Benefits and Risks of Subsection Laminectomy with Pedicle Screw Fixation for Ossification of the Ligamentum Flavum of the Thoracic Spine: A Retrospective Study of 30 Patients

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Background: This study aimed to evaluate the effectiveness of subsection laminectomy with pedicle screw fixation (SLPF) for the treatment of ossification of the ligamentum flavum of the thoracic spine.

Material/Methods: Thirty patients (age, 40–71 years) with ossification of the ligamentum flavum of the thoracic spine underwent SLPF (13 men, 17 women). Operative time, intraoperative blood loss, preoperative and postoperative change in thoracic kyphosis, and perioperative complications were recorded. The Japanese Orthopedic Association (JOA) score for severity of myelopathy and the American Spinal Injury Association (ASIA) motor and sensory impairment scale were used before and after surgery.

Results: Mean operative time for SLPF was 208.4±38.3 min and mean intraoperative blood loss was 689.3±171.7 ml. The mean JOA score significantly increased from 5.7±1.9 before surgery to 8.8±2.2 at one month after surgery and 9.3±2.7 at the last follow-up (P<0.01). Postoperative improvement in neurological function increased by 68.3±14.4%. The postoperative ASIA grades significantly improved compared with the preoperative grades (P<0.01). The mean local Cobb angle significantly decreased from 17.8±4.3° before surgery to 15.4±3.6° at one month after surgery and 15.8±3.8° at the last follow-up (P<0.01). Three patients (10%) had operative cerebrospinal fluid (CSF) leak. Postoperatively, one patient had neurological deterioration, two patients had deep venous thrombosis (DVT), and one patient developed a wound infection.

Conclusions: SLPF was an effective procedure for the treatment of ossification of the ligamentum flavum of the thoracic spine.

MeSH Keywords: Internal Fixators • Ossification of Posterior Longitudinal Ligament • Thoracic Surgery • Treatment Outcome

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Background

Ossification of the ligamentum flavum of the thoracic spine is one of the most common causes of thoracic spinal stenosis, but the etiology and pathogenesis remain unclear. Genetic factors, diet, environmental factors, metabolic abnormalities, degenerative change, and other factors have been proposed as the cause [1]. There are many surgical methods for the treatment of ossification of the thoracic ligamentum flavum, including the laminar shelling decompression [2], open-door or French-door laminectomy [3], en bloc resection of the vertebral laminae [4,5], and *in situ* lamina osteotomy and replantation [6]. Each type of surgical procedure has its own characteristics. The laminar shelling decompression method is the classical surgical procedure and is easy to perform, but involves continuous surgical involvement of the spinal canal when the lamina is being removed piecemeal.

Open-door and French-door laminectomy can be performed using a high-speed drill and piezosurgery. However, although the spinal cord is fully decompressed, the loss of spinous processes and lamina causes severe damage to the stability of the posterior column, and long-term instability and kyphosis of the decompression area are prone to occur following surgery. Lamina osteotomy and replantation techniques have been developed in spinal surgery to maintain the integrity of the spinal canal and maintain the stability of the spine using micro titanium plate implantation [6,7]. However, there remain disadvantages to these new techniques, including complicated surgical steps, a long operation time, large amounts of intra-operative bleeding, and high incidence of dural tears during surgery.

Therefore, following review of the advantages and disadvantages of current surgical procedures, for the treatment of ossification of the ligamentum flavum of the thoracic spine, our institution implemented the use of subsection laminectomy with pedicle screw fixation (SLPF). The current study presents SLPF as a new surgical technique to treat ossification of the ligamentum flavum of the thoracic spine. This aim of this retrospective study was to evaluate the effectiveness of SLPF for the treatment of ossification of the ligamentum flavum of the thoracic spine and to assess the complications from surgery that occurred during and after surgery.

Material and Methods

Patients

From October 2014 to November 2016, 38 patients were diagnosed with ossification of the ligamentum flavum of the thoracic spine in the Third Hospital of Hebei Medical University

and underwent treatment with subsection laminectomy with pedicle screw fixation (SLPF). There were 30 patients with complete postoperative follow-up visits of >12 months who were included in the study, including 13 men and 17 women aged between 40–71 years (mean, 57.6±8.7 years). The duration of preoperative symptoms ranged from 11–36 months (mean, 24.9±7.2 months). The 30 patients included in this retrospective study included six patients with two-segment ossification of the ligamentum flavum, 15 patients with three-segment ossification, seven patients with four-segment ossification, and two patients with five-segment ossification. Figure 1 shows a schematic diagram of the SLPF procedure for the treatment of ossification of the ligamentum flavum of the thoracic spine.

## Inclusion and exclusion criteria

Study inclusion criteria were preoperative symptoms, signs, and imaging data that were consistent with thoracic spinal stenosis, a postoperative follow-up of >12 months, complete imaging data before and after surgery, and normal function of the major organs, normal blood glucose, and blood pressure. Exclusion criteria included patients with cervical spinal stenosis and lumbar spinal stenosis combined with ossification of the posterior longitudinal ligament, patients with thoracic vertebral fracture, infection, tumor, or coagulation abnormalities.

Symptoms and signs of patients with ossification of the ligamentum flavum of the thoracic spine

From the medical history, patients with ossification of the ligamentum flavum of the thoracic spine who underwent surgery had chronic and progressive symptoms characterized by unstable walking, numbness of the lower limbs, uncontrolled movement of the lower extremities, a constrictive sensation of the chest and abdomen, atrophy of the lower limbs, and sphincter dysfunction. Eight cases out of the 30 cases showed upper motor neuron damage with hypermyotonia, and tendon hyperreflexia. There were 21 patients who had lower motor neuron damage with reduced muscle strength, reduced skin sensation, weakened or absent knee reflexes, and Achilles tendon reflexes, and one patient had mixed upper and lower motor neuron symptoms and signs.

Imaging data

Routine imaging of the spine was performed using X-ray, computed tomography (CT) and magnetic resonance imaging (MRI) to confirm the diagnosis of ossification of the ligamentum flavum of the thoracic spine. Typically, patients had high-density ossification from the vertebral lamina to the nerve root canal on the lateral X-radiograph (Figure 2A). CT imaging confirmed the morphology of the ossification and the degree of spinal stenosis (Figure 2B, 2C). MRI showed that low-signal
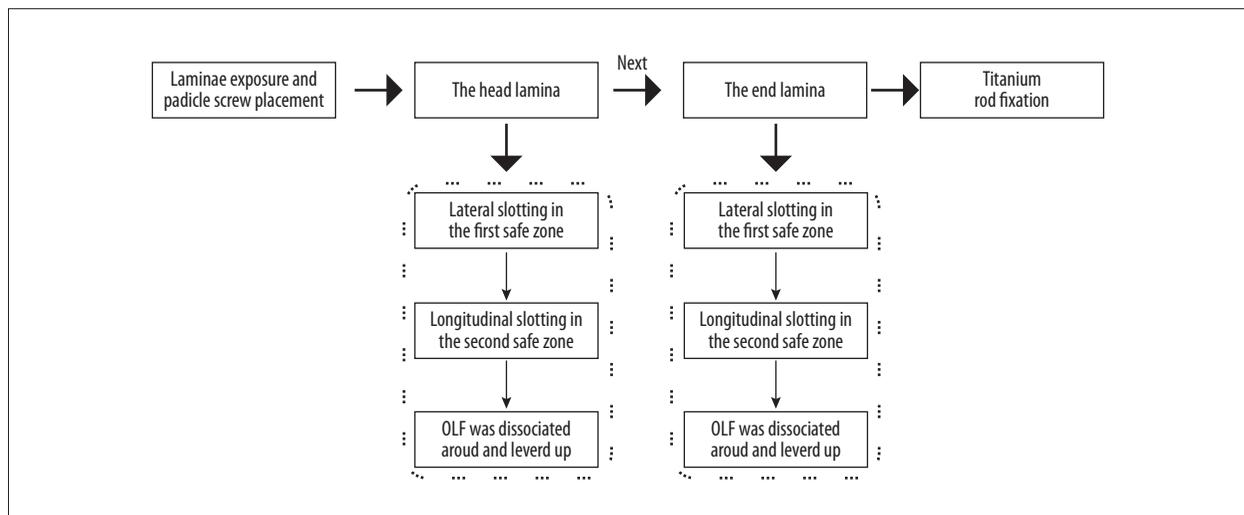
Figure 1. Schematic diagram of the subsection laminectomy with pedicle screw fixation (SLPF) for the treatment of ossification of the ligamentum flavum of the thoracic spine.

protrusions were found from the posterior to the spinal canal, and the thoracic spinal cord was compressed and thinned. From the 30 patients studied, 18 patients showed an intramedullary high signal intensity (IHSI) on the T2-weighted MRI imaging (Figure 2D).

Subsection laminectomy with pedicle screw fixation (SLPF) surgery

As shown in Figure 1, surgery was performed under somatosensory evoked potential monitoring (SSEP). After undergoing induction of general anesthesia, the patients were placed in the prone position, and a posterior median incision was made with the lesion at the center. The bilateral paravertebral muscles were removed to reveal the vertebral lamina, articular processes, and bilateral transverse processes (Figure 2E). The pedicle screw (Weigao Orthopaedic Device Co. Ltd., Weihai City, China) was inserted into the lesion segments (Figure 2F). At the head and lower end of the decompression zone, the supraspinous ligament and interspinous ligaments were cut transversely, and the spinous processes together with the attached tissue were removed. The laminae were removed from top to bottom and section by section. First, cuts were made to the inner cortex with a 3 mm diameter high-speed micro saw (Stryker Micro Power, Kalamazoo, MI, USA) along both sides of the vertebral lamina and transverse processes (Figure 2G), The middle of the upper and lower lamina adjacent to the ossification were separated laterally with a sharp-nosed rongeur to the inner cortex (Figure 2H). Second, the root of the spinous process was clamped with a padded clamp and lifted up and a bone dissector was inserted into the gap at the edge of the free lamina, pressed to the posterior end to move the lamina backward using leverage (Figure 2I). Third, the adhesions between the ossified tissue and the dura mater were separated

using a nerve dissector and, when necessary, sharp dissection was undertaken with a scalpel to entirely remove the lamina and the ligamentum flavum (Figure 2J, 2K). The remaining articular process and the edge of the lamina on both sides were further trimmed for complete decompression. Finally, the vertebral lamina was trimmed into bone fragments that were implanted into the bilateral transverse processes. A titanium rod of appropriate length was bent and placed into the U-shaped groove of the pedicle screw, and the screw nut was then tightened for fixation (Figures 1, 2L).

Patients with non-ruptured dura mater were routinely treated with conventional vacuum drainage for 24–48 hours. Dehydration, improvement of microcirculation and neurotrophic drugs were given after the operation. Intensive treatment with methylprednisolone 80 mg was given for three days and exercises were commenced as early as possible to assist in functional recovery of the patients.

Evaluation of surgical efficacy

The Japanese Orthopedic Association (JOA) 11-point scoring system was used to evaluate preoperative and postoperative neurological function (Table 1) [8]. The recovery rate was calculate as: recovery rate=(postoperative score–preoperative score)/(11-preoperative score)×100%.

The American Spinal Injury Association (ASIA) motor and sensory impairment scale was used to determine the recovery of neurological function [9]. Thoracic kyphosis was evaluated by measuring the Cobb angle [10], which was the angle from the upper end of the previous vertebral body of the segment of the lesion to the lower end of the next vertebral body of the lesion segment.
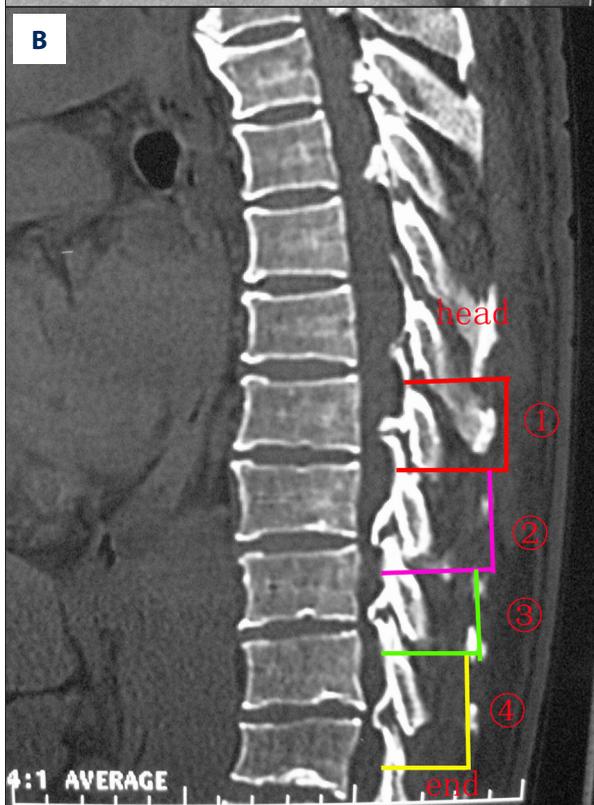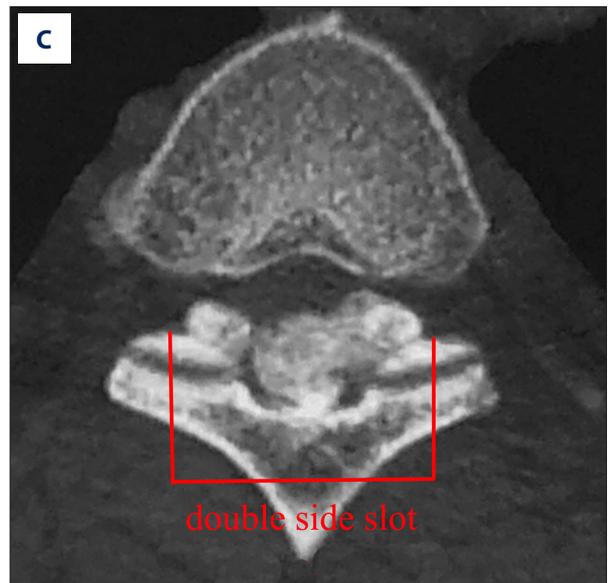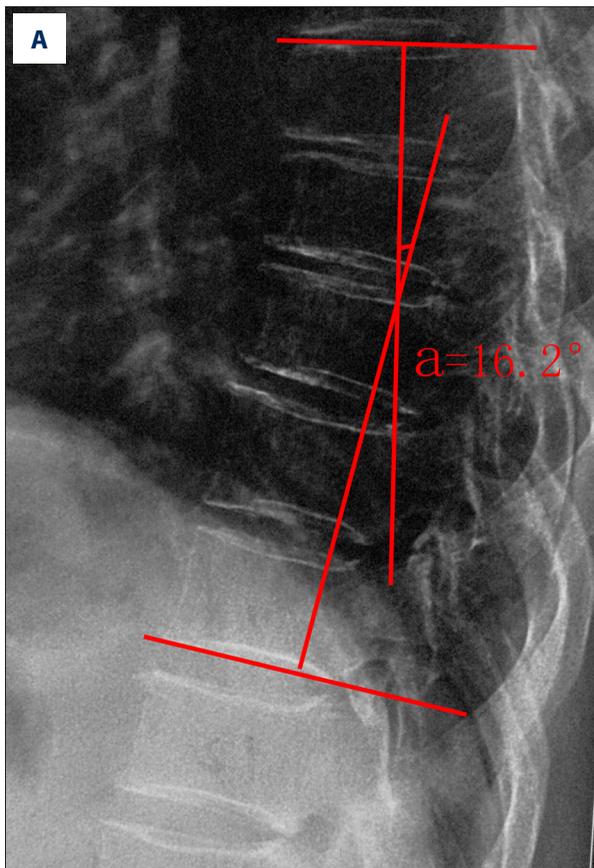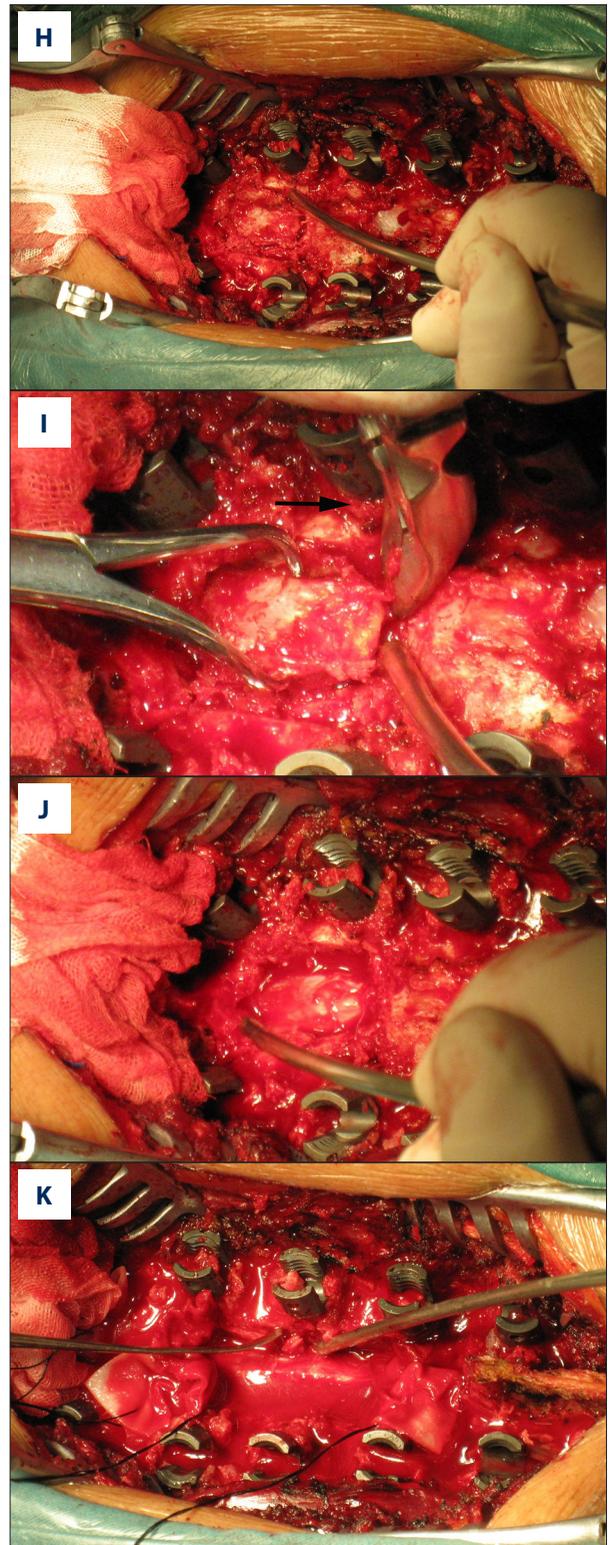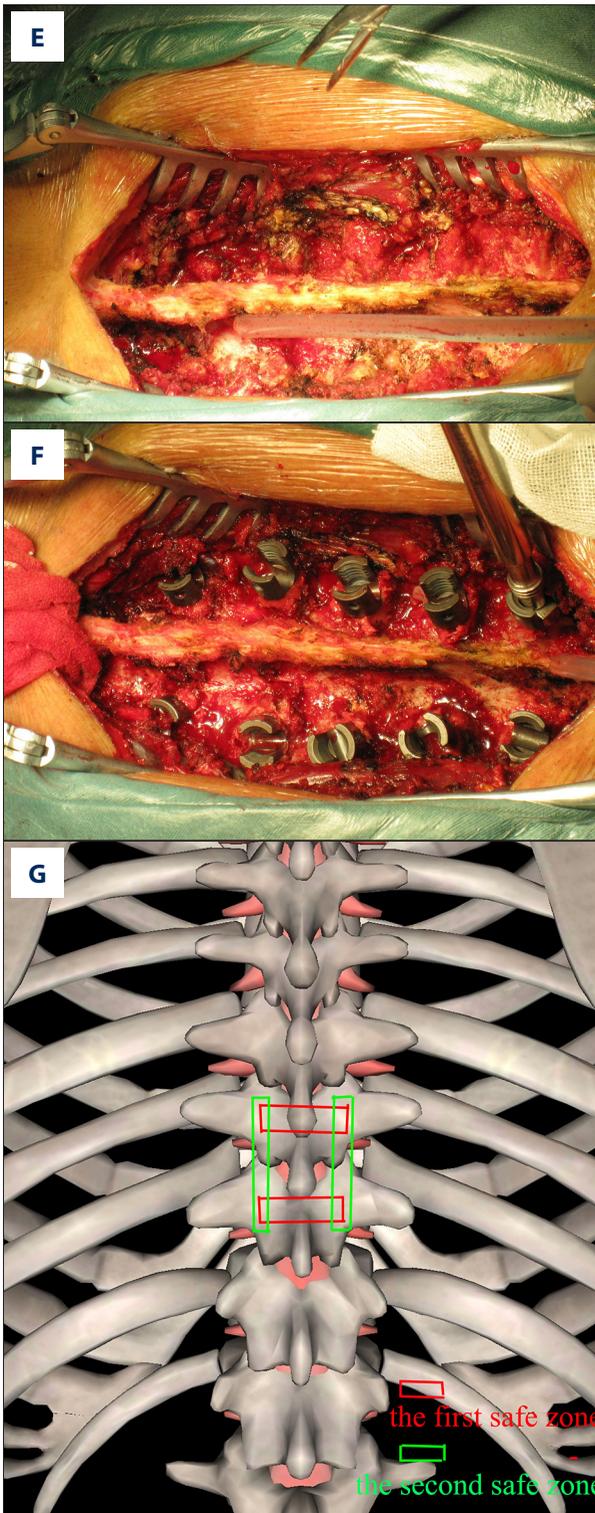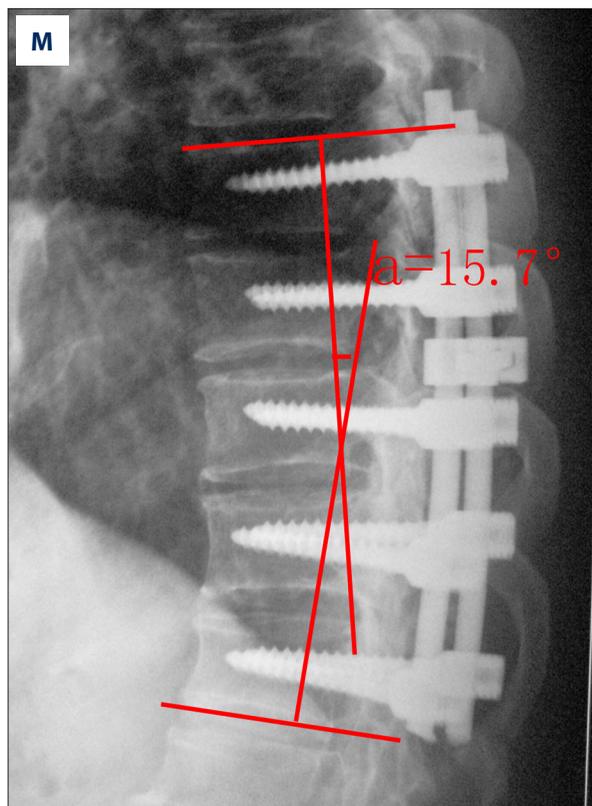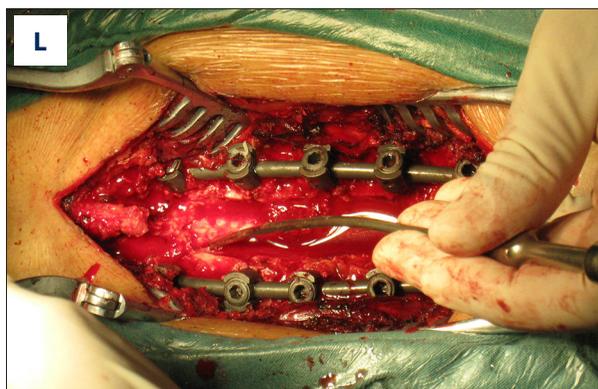
Figure 2. A 68-year-old man with ossification of the ligamentum flavum of the thoracic spine who presented with a 36-month history of limb numbness and weakness (Case 9). (A) Nodular projections are seen in the nerve root canal. The Cobb angle is 16.2°. (B, C) Ossification of the ligamentum flavum is present at T8–T12 and T3–T6 level, and the main lesion is present at T8–T12. The colored lines indicate the decompression steps and ranges. (D) The spinal cord is compressed at T8–T12 and has an intramedullary high signal intensity (IHSI). (E) A straight longitudinal incision was made along the spinous processes, and the tissue explored. (F) Pedicle screw implantation. (G) Schematic diagram of the first safe zone and the second safe zone. (H) A free single lamina from the periphery. (I) A towel clamp is used to hold the root of the spinous process, with the insertion of a bone dissector into the gap (black arrow) with the lamina obtained. (J) Completed decompression of the head of the lamina. (K) Sequential resection and decompression of the lower laminae. (L) Bilateral placement of a titanium rod. (M) Stabilization of the internal fixation with a Cobb angle of 15.7° at the last follow-up.

Statistical analysis

Data were analyzed using SPSS version 16.0 software (IBM, Chicago, IL, USA). The JOA scores and changes in Cobb angle were analyzed by repeated analysis of variance (ANOVA). Data from the scoring grades were analyzed by the Kruskal-Wallis rank sum test. The data were expressed as the mean ± standard deviation (SD). Two-sided P-values of <0.05 were considered statistically significant.

Results

This study included 30 patients who underwent subsection laminectomy with pedicle screw fixation (SLPF) for the treatment of ossification of the ligamentum flavum of the thoracic spine. The mean operative time was 208.4±38.3 min and ranged from 156–245 min. The mean intraoperative blood loss was 689.3±171.7 ml and ranged from 450–1120 ml. The mean

Table 1. The Japanese Orthopaedic Association (JOA) score for the assessment of myelopathy.

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

Table 2. Clinical and demographic data for the 30 patients with ossification of the ligamentum flavum (OLF) of the thoracic spine who underwent subsection laminectomy with pedicle screw fixation (SLPF).

Case No.	Age/gender	Symptom duration (mo)	Level of OLF	HIS	Operative time (min)	Blood loss (ml)	Follow-up (months)	Complications
1	48/F	21	T10–L1	Y	195	690	28	–
2	57/F	30	T3–5	Y	162	480	23	CSFL
3	52/M	25	T8–11	Y	203	640	32	–
4	59/F	31	T9–L1	N	196	860	31	–
5	54/M	28	T9–12	Y	209	600	28	–
6	42/F	17	T3–6	N	169	560	30	–
7	63/M	29	T9–12	Y	221	750	25	–
8	43/F	12	T4–7	N	210	620	35	–
9	68/M	36	T8–12	Y	244	790	31	DVT
10	56/F	22	T3–5	N	159	510	32	–
11	69/F	34	T7–10	Y	215	620	21	–
12	51/M	15	T4–8	Y	168	760	35	–
13	64/F	33	T7–11	Y	220	710	40	–
14	47/M	28	T4–7	N	185	590	33	–
15	65/F	21	T10–12	Y	162	550	20	–
16	51/M	25	T1–4	N	219	600	26	–
17	40/F	19	T2–6	Y	235	960	39	ND, DVT
18	63/F	11	T7–12	N	292	1050	21	CSFL
19	55/M	29	T8–11	Y	174	680	23	–
20	71/F	18	T5–7	N	156	410	16	–
21	68/M	38	T9–12	Y	245	650	14	–
22	66/F	22	T9–L1	N	238	890	32	–
23	69/M	34	T5–10	Y	310	1120	29	CSFL
24	58/M	18	T6–9	Y	231	580	41	–
25	64/F	32	T10–12	Y	170	450	35	infection
26	52/M	27	T8–11	N	196	540	34	–
27	62/F	35	T10–L1	Y	257	810	18	–
28	67/F	22	T7–9	N	168	540	23	–
29	53/M	27	T9–12	N	201	780	15	–
30	50/F	18	T6–10	Y	241	890	24	–
Mean ±SD	57.6±8.7	24.9±7.2	–	–	208.4±38.3	689.3±171.7	27.8±7.3	–

F – female; M – male; OLF – ossification of the ligamentum flavum; HIS – intramedullary high signal; CSFL – cerebrospinal fluid leakage; ND – neurological deterioration; DVT – deep vein thrombosis.

Table 3. The preoperative and postoperative Japanese Orthopedic Association (JOA) scores and Cobb angles ($\bar{x}\pm s$).

	Preoperative	One month after surgery	Final follow-up	F-value	t-value
JOA score	5.7±1.9	8.8±2.2	9.3±2.7	21.747	<0.001
Cobb angle (°)	17.8±4.3	15.4±3.6	15.8±3.8	3.423	0.0396

Table 4. Comparison of the American Spinal Injury Association (ASIA) motor and sensory impairment grades before and after surgery (n).

Preoperative ASIA classification	ASIA classification at the last follow-up				
	Class A	Class B	Class C	Class D	Class E
Class A	0	2	1	0	0
Class B	0	1	4	4	3
Class C	0	0	3	3	5
Class D	0	0	0	1	3

Z=–4.502; P<0.001.

follow-up period was 27.8±7.3 months and ranged from 14–41 months. There was no loosening, prolapse, or deterioration of thoracic kyphosis during the follow-up period (Table 2).

The Japanese Orthopedic Association (JOA) score for the severity of myelopathy significantly increased from a mean of 5.7±1.9 before surgery to a mean of 8.8±2.2 at one month after surgery and to a mean of 9.3±2.7 at the last follow-up (P<0.01). The postoperative improvement in neurological function reached a mean of 68.3±14.4%. The Cobb angle significantly decreased from a mean of 17.8±4.3° before surgery to 15.4±3.6° at one month after surgery and 15.8±3.8° at the last follow-up (P <0.01) (Figure 2M; Table 3).

According to the American Spinal Injury Association (ASIA) motor and sensory impairment scale, at the last follow-up there were three patients with grade B, eight patients with grade C, eight patients with grade D, and 11 patients with grade E scores, which were significant improvements when compared with the preoperative ASIA scores (Z=–4.502; P<0.001) (Table. 4).

During surgery, three patients (10.0%) had cerebrospinal fluid (CSF) leak, and one patient had ligamentum flavum and dural adhesions. When blunt dissection was performed, the dural sac was torn, and 2-0 silk suture was used to repair the defect. The other two cases included dural ossification. CSF leak occurred after the ossified dura mater was removed together with the vertebral lamina, the defect was covered with artificial dura mater, and the repairs all healed well. After surgery, one patient was found to have neurological deterioration, as the lower limb muscle strength decreased by two levels when compared with the preoperative level. Methylprednisolone treatment and

rehabilitation training resulted in a return of muscle strength to the preoperative level by one year following surgery (Case 17). Postoperatively, two patients developed deep vein thrombosis (DVT), and one patient had a postoperative wound infection.

Discussion

With the development of medical imaging technology, the clinical diagnosis of ossification of the ligamentum flavum can be made using magnetic resonance imaging (MRI). In 2010, Guo et al. [11] conducted a large-scale cross-sectional imaging study on 1,736 volunteers in southern China using MRI and found that 3.8% (66 cases) of the population had ossification of the ligamentum flavum. In the 66 cases, 21 patients (31.8%) had ossification at multiple levels, and 11 patients (16.7%) had continuous ossification. Ossification of the ligamentum flavum of the thoracic spine, especially at multiple levels, is no longer a rare orthopedic disease. It can be diagnosed by computed tomography (CT) or magnetic resonance imaging (MRI). In clinical practice, patients with symptoms of thoracic spinal cord injury should be thoroughly investigated for this condition. However, ossification of the ligamentum flavum of the thoracic spine can also involve the lower thoracic vertebra [1,4,11], and this distribution may be related to biomechanics. As the mobility and range of motion of the lower thoracic spine are high, the local stress changes resulted from frequent flexion, extension, and rotation can cause ossification of the ligamentum flavum in this area [1,12]. In this study, 46 ossified segments were distributed in the lower thoracic segments (T9–T12), accounting for 48.4% (46/95) of all ossified segments, which is a finding supported by previous studies[5,8,10].

Currently, there are many methods of surgical laminectomy used for the treatment of ossification of the ligamentum flavum of the thoracic spine, which include laminar shelling decompression [2], open-door and French-door laminectomy [3], lamina en bloc resection [4,5] and lamina osteotomy and replantation *in situ* [5], and each method has its particular characteristics. However, all these surgical procedures inevitably have risks, including tearing of the dura, cerebrospinal fluid (CSF) leak, and spinal cord injury. In a previously published study by Yan et al. [2], a high-speed grinding drill was used to polish the vertebral laminae layer by layer, and then ultra-thin pliers were used to decompress the lamina at their edges using a grinding method. This procedure is the most commonly used in clinical practice and is regarded as a safe procedure. However, in this previous study, there were five cases of cerebrospinal fluid leakage and two cases of paralysis after surgery [2]. Wang et al. [3] divided the cases of ossification of the ligamentum flavum into fused and non-fused types according to the CT and MRI findings. For the fused type, open-door laminectomy and for the non-fused type, French-door laminectomy surgical techniques were performed. However, when the ossified ligamentum flavum is in the diffuse type [13], the ossification is diffusely thickened in the lateral and central areas of the spinal canal, and it can be difficult to cut the lamina in its entirety either by using open-door or French-door laminectomy. Chen et al. [4] and Nie et al. [6] used a high-speed grinding drill to form a groove on both sides of the lamina, and then removing the lamina as a whole to decompress the spinal cord. This procedure is highly innovative, but there is still a high risk of tearing the dura during the long segment laminectomy, with the incidence rates of 18.8% (3/16) and 22.2% (4/18), respectively and both studies had one case with postoperative lower limb paralysis [4,6].

Wang et al. [14] defined the adjacent two segmental laminae and the facet joints involved in each ossified segment of the ligamentum flavum as a decompression segment, with the decompression range including the ossified ligamentum flavum, the adjacent head lamina, and the upper one-half of the caudal lamina. The upper part of the ligamentum flavum is attached to the anterior inferior part of the upper lamina, and the lower part is attached to the upper edge of the lower lamina, so that the upper one-third of the inner side of each lamina is an area without the attachment of the ligamentum flavum [11]. Even if the ossification of the ligamentum flavum is severe, there is also a normal lamina structure in this range, which we refer to as the first safe zone for surgical decompression. The bilateral lamina and transverse process are located in the extension of the ligamentum flavum, where the ossification is often mild and which is referred to as the second safe zone for surgical decompression.

In this study, subsection laminectomy was used to decompress the ossification of the ligamentum flavum of the thoracic spine. The position of the second safe zone was firstly sited

so that the lamina was free on both sides. Then, the sharp-nosed rongeur and the ultrathin laminal forceps were used to decompress along the first safe zone so that the segmental lamina was fully free at the upper and lower ends. Under the lifting force of the padded clamp and the lever force of the bone dissector, the lamina could be slowly moved back, and the ossified ligamentum flavum gradually disengaged from the dura mater. After separating the adhesions between the ossified ligamentum flavum and the dura mater, a decompression segment was removed. This procedure had several advantages. First, the compression area was divided into several decompression segments, which were removed from top to bottom by segments, reducing the risk of tearing the dura mater or damaging the spinal cord during multi-lamina resection. Second, when the laminectomy was performed outside the spinal canal, the laminal forceps rarely invaded the spinal canal, reducing damage to the thoracic spinal cord. Third, the pedicle screw placement could correct and maintain the sagittal sequence of the thoracic spine, the inter-transverse bone graft maintained the stability of the decompression area, and no kyphosis occurred even after the internal fixation was removed.

As the stability of the thoracic vertebra is higher than that of the cervical and lumbar spine, it is controversial whether the internal fixation should be implanted after decompression. In a study that included long-term follow-up visits, Aizawa et al. [15] and Chen et al. [4] found that the local Cobb angle in the decompression area increased by 3° to 4° after laminectomy. Kawahara et al. [16] proposed that the stable spinal sequence played an important role in promoting the recovery of neurological function, and that internal fixation not only maintained the stability of the spine, but also avoided the increase in spinal cord tension caused by increased kyphosis. Yamazaki et al. [17] reported a case of thoracic stenosis in a patient who underwent laminectomy at T10–T11 who had a delayed (18 h) postoperative neurologic deterioration. An additional posterior instrumented fusion at T7–L1 was performed, and the neurological deficits gradually resolved [17]. In the present study, 80.0% (24/30) of patients had more than three decompression segments, and internal fixation was particularly important to maintain the postoperative neurological function. Insertion of the pedicle screw not only maintained the stability of the thoracic spine but also corrected the sagittal alignment and reduced the local Cobb angle. At three-month postoperative follow-up and final follow-up, the Cobb angle was significantly decreased when compared with the preoperative angle. There were no patients whose neurological symptoms deteriorated due to a change in Cobb angle. Also, the postoperative neurological symptoms improved to different degrees. The Japanese Orthopedic Association Score (JOA) score had significantly increased postoperatively when compared with the preoperative level, and the neurological recovery rate reached 68.3%, which was also significantly higher

than the improvement rate of 48.4% previously reported for single laminectomy [4].

Cerebrospinal fluid (CSF) leakage following dural incision is one of the major intraoperative complications, occurring especially in cases with dural adhesion and dural ossification [2–7,10,13–19]. There are several ways to deal with cerebrospinal fluid leakage. For patients with dural tears, cotton material can be used to protect the exposed spinal cord, and the damaged dura mater can be sutured with 6-0 Mersilk, which can reduce CSF leak [4–6,17–19]. For CSF leak due to with defects in the dura mater, fascia from the thigh can be used to repair the dura in combination with the use of artificial dura mater [6]. In this study, the incidence of CSF leak was 10.0%, which was lower than the incidence reported during en bloc resection (18.8–22.2%) [4,5], but higher than the incidence reported during lamina shelling decompression (4.1%) [2], and the same as with open-door and French-door laminectomy (12.5%) [3].

Spinal cord injury is the most serious complication during this type of surgical procedure, especially in the upper thoracic spine where the spinal cord is very fragile and cannot withstand shock or compression. Also, at the T4–T9 level, the blood supply of the spinal cord is less, and the spinal canal volume is limited [20]. Even slight traction during surgery may have serious consequences. Intraoperative somatosensory evoked potential (SSEP) monitoring can reflect the condition of the spinal cord in time and help to increase the safety of the operation [4,6,21,22]. In this study, one patient who underwent T2–T6 decompression had postoperative neurological deterioration, and the lower limb muscle strength decreased by two levels when compared with that before surgery. Methylprednisolone shock treatment was given, and physical rehabilitation resulted in a return of muscle strength to the preoperative level at the final follow-up.

Conclusions

This retrospective study showed that in our center, for patients with ossification of the ligamentum flavum of the thoracic spine, subsection laminectomy with pedicle screw fixation (SLPF) was effective in completely removing the ossified tissue. Internal fixation corrected and maintained sagittal alignment of the thoracic spine and reduced thoracic kyphosis. This surgical procedure was safe and reduced the occurrence of cerebrospinal fluid (CSF) leak.

Conflict of interest

None.

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