLF progression. Posterior decompressive laminectomy and resection of the OLF can be considered an effective, reliable and safe alternative procedure. The OLF level, preoperative duration of symptoms, intramedullary signal change on T2WI and preoperative severity of myelopathy were confirmed and significantly correlated with the surgical outcome.

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INTRODUCTION

Thoracic myelopathy (TM) is a relatively rare spinal disorder secondary to several degenerative spinal disorders, including intervertebral disc herniation, posterior spurs, ossification of posterior longitudinal ligament and ossification of the ligamentum flavum (OLF).^{1–9} With the increasing use of diagnostic tools, such as computed tomography (CT) and magnetic resonance imaging (MRI), OLF is gradually being recognized as a major cause of acquired thoracic spinal canal stenosis. The ligamentum flavum is a connective tissue that is attached to the posterior side of the caudal lamina and the anterior side of the rostrally adjacent lamina. The ligamentum flavum extends laterally from the midline to the intervertebral foramen forming the superior-posterior boundary of the foramen. It then turns dorsally outside the foramen to fuse with the capsule of the articular facets.^{10,11} The normal ligament is highly elastic, based on the large proportion of elastic fibers, accounting for 60–70% of the dry weight, with little blood flow. Functionally, the ligamentum flavum provides a static, elastic force to support the spinal

column in its return to a neutral position after flexion and extension movements. Thus, when the ligamentum flavum is replaced by a mature bone, its osseous morphology should be V-shaped or a part of V shape on CT images.¹²

Although thoracic OLF has been reported in several Asian countries, such as Japan,^{11–14} China^{3,4,15–19} and South Korea,^{20–22} and also in Caucasian and Caribbean ethnic groups,^{23–28} extensive studies on thoracic OLF including a large number of patients have not yet been reported in the literature. This is partly due to the relatively low mean prevalence of thoracic OLF, which was reported as 3.8% in China and as 6.2% for Japanese men and 4.8% for Japanese women.^{11,17} Once the thoracic OLF is symptomatic, it is usually progressive and refractory to conservative treatment, and surgical decompression is indicated. The most common mode of treatment is posterior decompression by laminectomy. However, the surgical outcomes vary.^{29–32} Because obtaining detailed data and analysis from a single center study on this topic has been insufficient and difficult, we conducted a study on a large number of patients with TM caused

¹Department of Orthopaedics, First Affiliated Hospital of PLA General Hospital, Beijing, People's Republic of China; ²Department of Orthopaedics, the 210 Hospital of Chinese PLA, Dalian, Liaoning Province, People's Republic of China and ³Department of Orthopedics, Tenth People's Hospital of Tongji University, Shanghai, People's Republic of China
⁴These authors contributed equally to this work.

Correspondence: Professor Z Li, Professor Y Zhao or Dr S Hou, Department of Orthopedics, First Affiliated Hospital of PLA General Hospital, No.51, Fucheng Rd, Beijing 100048, People's Republic of China.

E-mail: lizhonghaipine@126.com, userzyt@qq.com or lvshunman@126.com

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by OLF; we analyzed their preoperative and postoperative symptoms, radiological findings, and intraoperative findings. The aim of this retrospective multicenter study was to describe the clinical features and radiological findings, to assess the safety and effectiveness of laminectomy, and to determine the prognostic factors relevant for patients with TM caused by OLF in China.

MATERIALS AND METHODS

Patient population

This is a retrospective clinical study. From July 1998 to May 2012, 96 patients having thoracic OLF-induced myelopathy at three institutes (First Affiliated Hospital of PLA General Hospital, First Affiliated Hospital of PLA Second Military Medical University and Tenth Affiliated Hospital of Tongji Medical University) were included and who were then observed for a minimum of 2 years postoperatively. Criteria supporting a diagnosis of TM caused by OLF were based on findings of clinical, radiologic and pathologic evaluations. Clinical evaluation was based on history and physical examination. Typical clinical symptoms and findings included numbness and sensory deficits in the lower limbs and below the relative level of the trunk, weakness in the lower extremities accompanied by difficulty in walking and sphincter dysfunction. Positive physical examinations included increased lower limb muscle tension and deep tendon and pathological reflexes.

MRI and three-dimensional CT were performed in every patient. The radiologic work-up provided the characteristics of OLF (that is, location, number of affected segments, axial and sagittal configuration), and showed possible spinal cord involvement. The new categorization of the axial configuration of OLF is by unilateral, bilateral and bridged type (Figure 1), and the categorization of the sagittal configuration of OLF is by beak type and round type (Figure 2) according to previous reports with some modifications.^{33,34}

To evaluate the effect of the thoracic OLF purely, OLF should be apparent and the direct cause of myelopathy. Patients were excluded on the basis of the following criteria: diagnosis of OLF occurring with concurrent ventral compressive lesion, such as thoracic disc herniation or ossification of posterior longitudinal ligament at the same level or cervical compressive myelopathy such as ossification of posterior longitudinal ligament or cervical spondylosis; receipt of surgery using an anterior approach or circumferential spinal cord decompression through a posterior approach; history of spinal tumor; or previous spinal surgery. In this study, 11 (11.5%) were lost to follow-up. The remaining 85 (88.5%) patients who could be followed up regularly comprised the patient cohort of this study, and their records were reviewed. Various factors that could affect surgical outcome were examined: age at surgery, sex, body mass index, current smoking, alcohol, diabetes mellitus, preoperative duration of symptoms, preoperative severity of myelopathy, intramedullary signal change on T2-weighted MRI, configurations of OLF in axial (unilateral, bilateral or bridged) and sagittal (beak or round) plane, number of levels involved, and dural ossification (DO) (Table 1).

Surgical technique

Posterior decompressive laminectomy and resection of the OLF at the involved levels were performed in all patients by highly experienced spine surgeons. Intraoperative somatosensory-evoked potentials were routinely used to observe spinal cord activity in all patients. Briefly, the patient was placed in a prone position and the posterior elements of the spine were exposed through a midline incision at the site of the lesion. After the necessary dissection, the spinous processes were resected during the operation, and laminectomies were performed by using rongeurs and a high-speed drill. The decompression covered at least one level above and below the area affected by the OLF. The width of the laminectomy was approximately one-third to one-half portion of the facet joint and could extend when ossification of the facet joint capsules occurred. The ossified lesions were carefully resected microscopically by use of a diamond drill or a small-angled punch rongeur. The OLF was detached on all sides, made free floating and elevated from the dura. Venous plexus bleeding was noted from the lateral gutters during decompression. Electrocautery, gelatin sponge strips and neuropathies were used to achieve hemostasis.

The dura mater usually adhered to the OLF and sometimes also ossified. In cases like this, we excised both the outer layer of the dura and the OLF with sharp dissection, leaving the inner dural layer intact. Some of the very small dural tears were covered only with gelatin sponge and did not receive suturing. Some patients had the defect repaired immediately with absorbable gelatin sponge, and with either muscle/fascia, artificial dura, or fibrin glue. The muscle/fascia was flattened with a mallet and placed over the dural defect to completely cover the defect. Two pieces of gelatin sponge were then layered over it. In cases when artificial dura was used, the material was cut into the appropriate size and shape and then placed over the dural defect. In cases when fibrin glue was used, the material was sprayed directly onto the dura mater and gelatin sponge was then layered over it.

Posterior fusion and instrumentation was also implemented mainly in the cervicothoracic junction and thoracolumbar junction, with the use of transpedicular screws and longitudinal rods to maintain normal spinal alignment and restore spinal stability. After the spinal cord was decompressed, the paravertebral muscle and the supraspinous ligament were sutured. All patients were required to stay in bed for 3 days after surgery, and they were encouraged to walk assisted by a thoracolumbar orthotic brace for an average of 8 weeks postoperatively.

Postoperative observation and follow-up

The follow-up examinations were scheduled at 3 months, 6 months and 1 year after surgery, and every half year beyond the first year after surgery. Operative time, intraoperative blood loss and complications were reviewed from the medical records. All patients were seen in follow-up visits, during which the neurologic outcomes were evaluated according to the Japanese Orthopaedic Association (JOA) scoring system for cervical myelopathy, excluding scores for the upper extremities (full score, 11 points) (Table 2), before and after surgery. Postoperative recovery rate (RR) was calculated as: $RR = (\text{postoperative} - \text{preoperative JOA score}) / (11 - \text{preoperative JOA score}) \times 100\%$. The RR was then used to define the surgical outcome: excellent ($RR \geq 75\%$), good ($75\% > RR \geq 50\%$), fair ($50\% > RR \geq 25\%$), unchanged ($24\% > RR \geq 0\%$) and deteriorated ($RR < 0\%$).³⁵

Figure 1 Axial configuration of thoracic OLF was classified into three subgroups: unilateral (a), bilateral (b) and bridged (c) types on schematic drawings and axial CT scan.

Figure 2 Sagittal configuration of thoracic OLF was classified into two subgroups: round (a) and beak (b) types on schematic drawings and T2-weighted sagittal MRI/sagittal CT scan.

Table 1 Summary of demographic data and perioperative parameters in 85 patients with thoracic OLF

Variable	Observed value
Age at surgery, years, mean (range)	60.2 (40–78)
Sex (male/female)	54/31
BMI, kg m ⁻² , mean (range)	23.7 (17.1–33.6)
Current smoking, number (%)	19 (22.4)
Alcohol, number (%)	13 (15.3)
Diabetes mellitus, number (%)	9 (10.6)
Preoperative duration of symptoms, months, mean (range)	13.5 (1–32)
Preoperative JOA score, mean (range)	3.8 (1–9)
JOA scores at final follow-up, mean (range)	8.2 (3–11)
Postoperative improvement rate, %, mean (range)	63.0 (0–100)
Hospital stay, days, mean, (range)	16.4 (11–32)
Follow-up period, months, mean (range)	49.2 (24–190)
Operation time, minutes, mean (range)	143.5 (70–425)
Blood loss, ml, mean (range)	495.3 (120–1,890)

Abbreviations: BMI, body mass index; JOA, Japanese Orthopaedic Association; OLF, ossification of the ligamentum flavum.

Statistical analyses

The Statistical Package for Social Sciences software for Windows (Ver. 17.0, SPSS Inc, Chicago, IL, USA) was used for the analysis. The chi-square test was used to compare the categorical variables between two and three groups. Student's *t*-tests and one-way analysis of variance were used to compare the statistical significance of the association for continuous data. Pearson's and Spearman's rank correlation coefficients were used to test the correlations between various factors and RR. Multiple regression analysis was performed to identify the independent factors associated with RR. Results are expressed as the mean $\pm$ standard deviation, with a *P* value of <0.05 considered statistically significant.

RESULTS

Clinical characteristics and surgical outcome

The study group consisted of 31 female and 54 male patients between 40 and 78 years of age, averaging an age of 60.2 years. The average disease duration from onset to surgery was 13.5 months (range, 1–32 months). Twenty-two patients had lesions located in the upper

Table 2 Japanese orthopaedic association (JOA) scoring system modified for thoracic myelopathy

Neurological status	Score (points)
A. Motor dysfunction of lower limbs	
Unable to walk	0
Able to walk on flat floor with walking aid	1
Able to walk up and/or down stairs with handrail	2
Lack of stability and smooth reciprocation of gait	3
Normal	4
B. Sensory deficit in lower limbs	
Severe sensory loss or pain	0
Mild sensory loss	1
Normal	2
C. Sensory deficit in trunk	
Severe sensory loss or pain	0
Mild sensory loss	1
Normal	2
D. Sphincter dysfunction	
Unable to void	0
Marked difficulty in micturition	1
Mild difficulty in micturition	2
Normal	3

thoracic spine (T1–T4), 19 patients in the middle thoracic spine (T5–T9) and 44 patients in the lower thoracic spine (T10–T12). DO occurred in 21 cases, and the incidence was 24.7%. Intramedullary signal change on T2-weighted MRI was shown in 18 patients (Figure 3). The average operative time was 143.5 min (range, 70–425 min). The average blood loss was 495.3 ml (range, 120–1890 ml). No patient received a blood transfusion. All cases were followed up for a mean of 49.2 months (range, 24–190 months) postoperatively. All patients received posterior decompressive laminectomy (Figure 4). Posterior laminectomy combined with lateral fusion with instrumentation was performed in 28 patients (32.9%). The mean JOA score was 3.8 points preoperatively, and 8.2 points at the final follow-up, yielding

a mean RR of 63.0%. Thus, a statistically significant improvement in the JOA score was obtained at the final follow-up examination ($P < 0.05$). No improvement or symptom aggravation was found in 4 patients (4.7%), and a RR of more than 50% was observed in 63 patients (74.1%).

Complications

Transient deterioration of TM occurred immediately after the surgery in nine patients (10.6%). After dehydration and corticosteroid therapy,

Figure 3 Round type of OLF on T2-weighted MRI shows hypointense signal.

all of them recovered spontaneously and improved beyond their preoperative condition during in-hospital course or until clinical follow-up 3–6 months postoperatively in all patients. There were four patients who suffered from late postoperative neurologic deterioration or persistent aggravation of paralysis. Potential etiologies include ischemia-reperfusion injury, microthrombi and altered perfusion due to internal recoil of spinal cord architecture following decompression.

Of the 85 patients, 17 had dural tears in the operation period, yielding an overall incidence of 20.0%. Cerebrospinal fluid (CSF) leakage occurred in 9 of 17 patients (52.9%). Leakage of CSF did not result in any neurologic degradation but was associated with patient discomfort, which improved gradually within the first postoperative month. These patients were kept in the prone or lateral position in bed for about 2–3 days after operation. The color and volume of drainage fluid were recorded. When the drainage had reduced to less than 50 ml per 24 h, the subfascial drain was removed. CSF leakage stopped after 5–7 days in all nine cases. Two patients developed CSF pseudocyst during the follow-up, both of which were cured by repeated ultrasound-guided puncture and aspiration.

There were two patients who experienced wound dehiscence, making for an incidence of 2.4%. Both of them were cured by a debridement procedure performed under anesthesia. Three cases (3.5%) developed postoperative wound infections that resolved after a single surgical irrigation and debridement, primary closure, and intravenous antibiotics for 2–3 weeks. No thoracic kyphosis was seen at the final follow-up. No instrumentation-related complication was observed in any patient during the entire follow-up period.

Various factors associated with surgical outcomes

Univariate analysis revealed that sex, body mass index, current smoking, alcohol, diabetes mellitus, number of levels involved, sagittal configurations of OLF, DO and aided by fusion with instrumentation were not significantly related to the surgical outcome ($P > 0.05$, Table 3). The RR at the final follow-up correlated significantly with age at surgery, preoperative duration of symptoms, the OLF level, axial configurations of OLF, intramedullary signal change on T2WI and preoperative severity of myelopathy ($P < 0.05$). Furthermore, multiple

Figure 4 A 65-year-old male was diagnosed as having TM caused by OLF in T9-T10. Posterior decompressive laminectomy and resection of the OLF without surgery related-complications was performed on the patient. After operation, the patient was satisfied and showed excellent clinical result. Preoperative sagittal T2-weighted MRI (a) showed the sagittal configuration of OLF (round type). Preoperative axial CT scan (b) showed the axial configurations of OLF (bilateral type). Postoperative axial (c), sagittal (d) and coronal (e) CT scans showed decompression of the spinal cord at T9-T11.

Table 3 Correlations of postoperative RR and various factors by means of univariate statistics ($n=85$)

Factors	Classification	No.	Mean $\pm$ s.d.	Range	<i>t</i>	P
Sex	M	54	62.94 $\pm$ 21.98	20.00–100.00	0.01	0.9922
	F	31	62.89 $\pm$ 24.80	0.00–100.00		
Age at surgery, (years) ^a	<60	46	67.75 $\pm$ 23.74	0.00–100.00	4.94	0.0094
	60–70	28	62.14 $\pm$ 18.84	22.22–100.00		
	>70	11	44.70 $\pm$ 20.88	20.00–80.00		
BMI, (kg m ⁻²)	<25	56	61.28 $\pm$ 22.55	0.00–100.00	0.91	0.3632
	≥ 25	29	66.08 $\pm$ 23.65	20.00–100.00		
Current smoking	Yes	18	54.68 $\pm$ 24.93	0.00–100.00	1.74	0.0857
	No	67	65.13 $\pm$ 22.00	11.11–100.00		
Alcohol	Yes	13	66.23 $\pm$ 21.58	30.00–100.00	0.56	0.5741
	No	72	62.32 $\pm$ 23.23	0.00–100.00		
Diabetes mellitus	Yes	9	55.56 $\pm$ 33.42	0.00–100.00	1.02	0.3106
	No	76	63.79 $\pm$ 21.47	11.11–100.00		
Preoperative duration of symptoms, (months) ^a	≤ 6	25	81.77 $\pm$ 14.00	57.14–100.00	37.60	<0.0001
	6–12	15	75.66 $\pm$ 13.12	50.00–100.00		
	≥ 12	45	48.20 $\pm$ 18.99	0.00–83.33		
OLF level ^a	Upper thoracic	22	60.68 $\pm$ 22.23	11.11–100.00	6.67	0.0021
	Middle thoracic	19	48.83 $\pm$ 22.26	20.00–100.00		
	Lower thoracic	44	70.12 $\pm$ 20.80	0.00–100.00		
Number of OLF levels	1	44	63.07 $\pm$ 19.18	11.11–100.00	0.06	0.9487
	≥ 2	41	62.75 $\pm$ 26.57	0.00–100.00		
Type of OLF (axial configurations) ^a	Unilateral	19	74.09 $\pm$ 19.64	28.57–100.00	5.62	0.0051
	Bilateral	27	66.74 $\pm$ 18.85	37.50–100.00		
	Bridged	39	54.83 $\pm$ 24.36	0.00–100.00		
Type of OLF (sagittal configurations)	Beak	32	62.36 $\pm$ 22.29	11.11–100.00	0.17	0.8633
	Round	53	63.25 $\pm$ 23.47	0.00–100.00		
DO	Yes	21	56.83 $\pm$ 25.02	22.22–100.00	1.41	0.1617
	No	64	64.92 $\pm$ 22.00	0.00–100.00		
Aided by fusion with instrumentation	Yes	28	67.67 $\pm$ 22.88	20.00–100.00	1.35	0.1814
	No	57	60.58 $\pm$ 22.75	0.00–100.00		
Intramedullary signal change on T2WI ^a	Yes	18	43.39 $\pm$ 26.08	0.00–100.00	4.52	<0.0001
	No	67	68.16 $\pm$ 18.99	11.11–100.00		
Preoperative severity of myelopathy (JOA score) ^a	≥ 7	32	44.93 $\pm$ 17.71	11.11–87.50	29.39	<0.0001
	4–6	43	70.97 $\pm$ 17.32	0.00–100.00		
	≤ 3	10	85.83 $\pm$ 19.27	50.00–100.00		

Abbreviations: BMI, body mass index; DO, dural ossification; JOA, Japanese Orthopaedic Association; OLF, ossification of the ligamentum flavum; RR, recovery rate.

^aStatistically significant difference ($P<0.05$).

regression analysis showed that the OLF level (middle thoracic), preoperative duration of symptoms, intramedullary signal change on T2WI and preoperative severity of myelopathy were important predictors of surgical outcome ($P<0.05$, Table 4).

DISCUSSION

Epidemiology and pathogenesis

Thoracic OLF is rare and usually asymptomatic. The disease usually progresses insidiously over a long period of time and can eventually cause myeloradiculopathy and pain. Analysis of previously published epidemiological data revealed that the mean age of thoracic OLF patients ranged from 50 to 60 years and most required surgical treatment.^{17,18,21} Another large-scale epidemiological study on OLF in patients who presented with chest symptoms and underwent multi-detector CT examination showed that the prevalence rate of OLF was much higher, at 63.9%, than in previous reports.¹⁸ The process of OLF occurred earlier than was previously thought and was even found in 10–19-year-old individuals. The prevalence peaked in the 50–60 years age group, and tended increase with increasing age. Our data show that 54.2% of patients were diagnosed with symptomatic thoracic OLF at less than 60 years of age, followed by those of 60–70 years (32.9%)

and more than 70 years of age (12.9%). We also found that the prevalence of OLF in men was higher than in women at most segments, which was in line with most of the literature.^{12,15,18,36} This finding may be due to heavier physical activity in men, which causes heavier stress on the ligamentum flavum. However, in some studies, the prevalence rates were reported to be higher in women than in men.^{4,17,20}

OLF is not only an isolated form of spinal column ossification but also occurs in association with diffuse idiopathic skeletal hyperostosis, ankylosing spondylitis and metabolic diseases such as Paget disease, hypoparathyroidism and X-linked hypophosphatemia.^{25,34,37} Although it has been 90 years since the first description of OLF, very little is known about the pathophysiology of OLF. Currently, several studies have described the possible roles of mechanical/traumatic,^{14,38–41} metabolic,^{42,43} chronic degenerative,^{44,45} biological/hereditary,^{46,47} environmental^{48,49} and genetic factors^{50–53} in the development and progression of OLF.

In the literature, the lower thoracic spine (T10–T12) is the most frequently affected segment whereas the middle thoracic vertebrae (T5–T8) are rarely affected within the thoracic spine.^{15,18,34,54,55} In our study, we also found similar results. In addition, it has been reported

Table 4 Risk factors associated with surgical outcomes by means of multiple linear regression (*n* = 85)

Risk factors	Parameter estimate	Standard error	<i>t</i>	P
Age at surgery	-0.20334	0.20857	-0.97	0.3331
Intramedullary signal change on T2WI ^a	-14.18303	4.19263	-3.38	0.0011
OLF level (middle thoracic) ^a	-7.77402	3.63471	-2.14	0.0355
Type of OLF (axial classification)	4.19031	4.01387	1.04	0.3003
Preoperative duration of symptoms ^a	-8.80622	2.19473	-4.01	0.0001
Preoperative severity of myelopathy ^a	5.00222	1.02951	4.86	<.0001

Abbreviation: OLF, ossification of the ligamentum flavum.

^aStatistically significant difference (*P* < 0.05).

that the location of OLF is less vulnerable in mobile segments such as the cervical and lumbar vertebra than in the thoracic vertebrae.^{26,30,40,55,56} This phenomenon gives us insight about the pathogenetic mechanism of OLF. On the basis of the literature review, we hypothesized that biomechanical and anatomical factors might have a key role in thoracic OLF progression. The lumbar and cervical regions are much more flexible than the thoracic spine in terms of flexion/extension and lateral bending. The unstable mechanical environment is not suitable for osteogenic differentiation of ligamentum flavum cells. As the range of motion becomes more restricted in thoracic spine relative to the cervical or lumbar spine, the length of the elastic fibers in the ligamentum flavum is kept in a narrow range during dynamic motion, and calcification may occur more frequently in this relatively stable environment. This hypothesis was histologically supported by the OLF found in the hypertrophic ligament flavum with fibrocartilage proliferation, which was thought to be a result of mechanical stress because of tensile force.³⁰ As the lower thoracic spine is a transitional area in spinal curvature, the elastic fibers in ligamentum flavum may be relaxed and thickened relatively. In addition to the anatomical difference relating to mechanical stress involving constraints on the articular processes during segmental motion, this difference may also be attributed to increased instability in lower thoracic spine.^{41,55,57} Compared with the middle thoracic spine, it seems to be more particularly easy to make degenerative processes on the lower thoracic spine owing to the high tensile force present on the posterior column.^{22,55} Maigne *et al.*⁵⁵ reported that OLF occurred most frequently at the lower thoracic spine especially at the thoracolumbar junction, and its appearance correlated with a unique orientation of the facet joints that generated increased rotatory instability and micromotion.

Clinical and radiographic characteristics of thoracic OLF

Ligamentum flavum has two portions, the interlaminar and the capsular ones.⁵⁸ Ossification usually begins in the capsular portion and spreads to the laminar portion.¹¹ OLF compresses the spinal cord or root from the posterolateral side and causes symptoms. Most of the thoracic OLF patients showed the typical features of TM: that is, sensory and motor deficits in the trunk and lower extremities, sphincter disturbance and exaggerated tendon reflexes. OLF is most often asymptomatic but may present as two different symptoms. The first involves chronic spinal cord compression over a long period of time and presents with unsteady gait, difficulty with balance and climbing stairs, with or without unilateral/bilateral neurogenic claudication. In the second one, OLF may present as acute myelopathy after minor trauma. There is a sudden compromise in an asymptomatic, but narrowed, spinal canal by hematoma and edema, with or without bony/soft tissue impingement secondary to the trauma. The motor and sensory deficits are usually more severe than the first one

and recovery is usually poor. To improve the clinical outcome of thoracic OLF, early diagnosis in patients with a less severe pathologic lesion would be critical. In this view, meticulous physical examination might help to make an accurate diagnosis for thoracic OLF patients.

Before the early 1990s, when MRI was not commonly used for neurological diagnosis, CT was considered the best diagnostic tool to detect thoracic OLF.^{23,26,30,36} OLF can be confirmed to mainly present in the foraminal region on CT, which not only provide an accurate assessment of the contour of the ossification but also show the ossification of dura mater and the size of the spinal canal. Pascal-Moussellard *et al.*²⁸ reported sagittal reconstructions of CT that are helpful for distinguishing OLF from calcification of the ligamenta flava, which is the only differential diagnosis of OLF. Myelography combined with CT can show spinal cord compression but is, at present, commonly replaced by MRI as the modality of choice for neural elements and the cord. As OLF tends to occur in multiple locations, MRI should be used to show the distribution of OLF to prevent missing affected levels. Additionally, MRI is able to detect coexisting spinal lesions in the cervical and/or lumbar spine, which are not uncommon in thoracic OLF patients. A high-intensity signal in the spinal cord on T2-weighted MRI is thought to indicate edema, demyelination, myelomalacia, cavitation or necrosis and related to the severity of the myelopathy.^{56,59–61} However, MRI alone is insufficient for the diagnosis of OLF because a low-intensity signal on T1- and T2-weighted sequences is indistinguishable from that corresponding to a hypertrophic ligamentum flavum. Consequently, as we have performed in our study, preoperative whole-spine MRI combined with CT are recommended to establish an accurate diagnosis and to determine the extent of surgical procedure.

Surgical treatment and complication of thoracic OLF

Conservative treatments have proven to be ineffective for symptomatic patients of thoracic OLF.^{26,28,57} Surgery is the only treatment that can adequately address the significant compression of neurologic structures caused by OLF.^{1,29,62–64} The goal of surgical intervention is to excise the ossified segments and provide sufficient decompression. Posterior decompression is the most commonly reported surgical method, and total laminectomy is the most commonly used means of achieving such decompression. The range of decompression used differs in various reports,^{29,30,32,64} and most researchers consider that the range of decompression should encompass the medial one-third to one-half of the facet joint and one or possibly two laminae superior and inferior to the diseased segment.^{15,26} All patients in our study received posterior decompressive laminectomy. A statistically significant improvement in the JOA score was obtained at the 4-year follow-up examination. However, most of the recoveries were incomplete, with a mean of 63.0%, which was similar to those in prior reports.^{4,15,19,30,56}

Use of spinal fusion to treat TM caused by OLF is controversial. Kyphotic spinal deformity after thoracic laminectomy may cause neurologic deterioration. To minimize the risk of spinal instability or kyphotic deformity, spinal fusion with internal instrumentation was partially performed for patients with multilevel OLF mainly at the cervicothoracic junction and thoracolumbar junction. In our study, posterior laminectomy combined with spinal fusion with instrumentation was performed in 28 patients (32.9%). No obvious instability or kyphotic deformity was seen at the final follow-up. However, the essentiality of this procedure should be evaluated in further comparative studies.

Some authors have recommended laminoplasty for the treatment of OLF, because of late neurological deterioration due to the recurrence of OLF at the same site or increased kyphotic deformity of the spine.^{30,65} However, laminoplasty is not suitable for severe OLF because they will only achieve limited decompression and because the possibility of reclosure exists. Laminoplasty, for example, merely expands the volume of the spinal canal and does not remove the ossified ligamentum flavum. Residual compression may remain if the size of the ossified lesion is large. Furthermore, lamina treated with laminoplasty may return to the preoperative position, the surgical procedure is relatively complicated and the long-term effect is less reliable than that of the surgical technique reported here.^{56,65}

As we all know, each surgical procedure has its own complications. Dural tears and CSF leakage are the most common complications of thoracic OLF surgery and can lead to CSF pseudocyst, respiratory obstruction, wound dehiscence and meningitis.^{66–68} Because dural adhesion and DO are more common in thoracic OLF than in cervical or lumbar spine, the incidence of CSF leakage in OLF patients may be higher.^{56,68–70} Miyakoshi *et al.*⁵⁶ reported that dural adhesion was observed in 62% of the 34 patients with OLF, and found that dural adhesion was frequently observed in larger types of OLF. Aizawa *et al.*¹¹ reported that 9 of 72 patients with OLF had dural tears during surgery and 8 of them had DO. Ben Hamouda *et al.*²⁶ reported the incidence of dural tears as being 22% (4/18). In our series, the incidence of DO, dural tears and CSF leakage was 24.7%, 20% and 10.6%, respectively. Among the nine patients in our study with CSF leakage, seven had DO, for an incidence of 77.8%; therefore, DO was characterized as the main reason of CSF leakage in patients with OLF. In addition, compared with other thoracic pathologies that do not cause DO, the incidence of dural tears and CSF leakage with thoracic laminectomies in our study is relatively high.^{71,72} This would strengthen the statement that dural tears and CSF leakage are associated with DO and complicates surgical repair of the disorder. The intraoperative manipulation should be gentle to avoid dural tears as much as possible, and once a dura mater tear is noticed, immediate repair should be carried out.^{56,68,70} Eight cases underwent dura mater repair and no CSF leakage happened after the operation, and the surgical effect was satisfactory. Although the procedure and success of intraoperative repair is important, comprehensive treatments after operation should not be ignored. In our study, we kept the patient with dural tears in a prone or lateral position. These positions played an important role in the process of dural healing because they reduced hydrostatic pressure on the repaired dura and reduced the caustic effect of CSF, providing an environment amenable to the healing process. In our study, CSF leakage stopped after 5–7 days in all nine cases. CSF pseudocyst was a common complication related to CSF leakage. Two patients developed CSF pseudocyst during the follow-up in our series, both of which were cured by repeated ultrasound-guided puncture and aspiration with strict aseptic measures. CSF leakage did not result in any neurologic degradation but was associated with

patient discomfort, which improved gradually within the first post-operative month. Therefore, accurate preoperative identification of the DO, active preparation for the repair of dura mater and comprehensive treatments after operation can make the patient recover more quickly and completely. Some research showed that, if OLF encroached dura mater, we can select ‘floating method’ which is a microscopic technique for decompression to avoid CSF leakage.^{73,74}

Another serious surgical complication in thoracic OLF surgery is spinal cord injury.^{62,75,76} Several procedures were followed with the aim of minimizing the risk of spinal cord injury. To avoid injury to the blood supply to the spinal cord, the microcirculation around the intervertebral foramen should be protected when ligating the vertebral segmental vessels. The Adamkiewicz artery should be carefully protected. This artery lies on the left side at T7–L4 in about 80% of cases and usually supplies the nutrient arteries to the spinal cord at T9–L1.^{15,57,62,67,77} Injury to the Adamkiewicz artery may be disastrous. Intraoperative evoked-potential monitoring can reduce the risk of spinal cord injury. In our study, evoked-potential monitoring was utilized as an intraoperative monitoring tool for all the cases, iatrogenic spinal cord injury was effectively avoided. Besides, a high-speed air drill was used for all patients in our study during the decompression process, and, after sufficiently dissociating the bilateral borders and the cranial and caudal ends over the selected decompression area, the compressing materials were excised at once to avoid the repeated irritation to the spinal cord caused by a sequential excision process. However, there were four patients suffering from late postoperative neurologic deterioration or persistent aggravation of paralysis in our series. We think that potential etiologies may include ischemia-reperfusion injury, microthrombi and altered perfusion due to internal recoil of spinal cord architecture following decompression.

Postoperative epidural hematomas are another complication, usually on the day of surgery, and can cause postoperative spinal cord compression and induce symptom aggravation.³² Their occurrence is correlated with incomplete intraoperative hemostasis, blocked drainage tubes or coagulopathy. No postoperative epidural hematoma occurred in the present study. This lack of epidural hematomas was probably due to the intraoperative hemostasis and postoperative draining used in the current study. Hematomas in the vertebral canal can injure the spinal cord with catastrophic consequences if it is not treated urgently. If neural dysfunction gradually increases after the operation, the possibility of epidural hematoma should be considered and, if high doses of methylprednisolone do not improve the symptoms, surgical exploration should be carried out after a short period of observation.

Prognostic factors for thoracic OLF

Several authors reported that some factors might affect the surgical outcome which included preoperative neurological status, duration of preoperative symptoms, CT findings, intramedullary signal change on T2WI, age, sex, number of levels involved, and type of OLF and so on.^{13,19,20,22,33,34,56} Preoperative severity of myelopathy was considered as the most important predictor of the postoperative outcome.^{19,20,22,56} In accordance with this finding, our research confirmed that preoperative severity of myelopathy was the most important predictor of the highest postoperative JOA score and the lowest percentage RR in multiple linear regression analyses. In addition, the OLF level (middle thoracic), preoperative duration of symptoms and intramedullary signal change on T2WI were also confirmed and significantly correlated with the surgical outcome by multiple regression analysis. Meanwhile, our research revealed that sex, age at surgery, body mass index, current smoking, alcohol,

diabetes mellitus, number of levels involved, sagittal configurations (beak or round), axial configurations (unilateral, bilateral or bridged), DO and aided by fusion with instrumentation were not significantly related to the surgical outcome.

Limitations

A limitation of this study was that it was a retrospective unrandomized case-control study, and the numbers of patients in this study were relatively small. The mean 49.2 months follow-up duration in this study was too short to evaluate the efficacy of posterior decompressive laminectomy and resection of the OLF in treatment of TM caused by OLF. In addition, patients of thoracic OLF are often associated with the coexisting spinal disorders, such as ossification of posterior longitudinal ligament, disc herniation, canal stenosis or OLF at other spinal levels, were reported to make the surgical decision more complicated and the surgical outcome more unpredictable. However, the subjects were excluded in our study. Further large-scale prospective investigations on the predictive factors for poor surgical outcome in thoracic OLF surgery through long-term follow-up period will be necessary in the future.

CONCLUSIONS

Thoracic OLF is a relatively common disease that produces myelopathy in the thoracic area. The thoracic OLF has the problems of relatively high surgical risk and unpredictable surgical outcome. On the basis of the results of this study, we think that biomechanical and anatomical factors may have a key role in thoracic OLF progression. Posterior decompressive laminectomy and resection of the OLF can be considered an effective, reliable and safe alternative procedure in the treatment of TM caused by OLF. The OLF level, preoperative duration of symptoms, intramedullary signal change on T2WI and preoperative severity of myelopathy were confirmed and significantly correlated with the surgical outcome.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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