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ORIGINAL ARTICLE

Percutaneous full endoscopic posterior decompression of thoracic myelopathy caused by ossification of the ligamentum flavum

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Abstract

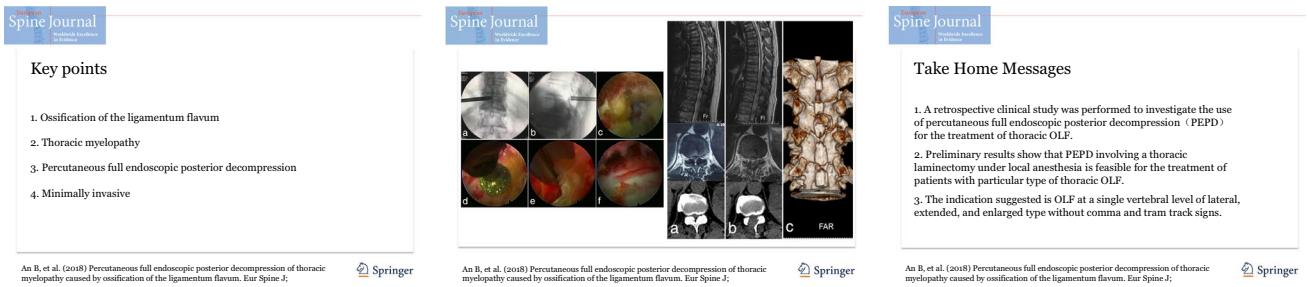
Purpose Ossification of ligamentum flavum (OLF) is the leading cause of progressive thoracic myelopathy (TM) in East Asian countries. Surgical decompression is the general treatment for TM. This study investigated the application of percutaneous full endoscopic posterior decompression (PEPD) for the treatment of thoracic OLF.

Methods Eighteen patients with TM were treated by PEPD under local anaesthesia. Patients had an average age of 59.1 years and single-level lesions mostly at the lower thoracic vertebrae. Computed tomography and magnetic resonance imaging were used to classify the OLF. The pre- and postoperative neurological statuses were evaluated using the American Spinal Injury Association (ASIA) sensory and motor score, modified Japanese Orthopaedic Association (mJOA) score and Frankel grade.

Results OLF for all patients was classed as lateral, extended, and enlarged types without comma and tram track signs. Decompression was completed, and a dome-shaped laminotomy was performed through limited laminectomy and flavectomy. Dural tears in 2 patients were the only observed complication. The average score of ASIA sensory and motor, mJOA, as well as the Frankel grade improved significantly after surgery at an average follow-up time of 17.4 months. The average recovery rate (RR) was 47.5% as calculated from the mJOA scores. According to RR, 10 cases were classified as good, 4 cases fair, and 4 cases unchanged.

Conclusions For patients with thoracic OLF at a single level and lateral, extended, and enlarged types without comma and tram track signs, it is safe and reliable to perform PEPD, which has satisfactory clinical results.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



Keywords Ossification of the ligamentum flavum · Thoracic myelopathy · Percutaneous full endoscopic posterior decompression · Minimally invasive

Bo An and Xing-Chen Li contribute equally to this work.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-018-05866-2) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Introduction

Ossification of the ligamentum flavum (OLF) was first reported in 1920s and mostly occurs in the lower thoracic spine [1] at an average age of 50–60 years [2]. OLF is the

leading cause of thoracic myelopathy (TM) in East Asian countries, such as China [3]. The duration of preoperative symptoms and preoperative severity of TM are important prognostic factors [4], and posterior decompression should be performed in the early stage. Decompression procedures include traditional open surgeries, such as laminectomy with or without posterior fusion [5, 6], and minimally invasive surgeries, such as microendoscopic decompression [7–9].

More complications are associated with thoracic surgery compared with cervical and lumbar surgeries [10, 11]. The most common complication is dural tear [11, 12], and the most severe complication is neurological deficit [13, 14]. Due to the removal of bone tissue and destruction of the posterior tension band in traditional open surgery, patients may experience neurological deterioration, kyphosis, local recurrence of OLF, and the development of OLF at adjacent proximal levels [15–17]. The clinical outcomes may not be satisfactory. However, preliminary results revealed that microendoscopic posterior decompression could be used to treat thoracic OLF with satisfactory results and rapid recovery with a considerably reduced incidence of complications [8, 9]. Therefore, a trend towards minimally invasive surgery has been noted.

Percutaneous endoscopic lumbar discectomy began in the late twentieth century and is currently the most minimally invasive spinal surgery. The procedure could be performed under local anaesthesia using a 7.5-mm-diameter bevelled cannula, causing the smallest amount of paravertebral muscle and bone destruction and minimizing postoperative instability [18]. Based on improvements in equipment and optical technology, percutaneous full endoscopic surgery could be performed using special instruments, such as circular saw, abrasor, and forceps, to remove the bony structures to achieve enlargement of the intervertebral foramen and decompression of spinal stenosis [19]. However, there were few reports of endoscopic decompression for the treatment of thoracic OLF [20, 21]. The use of percutaneous full endoscopic posterior decompression (PEPD) was investigated regarding its safety, efficacy, and appropriate indications.

Materials and methods

The Ethics Committee of Tangdu Hospital approved the study, and all patients signed informed consent. Eighteen consecutive patients with TM caused by thoracic OLF at a single vertebral level underwent PEPD between April 2016 and April 2017 using the endoscopic system (iLESSYS®, Joimax® GmbH, Karlsruhe, Germany). Patients with TM caused by ventral compression (thoracic disc herniation, ossification of the posterior longitudinal ligament), and concomitant cervical or lumbar lesions and severe cardiopulmonary disease were excluded.

OLF is classified into lateral, extended, enlarged, fusion, and nodular types based on axial CT [14], and round and beak types based on sagittal MRI [22]. Considering safety and technical difficulties, we excluded patients with fused and nodular types based on axial CT given that these patients may exhibit more severe clinical manifestations and poor prognosis [1, 23]. The pathophysiology of OLF could lead to dural ossification, which represents a technical challenge during endoscopic decompression. Thus, patients with track or comma signs on axial CT were excluded given that these signs are predictive of dural adhesion and dural ossification [10, 24].

The same surgeon who was skilled in spinal endoscopy performed all surgeries. Neurological examinations and preoperative MRI and CT were performed to determine the location of OLF and the target area for decompression. All patients underwent electrophysiological examination before surgery, including somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs). Pre- and postoperative neurological statuses were evaluated using the mJOA score [25] (Table 1), the Frankel grade [13, 26], the ASIA sense score (ASS) [27], and the ASIA motor score of lower extremities (AMS) [27]. All patients were followed up for at least 1 year. The Frankel grade was scored as follows: A: complete paralysis, B: sensory function only below the injury level, C: incomplete motor function below injury level, D: fair to good motor function below injury level, E: normal function. Recovery rate (RR) was calculated as

Table 1 Summary of the JOA scoring system for the assessment of thoracic myelopathy

Neurological status	Sore
Lower-limb motor dysfunction	
No dysfunction	4
Lack of stability and smooth reciprocation of gait	3
Able to walk on flat floor with walking aid	2
Able to walk up/downstairs with handrail	1
Unable to walk	0
Lower-limb sensory deficit	
No deficit	2
Mild sensory deficit	1
Severe sensory loss or pain	0
Trunk sensory deficit	
No deficit	2
Mild sensory deficit	1
Severe sensory loss or pain	0
Sphincter dysfunction	
No dysfunction	3
Minor difficulty in micturition	2
Marked difficulty in micturition	1
Unable to void	0

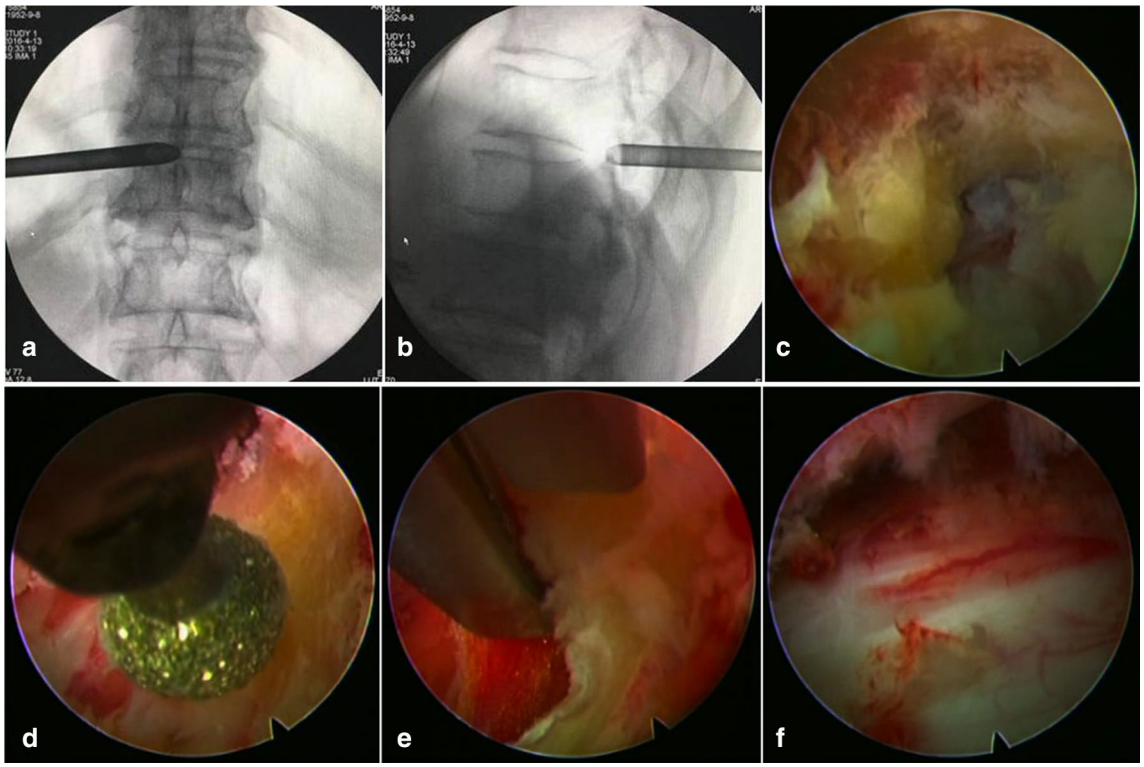


Fig. 1 Fluoroscopic views of bevelled cannula (**a**, **b**) and intraoperative endoscopic views (**c**–**f**) (case 6). **a** The bevelled cannula was placed on the anterior edge of the lamina in lateral fluoroscopic view. **b** Bevelled cannula was placed on the midline of the spinous process in AP fluoroscopic view. **c** Unossified ligamentum flavum (LF) and soft tissue in midline were removed by forceps and radiofrequency; then the spinal cord and ossified LF were visible. **d** Endoscopic view of diamond abrasor reaming and drilling the ossified LF and bone. **e** Ossified LF with a thin and translucent shape was carefully removed by Endo-Kerrison punch. **f** The area of the dura sac was exposed (white area with blood vessels) and fluctuated well

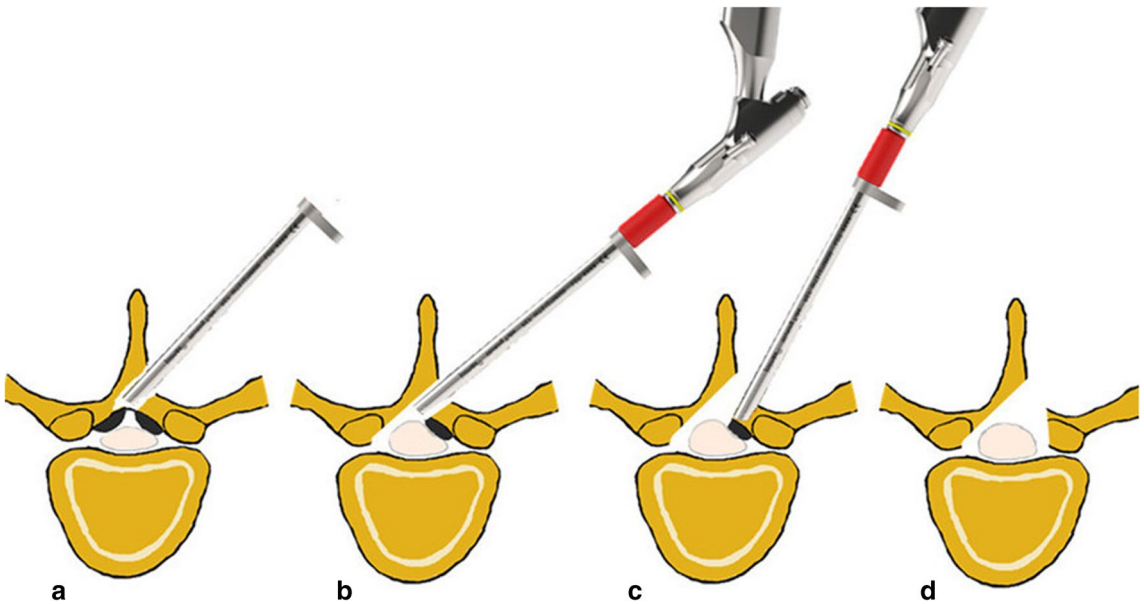


Fig. 2 Illustrations of percutaneous full endoscopic posterior decompression (PEPD) and the procedure of "over-the-top". **a** A bevelled working cannula was placed after laminotomy by circular saw, and the bilateral ossified LF was viewed. **b** Removal of the contralateral ossified LF and bone. **c** The position of the cannula was adjusted to treat the ipsilateral side. **d** Unilateral laminotomy for bilateral decompression was performed with limited laminectomy and flavectomy, and a dome-shaped laminotomy was performed

Table 2 Summary of characteristic features for the eighteen patients

Case number	Age, sex	Level	Type (axial CT)	Type (sagittal MRI)	Approach	Operation time (min)	Blood loss (ml)	Hospitalization time
1	64, M	T10–T11	Enlarged	Round	Right	220	50	6
2	76, F	T11–T12	Enlarged	Round	Right	210	40	5
3	63, F	T9–T10	Enlarged	Beak	Right	210	45	5
4	52, M	T9–T10	Enlarged	Round	Left	200	45	4
5	65, M	T11–T12	Enlarged	Round	Right	200	40	4
6	48, M	T10–T11	Extended	Round	Left	210	40	4
7	59, F	T11–T12	Enlarged	Round	Right	180	30	4
8	52, F	T8–T9	Enlarged	Beak	Right	240	45	10
9	52, F	T9–T10	Enlarged	Round	Right	180	40	5
10	77, M	T11–T12	Enlarged	Beak	Left	180	30	4
11	57, F	T2–T3	Enlarged	Round	Right	240	30	4
12	51, F	T9–T10	Extended	Round	Right	170	30	4
13	52, M	T10–T11	Lateral	Round	Left	180	30	4
14	71, F	T9–T10	Enlarged	Beak	Right	160	25	4
15	70, M	T10–T11	Enlarged	Beak	Right	190	40	4
16	55, F	T10–T11	Extended	Round	Left	170	25	4
17	44, M	T6–T7	Enlarged	Round	Left	230	40	5
18	55, F	T9–T10	Enlarged	Beak	Right	160	30	11

follows [28]: RR = (postoperative JOA-preoperative JOA)/(11-preoperative JOA) × 100%. According to the RR, surgical results were divided into good (50–100%), fair (25–49%), unchanged (0–24%), or deteriorated (< 0%) [29]. Twenty-eight dermatomes were assessed bilaterally using the light touch and pinprick sensation (0: absent; 1: impaired or 2: normal) for ASS, and five key muscles in lower extremities (from 0: total paralysis to 5: full ROM against resistance) were assessed bilaterally for AMS. ASS scored out of 224 (28 locations bilaterally with a max score of 4 at each location), while AMS scored out of 50 (5 locations bilaterally with a max score of 5 at each location).

Statistical analysis

All statistical analyses were performed by SPSS software (version 18; IBM Corp., Armonk, NY) using Student's t test or the Mann–Whitney U test. The threshold for significance was $P < 0.05$.

Surgical technique

Patients were carefully arranged into the prone position with oxygen inhalation and monitoring of ECG, blood pressure, and oxygen saturation. Dexmedetomidine (0.2–0.7 μg/kg/min) and sufentanil (0.1 μg/kg) were added to alleviate the pain and maintain the sober situation in patients according to anaesthesiologists. A C-arm fluoroscope was used to locate the target segment, and the heavier compressed side was selected as the approach side. The puncture entry point in the skin was determined as 5–6 cm from the midline. An 18-gauge spinal needle was introduced under fluoroscopic guidance after the infiltration of local anaesthetics (0.5% lidocaine). Then, the needle tip was positioned at lamina on the root of spinous process via an angle that was 70–80° to the midline and 50–60° to the sagittal plane. After the guide wires were inserted, the needle was removed and a skin incision of approximately 8-mm was made with the entry point as the midpoint. The dilation catheter was inserted in sequence along the guide wire, and then the circular saw was inserted in sequence to achieve laminotomy. Finally a 7.5-mm-diameter bevelled working cannula was placed (Fig. 1a, b). Percutaneous full endoscopy was placed through cannula, and unossified ligamentum flavum (LF) and soft tissue on the midline were removed by forceps and radiofrequency. Then, the spinal cord compressed by OLF was visible (Fig. 1c). The angle between the cannula and the sagittal plane was increased to treat the contralateral lesion at first. The ossified LF was ground into a thin and translucent shape by diamond abrasor (Fig. 1d) and then was removed by Endo-Kerrison punch gently and carefully (Fig. 1e). The ventral portion of the lamina and the medial portion of the articular process were also subject to grinding and removed if necessary. The angle was reduced to treat the ipsilateral lesion in the same manner. Finally, the dural sac was exposed (Fig. 1f), and pulsation of the dural sac improved. The whole procedure was a technique of "over-the-top" decompression (Fig. 2), which had long been established with microsurgery

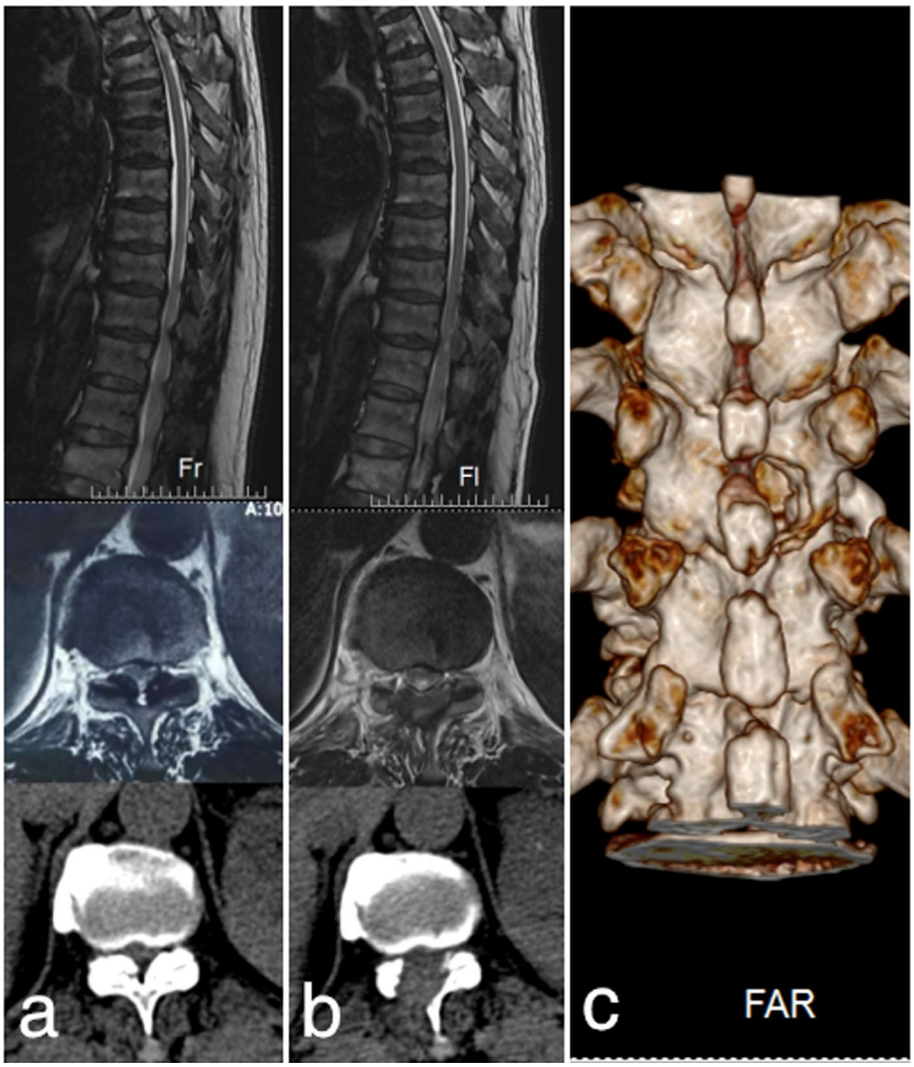


Fig. 3 Pre- and postoperative views of a right-side approach (case 15). **a** Sagittal MRI, axial MRI and CT revealed OLF at the T10/11. **b** Satisfactory decompression was completed, and a dome-shaped laminotomy was performed. **c** Right-side laminotomy at the T10/11 was observed via the three-dimensional reconstruction of the CT images

[9, 30]. Tight dural adhesions remained but were completely isolated from surrounding LF to avoid a dural tear, which was called "partial floating method" [8]. After decompression, the cannula was removed, and the incision was seamed without a suction drain.

Patient's feedback should be received promptly during the operation. Surgical manipulation should discontinue immediately when transient symptoms of neurological stimuli were observed and should not resume until the symptoms disappear.

Results

This study included eight male patients and ten female patients with an average age of 59.1 years (range 44–77 years) and an average follow-up of 17.4 months (range 12–24 months) (Table 2). Patients' symptom included numbness, weakness, and paresthesia in lower extremities, as well as gait instability, claudication, and urinary sphincter dysfunction. Hyperreflexia and increase in the conduction time of SEPs and MEPs occurred in all patients before surgery. Fifteen lesions were located in the lower thoracic vertebrae (T9–T12), two in the middle thoracic spine (T5–T8) and one in the upper thoracic spine (T1–T4). The mean operative time was 172.22 ± 30.40 min, and the mean blood loss was 36.39 ± 7.63 ml. The mean hospitalization time was 5.06 ± 2.07 days. Patients without dural tears were able to walk the day after surgery with or without assistance.

A right-side approach was used in 12 patients (Fig. 3); a left-side approach was used in 6 patients (Fig. 4). During the operation, discharge feelings and muscle convulsions in the lower extremity occurred in 3 patients (cases 1–3), and ankle clonus occurred in one patient (case 5). The symptoms of neurological stimuli disappeared in a few minutes after manipulation discontinued. Dizziness and pain in the back neck occurred in 2 patients (cases 1 and 2) and disappeared in a few minutes after the reduction in saline pressure

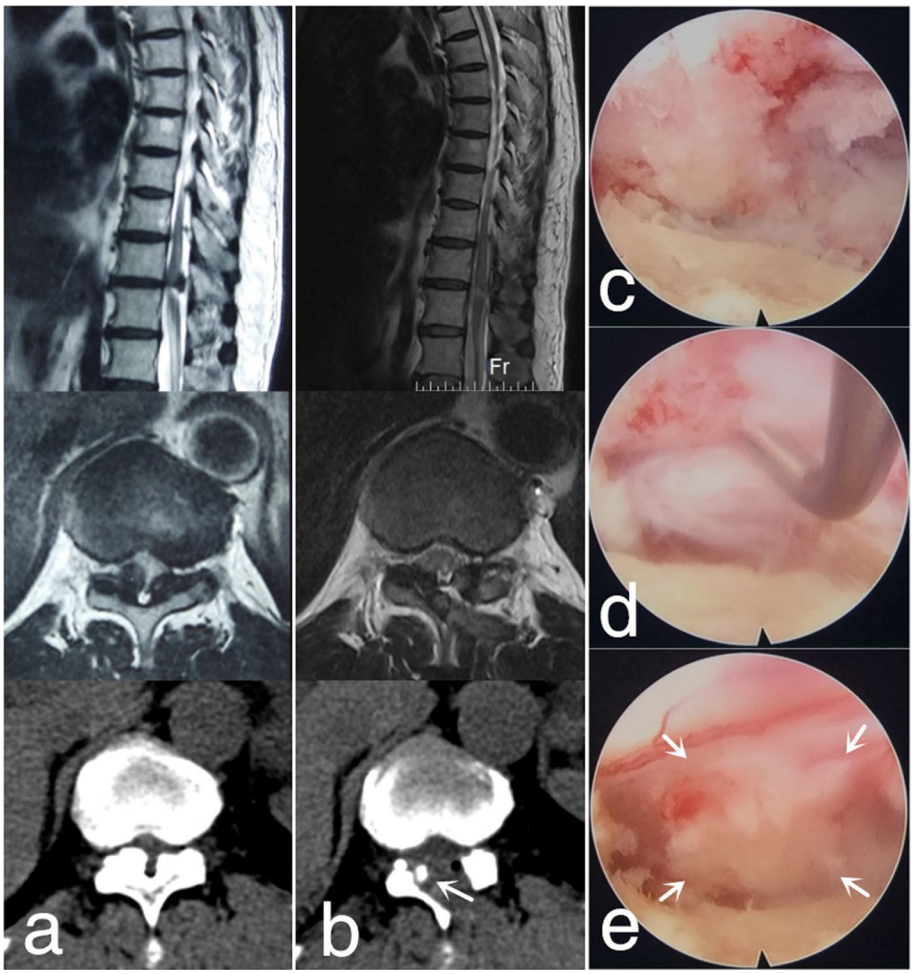


Fig. 4 Pre- and postoperative views of left-side approach (**a**, **b**) and intraoperative endoscopic views of "partial floating method" (**c**–**e**) (case 10). **a** Sagittal MRI, axial MRI, and CT revealed OLF at the T11/12. **b** Satisfactory decompression was completed with a dome-shaped laminotomy, and ossified LF tightly adherent to the dura remained in situ (white arrow). **c** Ossified LF tightly adherent to the dura was visible. **d** The surrounding LF was carefully removed by punch and neural stripper. **e** The remaining LF was floating (white arrow), and the pulsation of dural sac improved

(moving the saline flush bag to a lower position). No neurological deficits and other complications occurred during follow-up. Dural tears occurred in 2 patients (cases 8 and 18). However, they healed after staying in a prone position for 1 week with a pressure dressing, and no cerebrospinal fluid cyst or incision dehiscence occurred during their follow-up.

Two cases underwent the "partial floating method" (cases 10, 15) (Fig. 4). Postoperative images revealed that the decompression was completed, and a dome-shaped laminotomy was performed through limited laminectomy and flavectomy. At the last follow-up, the lamina defect in the surgical area became smaller significantly and tended to close (Fig. 5), but spinal cord herniation and recurrence of OLF were not observed.

The surgical results were satisfactory according to this preliminary study (Table 3). ASS significantly improved from preoperative values (184.2 ± 15.2) to final follow-up (208.3 ± 13.2; $P < 0.001$). Similarly, AMS (preop 37.5 ± 3.7, postop 43.7 ± 4.9; $P < 0.001$), and mJOA (preop 5.9 ± 1.6, postop 8.3 ± 1.6; $P < 0.001$) significantly improved after surgery. The average RR at the last follow-up was 47.5%. According to RR, 10 cases were classified as good, 4 cases fair, 4 cases unchanged and no case deteriorated. The Frankel grade improved significantly after surgery ($P < 0.01$). Two patients (cases 8, 17) exhibited incomplete paralysis before surgery and a Frankel grade of C. At the last follow-up, both of them could walk on crutches with an improved Frankel grade of D. Three patients (cases 3, 11, and 12) fully returned to normal work at the last follow-up with an improved Frankel grade of E.

Discussion

Percutaneous full endoscopic surgery was originally developed for the treatment of lumbar disc herniation and has been used to treat spinal stenosis [19]. Jia et al. [20] performed a two-step percutaneous transforaminal endoscopic decompression for the treatment of one OLF case at T10/11 and T2/3. Miao et al. [21] reported successful percutaneous endoscopic decompression for the treatment of two cases with unilateral OLF at T9/10 and T3/4 using the paramedian approach. To the best of our knowledge, this is the first follow-up study about the safety and effectiveness of PEPD for the treatment of thoracic OLF.

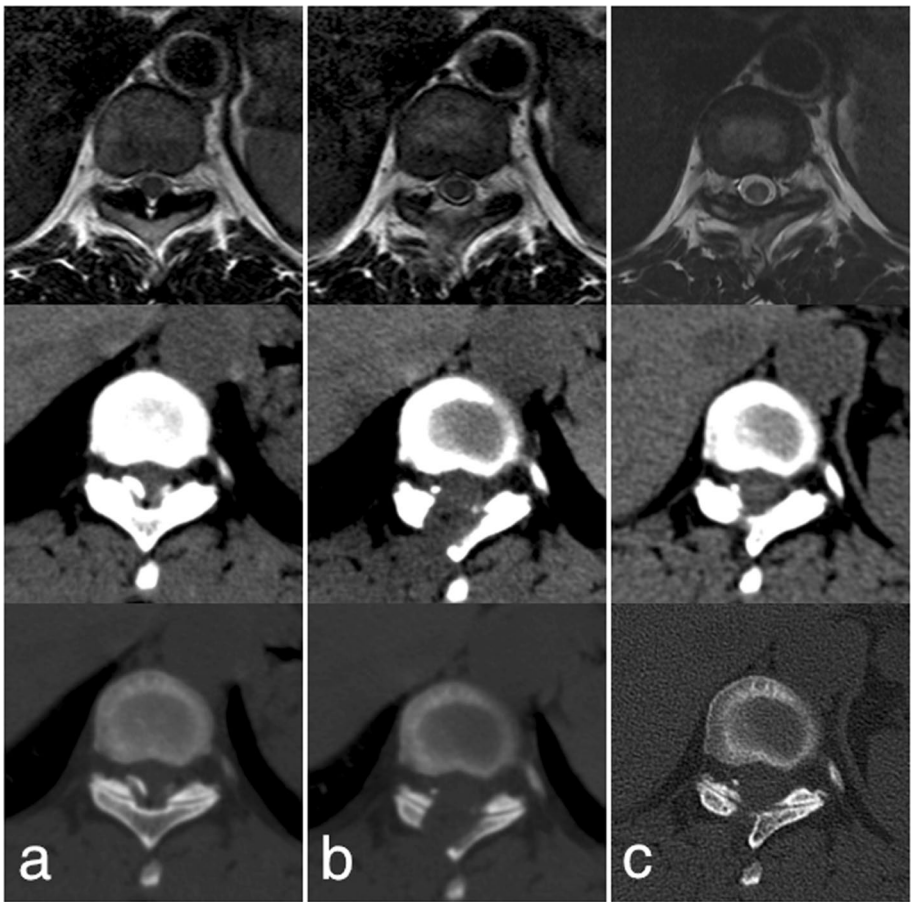


Fig. 5 Illustrations of the tendency to become smaller in the lamina defect (case 9). **a**, **b** Pre- and postoperative axial MRI and CT views of T10-T11. **c** Axial MRI and CT views at the last follow-up (18 months) revealed the significant bone ongrowth and no spinal cord herniation or recurrence of OLF

In this study, the average RR of 18 patients was 47.5%, which is comparable to 16–58.7% reported by most studies [1, 4, 23, 31–36]. The only complication was dural tear, and the incidence was 11.1% (2/18), which is considerably lower than previous reports [11, 24, 37]. We found that PEPD exhibited the following potential advantages: (1) *Minimally invasive* This approach used a 7.5-mm-diameter bevelled cannula with an 8-mm skin incision, which was smaller than microsurgical approach and minimized damage to the paraspinal muscles, lamina, facet joints and posterior ligamentous complexes. (2) *Local anaesthesia* The advantages of local anaesthesia were that the improved safety of the surgery and the reduced medical costs. Surgeons could receive patients' feedback promptly as they were conscious during the operation, thus the incidence of iatrogenic neurological injury would reduce. Local anaesthesia combined with dexmedetomidine and sufentanil could improve patients' comfort during the operation. In our study, no patient discontinued the surgery due to pain or psychological stress. Local anaesthesia without neuromonitoring costs much less than general anaesthesia with neuromonitoring, which is very beneficial to patients in developing countries such as China. (3) *Visualization* There is a liquid environment with continuous saline irrigation in PEPD, making the anatomical structure very clear under a magnified view of the endoscopic displayed. In addition, the working cannula did not need to be fixed, and surgeon could freely control the cannula to obtain better and wider visualization.

Intraoperative phenomena such as neurological stimuli were caused by direct manipulation of the spinal cord or high irrigation pressure during the early phase of the learning curve. Correspondingly, the longer mean operation time was also a learning curve phenomenon. Of note, we did not repair the dural tear and indwelled drainage. Given that the outer diameter of Endo-Kerrison punches used under endoscopic view was as small as 3.0 mm with a 1.5-mm footprint, the size of dural tears was very small in PEPD. Similarly, no cerebrospinal fluid leakage occurred after microendoscopic decompression although intraoperative dural tears were not repaired [8]. Small dural tears that occurred during traditional open surgery also did not require repair, but only tight sutures and indwelling drainage [5, 38].

OLF in the upper and middle thoracic spine is uncommon [31, 39] but carries a poorer prognosis [36, 40]. In this study, 2 patients had lesions located in the middle thoracic spine (cases 8, 17), and one in the upper thoracic spine (case 11). After PEPD, their surgical results according to RR were good, fair and good, respectively. However,

Table 3 Summary of surgical outcome for the eighteen cases

Case number	Postop follow-up (months)	Preop ASS	Postop ASS	Preop AMS	Postop AMS	Preop mJOA score	Postop mJOA score	RR (%)	Surgical results	Preop Frankel grade	Postop Frankel grade
1	24	188	216	39	44	6	9	60.0	Good	D	D
2	22	160	170	35	37	3	4	12.5	Uncharged	D	D
3	22	192	224	38	50	7	10	75.0	Good	D	E
4	20	190	210	36	40	6	7	20.0	Uncharged	D	D
5	21	188	214	36	48	5	10	83.3	Good	D	D
6	21	182	210	38	46	5	9	66.7	Good	D	D
7	19	204	206	40	40	8	8	0	Uncharged	D	D
8	18	176	210	28	37	4	9	71.4	Good	C	D
9	18	184	192	35	36	6	7	20.0	Uncharged	D	D
10	17	190	212	40	42	6	8	40.0	Fair	D	D
11	17	156	224	40	50	7	10	75.0	Good	D	E
12	15	200	224	40	50	8	10	50.0	Good	D	E
13	15	180	202	42	44	4	7	42.9	Fair	D	D
14	14	192	210	38	48	7	9	50.0	Good	D	D
15	13	196	212	42	46	7	9	50.0	Good	D	D
16	13	200	218	40	49	7	10	75.0	Good	D	D
17	13	150	196	30	38	3	6	37.5	Fair	C	D
18	12	188	200	38	42	7	8	25.0	Fair	D	D

intraoperative symptoms of neurological stimuli occurred in all the 3 patients, and the operation time of them was considerably increased. Although the clinical outcomes were satisfactory in this study, PEPD performed on the upper and middle thoracic spine still carries an increased risk and requires more consideration.

Some studies found that beak type of OLF demonstrated by T2-weighted sagittal MRI may lead to poor prognosis [22], but still controversial [33, 36]. There were six beak-type OLF cases in this study (cases 3, 8, 10, 14, 15, and 18), and the clinical outcomes were satisfactory (four good and two fair according to RR), which is similar to the results of Kang et al. [33]. We suggest that the beak-type OLF could be treated by PEPD under more meticulous manipulation. Based on our experience, PEPD should first enter the spinal canal through soft tissue from the midline. Then, the procedure of "over-the-top" could achieve. Given that the LF are ossified in the midline in the fused and nodular types of OLF based on axial CT, and the volume of spinal canal is considerably reduced [14], we excluded the fused and nodular types based on safety and technical difficulties.

In our study, decompression of the spinal cord was successfully completed by PEPD with the smallest skin incision and soft tissue trauma. One study revealed that OLF should be resected as much as possible to reduce the risk of recurrence [41]. However, another study suggested that the floating method could be used to avoid dural tears, and the remaining OLF could be reduced due to the pulsations of the dural sac and/or venous plexus [42]. In our experience, partial floating method could not be used in PEPD unless the surrounding LF was removed completely and the pulsation of dural sac improved.

At the last follow-up, we found that the lamina defect in the surgical area tended to become smaller, which was the indication of bone ongrowth. Similarly, laminoplasty was reported to preserve the posterior structure but was associated with risks of spinal cord herniation and reclosure [16, 43]. Although we did not observed spinal cord herniation or the recurrence of OLF at the last follow-up, a much longer-term follow-up is imperative to detect changes in the lamina defect and residual LF, as well as the surgical results.

Our surgical criteria of PEPD to treat thoracic OLF are as follows: (1) OLF at a single vertebral level; (2) lateral, extended, and enlarged types of OLF without comma and tram track signs as shown by axial CT; (3) a tight dural adherent of LF should remain in situ to avoid dural tears (partial floating method); (4) surgeons should be trained and be skilled in spinal endoscopy due to the steep learning curve; (5) patients with severe cardiopulmonary disease are not suitable for local anaesthesia for the inadequate airway control and suboptimal oxygenation in prone. We will continue to refine this minimally invasive technique and conduct longer-term follow-up studies.

Conclusions

Preliminary results with the small cohort in this study demonstrate that PEPD involving a thoracic dome-shaped laminotomy under local anaesthesia is safe and effective for the treatment of patients with a particular type of thoracic OLF.

Compliance with ethical standards

Conflict of interest All authors have declared that they have no conflictsof interest.

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