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The clinical effect of floating island laminectomy technique for severe thoracic spinal stenosis and myelopathy caused by ossification of the ligamentum flavum: a retrospective study

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Abstract

Background Severe thoracic ossification of the ligamentum flavum often leads to thoracic spinal canal stenosis and spinal cord injury, which generates severe symptoms. Generally, patients still require surgery and aggravated spinal cord function impairment is a common complication. We propose a novel surgical technique to remove the ossified ligamentum flavum with the adhesive dura as a floating island. The purpose of this study was to evaluate the clinical efficacy and safety of floating island in the treatment of severe ossification of ligamentum flavum.

Methods A total of 31 patients with thoracic spinal stenosis and myelopathy caused by thoracic ossification of the ligamentum flavum from January 2019 to April 2022 were included in the study and were followed up at 1, 3, 6, and 12 months, respectively. All patients were treated with floating island laminectomy technique. Neurological function was assessed by the modified Japanese Orthopaedic Association (mJOA) scoring system before and after operation and the rate of improvement was calculated. Perioperative complications were also recorded in this study.

Results All 31 patients were successfully managed by the same professional surgery team. The average operative time was 207.74 ± 58.54 min, the average hospital stay duration was 6.8 ± 1.27 days and the average intra-operative blood loss was 406.45 ± 217.85 ml. The average mJOA score at 1 month, 3 months, 6 months and 12 months after surgery increased from 4.68 ± 0.60 to 6.71 ± 0.73, 7.35 ± 0.76, 8.45 ± 0.85 and 9.06 ± 0.81, respectively. The average mJOA score after surgery was significantly higher than before ($P < 0.001$). The average recovery rate was (32.41 ± 8.55)%, (42.57 ± 9.00)%, (60.12 ± 11.07)% and (69.76 ± 11.38)% for 1 month, 3 months, 6 months and 12 months after surgery, respectively. Postoperative complications included dural tear in 3 cases (9.7%), defect in 1 case (3.2%) and cerebrospinal fluid leakage in 3 cases (9.7%). There was no recurrence of ossification or postoperative thoracic vertebra deformity in patients with aggravated neurological injury.

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Conclusion The floating island laminectomy method for the treatment of thoracic ossification of the ligamentum flavum is safe and feasibility, which can effectively avoid the aggravation of neurological symptoms and enable patients to obtain satisfactory neurological function improvement and functional recovery.

Keywords Floating island laminectomy, Ossification of ligamentum flavum, Thoracic spinal stenosis, Thoracic myelopathy, Compression of spinal cord

Introduction

Since thoracic ossification of the ligamentum flavum(TOLF) was first proposed by Polgar in 1920, TOLF has been increasingly recognized as a major cause of slowly progressive thoracic myelopathy in the world [1].TOLF is a degenerative disease, which has occurred in more than half of the patients with thoracic myelopathy [2].More frequently, low thoracic levels were involved in TOLF, especially in T9-T12. TOLF was characterized by the substitution of hypertrophied fibrous tissue within the ligaments by pathological ossification [3]. TOLF mostly occurred in East Asian countries, such as Japan(36%), South Korea(16.9%) and southern China(3.8%) [3–5]. Recently, other countries and areas except Asian countries have also reported the morbidity of TOLF, including North America, Middle East and Caribbean [6, 7].

The ossified lesion usually progresses insidiously for severe thoracic spinal stenosis caused by ossification of the ligamentum flavum. Even if the patients have only mild symptoms, the compression of the spinal cord by ossified blockage is often very serious [8]. The symptoms of the patient's lower limb weakness are not quite obvious and serious, while the main manifestations of the patient are ataxia, increased muscle tone, walking instability, etc [9]. Occasionally, the patient will occur paraplegia caused by sudden weakness of the lower limb due to minor trauma [10].Takenaka et al. have illustrated symptoms specific to anatomical pathology or compressed segments in thoracic myelopathy. Relationships between the manifestations and anatomical pathology can be helpful in the initial investigation of pre-operation patients, although auxiliary examination such as computed tomography (CT) and magnetic resonance imaging (MRI) are necessary for definitive diagnosis [11].

Surgery is the best solution for who has severe spinal cord compression, which is aimed at the resection of the calcified ligamentum flavum and the decompression of spinal cord, including conventional surgical procedures, such as en bloc laminectomy, fenestration, and laminoplasty [12–15].However, due to severe compression with calcification of the ligamentum flavum adherent to the dura mater or even dura calcification, the surgical resection of the calcified ligamentum flavum carries a high risk of iatrogenic spinal cord injury in the process of pulling the spinal cord which is already on the verge of paralysis. Several case series have reported that the risk of iatrogenic spinal cord injury and nerve root was as high as 30% [16].Therefore, how to reduce the incidence of spinal cord injury caused by operative manipulation is a main challenge that needs us to resolve in the treatment of TOLF [17].

In this study, we present a novel technique, floating island laminectomy, which uses specific surgical procedures to reduce the risk of spinal cord injury during surgery and improves clinical outcomes in the treatment of TOLF.

Materials and methods

Study design and patient population

This study was a retrospective, single-center clinical study and was approved by the Ethics Committee of our hospital (No.2023241). There were 31 patients who presented with thoracic stenosis and myelopathy caused by severe TOLF from January 2019 to April 2022 in this study (Fig. 1). Informed consents were obtained from all patients in this study. Those patients were admitted to the Department of Spine Surgery at the West China Hospital of Sichuan University. The inclusion criteria were as follows: (1) Typical symptoms of thoracic stenosis and spinal cord compression caused by TOLF (mainly including ataxia, increased muscle tone, walking instability, lower limb weakness); (2) Presenting with spinal stenosis and myelopathy by computed tomography (CT) scan and magnetic resonance imaging (MRI) scan; (3) Patients with a poor conservative treatment and with a general condition allowing and requiring surgical interventions. The exclusion criteria were as follows: (1) Other thoracic diseases, such as thoracic fractures, thoracic tumors, thoracic tuberculosis, etc.; (2) Unable to undergo surgery with poor systematic conditions, such as severe hepatic and renal dysfunction, severe coagulation dysfunction, severe infectious diseases; (3) Previous thoracic surgery for various reasons such as trauma or infections; (4) Incomplete information or the follow-up was lost.

Preoperative planning

It is very important to accurately locate the compression segments and sites caused by ossification of the ligamentum flavum(OLF), including the following aspects: (1) Thoracic stenosis often involves multiple segments, which is also combined with ossification of the posterior longitudinal ligament of thoracic spine. Meanwhile, the pathogenic factors are often limited to ascertain the

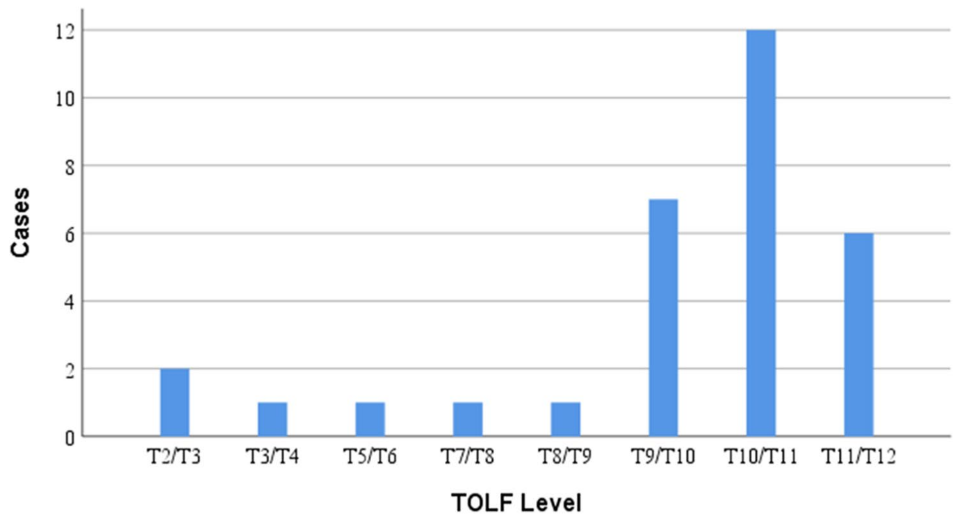

Fig. 1 Distribution of diseased vertebrae in 31 patients

exact segment, to avoid damage to adjacent segment, we identify the most stenosed and symptomatic segments in combination with physical examination and imaging examination. (2) The segment with the most compressed symptoms identified on sagittal CT and MRI before surgery was corresponding to the segment on plain film in the operating room, to facilitate the design of surgical incisions during intra-operative positioning and prevent the opening of wrong segments. (3) The location of the pedicle infusion and the fenestration were determined on sagittal CT and MRI before surgery.

Surgical technique

After endotracheal intubation and intravenous anesthesia, the patient was placed in prone position, and the accurate thoracic segment was located by using mobile radiographs intraoperatively. The incision was marked, and then routine disinfection and toweling were performed after accurate positioning. Bilateral lamina, spinous process and transverse process were exposed by using the standard posterior approach. The supraspinous and interspinous ligaments in the plane of ossification were resected to fully expose the spinous process. Then, centered on the spinous process, an ultrasonic osteotome was used to fenestrate at the vertebral plate above and below the spinous process, respectively, with a size of about 0.5 cm × 0.5 cm. The depth and boundary of the dural membrane above and below the segments of the ossified ligamentum flavum were exposed by subperiosteal dissection after the fenestration was completed. Next, the longitudinal osteotomy incisions which was approximately 0.5 cm away from the spinous process on both sides were made by ultrasonic osteotome laterally to the lamina involved in ossification of the ligamentum flavum with reference to the depth and boundary of the visible dura. Placement of four appropriate pedicle screws (5.5 × 40 mm) through the pedicles at the level of involvement of the ligamentum flavum ossification and above the affected segment. A floating island of the OLF was made at the end of longitudinally excising the lamina of the OLF. Gently lift and shake the lamina from side to side to free the lamina completely. Then, nerve stripper and blades were used to separate the OLF from the dura. The lamina and the OLF complex were completely separated. The screws were then affixed with 2 longitudinal rods for further stabilization (Fig. 2). Intraoperative improvements in pulsation of the lamina and ossified ligamentum flavum complex as well as dura pulsation were observed, indicating that decompression of the spinal cord had been achieved. Posterior bone graft fusion was performed between the longitudinal osteotomy incisions of the bilateral of the lamina. Finally, a drain is routinely placed as the incision is sutured layer by layer in order to observe for cerebrospinal fluid leakage and bleeding. All patients had spinal cord monitoring throughout at the beginning of the operation technique. No significant changes in somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs) and other neuroelectrophysiological monitoring indicators, were observed between pre-operation and postoperation in the operating room.

Assessment indicators

Demographic data (sex, age, symptom duration and TOLF level), operative time, intra-operative blood loss and clinical complications were recorded for all patients who were followed-up at least 12 months after surgery. Plain radiographs, CT scan of the thoracic spine were used for all patients to estimate the stability of the internal fixation and the effect of bone fusion before and after operation. MRI scan of the thoracic spine was used to assess the degree of the spinal cord compression and

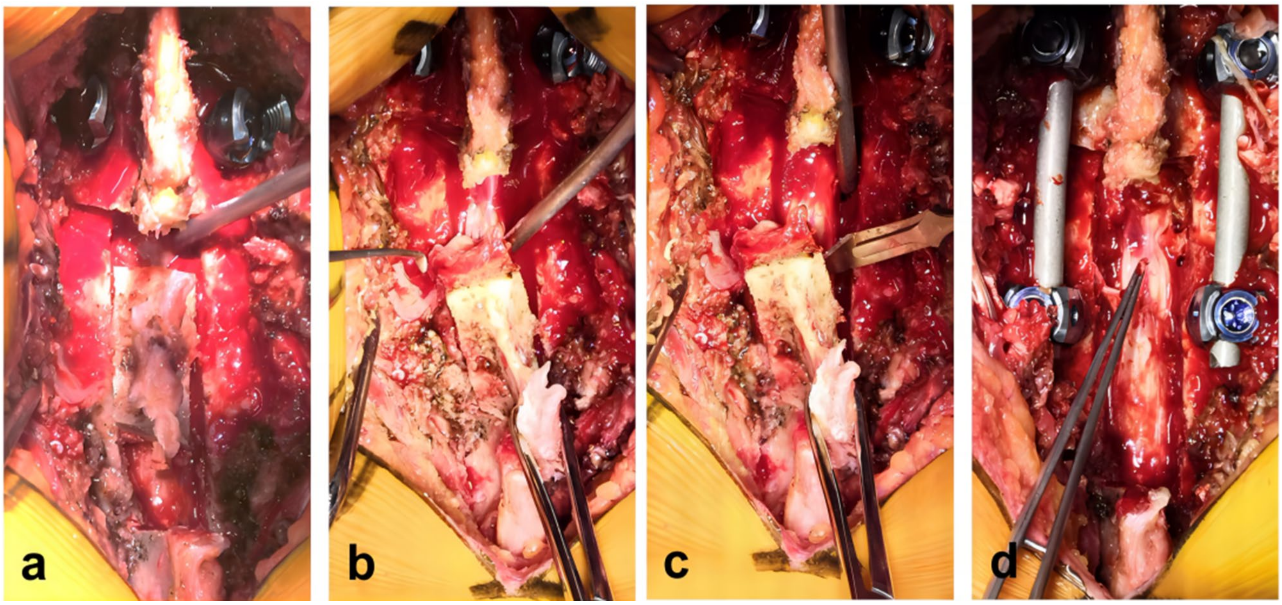

Fig. 2 (**a**) A floating island of the OLF was made in resecting the lamina around the affected vertebra and inserting the pedicle screws. (**b**) Gently lift and shake the lamina from side to side to free the lamina completely. (**c**) Nerve stripper and sharp knife were used to separate the OLF from the dura. (**d**) The lamina and the OLF complex were completely separated. The screws were then affixed with 2 longitudinal rods for further stabilization

decompression. Pre- and post-operative neurological function of all patients were evaluated by the modified Japanese Orthopaedic Association (mJOA) score system. The mJOA score of 1 month, 3 months, 6 months and 12 months after operation were recorded in comparison with pre-operation mJOA score to calculate recovery rate, which was calculated as follows: (final mJOA score - preoperative mJOA score)/(11- preoperative mJOA score) ×100% according to the Hirabayashi recovery rate. The recovery rate was defined as follows: excellent (75-100%), good (50-74%), fair (25-49%), and poor (0-24%). Peri-operative complications, including dural tears, dural defect, cerebrospinal fluid (CSF) leakage, neurological impairment (NI) surgical site infection (SSI) and thoracic deformity were recorded and analyzed.

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Armonls, NY, USA). The variable data was defined as mean ± standard deviation (SD). Paired Sample T-test was used to evaluate the mJOA scores of different follow-up periods relative to the previous period and differences of variables were considered statistically significant at $P < 0.05$.

Results

Demographic data outcomes

There were 17 males and 14 females with TOLF who accepted floating island laminectomy in our hospital from January 2019 to April 2022 were analyzed in this study. All patients were followed up for an average of 12.52 months. The mean operative time was 207.74 min, the mean intra-operative blood loss was 406.45 ml, the mean hospital stay duration was 6.8 days and the mean symptom duration time was 29.45 months. Demographic data of all patients in this study was performed in Table 1.

Table 1 Demographic data outcomes of patients

Item	Value
Sex: male/female	17/14
Age(years)	55.94 ± 9.95
Follow-up (months)	12.52 ± 0.51
Symptom duration (months)	29.45 ± 31.93
Intra-operative blood loss (ml)	406.45 ± 217.85
Operative time (minutes)	207.74 ± 58.54
Hospital stay duration(days)	6.8 ± 1.27
TOLF level	4
T1-T6	27
T7-T12	

Clinical outcomes

Clinical manifestations, such as weakness, gait disturbances and pain, of patients who have achieved the 12 months of follow-up were remarkably improved. The mJOA score respectively increased to 6.71 ± 0.73, 7.35 ± 0.76, 8.45 ± 0.85 and 9.06 ± 0.81 in 1 month, 3 months, 6 months and 12 months after operation, which were significantly higher than preoperative mJOA score of 4.68 ± 0.60. The postoperative mJOA scores compared with the preoperative mJOA score were noticeably improved (P<0.01) (Table 2). The postoperative 1 month mJOA score versus the preoperative mJOA score, the postoperative 3 months mJOA score versus

Table 2 Clinical outcomes of patients

Time	mJOA score
Preoperative	4.68 ± 0.60
Postoperative 1 month	6.71 ± 0.73[a]
Postoperative 3 months	7.35 ± 0.76[ab]
Postoperative 6 months	8.45 ± 0.85[ac]
Postoperative 12 months	9.06 ± 0.81[ad]
P-value	<0.01

a: $P < 0.01$, versus preoperative value; b: $P < 0.01$, versus post 1 month value; c: $P < 0.01$, versus post 3 months value; d: $P < 0.01$, versus post 6 months value

Table 3 Recovery rate after surgery

Follow-up	Recovery rate (%)
Postoperative 1 month	32.41 ± 8.55
Postoperative 3 months	42.57 ± 9.00
Postoperative 6 months	60.12 ± 11.07
Postoperative 12 months	69.76 ± 11.38

Table 4 Surgical outcomes of patients

Complications	Value
Dural tears (%)	3/31(9.7%)
Dural deficit (%)	1/31(3.2%)
Cerebrospinal fluid leakage (%)	3/31(9.7%)
Neurological deterioration (%)	0
Infection (%)	0
Deformity (%)	0

the postoperative 1 month mJOA score, the postoperative 6 months mJOA score versus the postoperative 3 months mJOA score and the postoperative 12 months mJOA score versus the postoperative 6 months mJOA score were also improved observably ($P < 0.01$) (Table 2). The Hirabayashi's recovery rate was (32.41 ± 8.55)%, (42.57 ± 9.00)%, (60.12 ± 11.07)% and (69.76 ± 11.38)% for 1 month, 3 months, 6 months and 12 months after surgery, respectively (Table 3). Ten patients were defined as excellent, twenty-one as good, and no one as fair and poor. The neurological function of all post-operative patients was significantly improved.

Postoperative complications included dural tears in 3 cases (9.7%), defects in 1 case (3.2%) and cerebrospinal fluid (CSF) leakage in 3 cases (9.7%) (Table 4). All patients with dural tears or defects had appropriate measures taken during surgery, such as the use of fine sutures and artificial dural repair. All patients with CSF leakage were successfully pulled out the drainage tube 5–7 days after surgery, and wound healed 10–14 days without wound infection, fluid leakage and other complications. There was no recurrence of ossification or postoperative thoracic vertebra deformity in patients with aggravated neurological injury.

Discussion

TOLF is usually rare, insidious and progressive that may cause severe spinal cord compression in spite of mild symptoms [18].Patients with TOLF have various symptoms, which can result in muscle weakness, numbness and sensory disturbance in the lower limbs and different degrees of walking dysfunction, even in severe cases, complete paraplegia [12].Other symptoms also occur in disease, including back pain, gait disturbance, neurogenic bladder and bowel dysfunction, etc [19]. Based on the characteristics of spinal stenosis and the continuity of ossification, Onishi et al. [20] proposed 5 types for TOLF: lateral type, extended type, enlarged type, fused type and tuberous type. Once the TOLF is severely symptomatic, it is generally refractory to conservative treatment and necessary to surgical decompression [21].

Compared with traditional laminectomy, there is an increasing demand for novel surgical methods for TOLF, and the attention to innovation and improvement continues to rise. In recent years, there have been more and more surgical techniques for TOLF treatments. N.S. Osman et al. [22] revealed that the incidence of complications after laminectomy is 35%, with a dural tear rate of 18.4% and a cerebrospinal fluid leakage rate of 12.1%. Sun et al. [23] compared bridge crane technology with laminectomy for the treatment of TOLF. The bridge crane technology involves separating the ossification of the lamina of the ligamentum flavum complex (LOC) and lifting it backwards to directly decompress the spinal cord, making it safer and more controllable. Due to the increasing demand for surgery, minimally invasive surgical treatment for TOLF has also received much attention, and spinal endoscopy has gradually been applied to TOLF. Xin et al. [24] designed and used a translaminar osseous channel-assisted full-endoscopic flavectomy decompression technique to treat TOLF derived thoracic spinal cord disease which achieved significant results. Ye et al. [25] systematically reviewed and evaluated the safety and efficacy of spinal endoscopic technology in treating TOLF. In order to promote the development of surgical techniques and to improve the safety and efficacy of surgery, we also used a novel surgical technique to treat ossification of the ligamentum flavum in the thoracic spine.

Neurologic function assessment is one of the most important indicators for evaluating postoperative clinical outcomes, in addition to assessing pain relief. The mJOA score has been widely applied for neurologic functional evaluation in TOLF [26]. In this study, the mJOA score increased from 4.68 ± 0.60 pre-operatively to 6.71 ± 0.73 in the first month postoperatively, and further increased to 9.06 ± 0.81 at the last follow-up. These results indicated that the efficacy of this technology was comparable to previous reports [27, 28]. The idea of the floating island technique was to remove the lamina of ossified ligamentum flavum under the direct vision of the depth and boundary of the dural mater, reducing disturbance with the spinal cord during spinal canal manipulation. Decompressing the spinal canal can be controlled, because we separated the ossified ligamentum flavum and the dural mater from the surrounding area to form a floating island, which allowed us to visualize the intraspinal situation during surgical resection. The key factors to ensure the effect of operation were to determine the location of the compression of OLF and the location of the fenestration. Complete decompression was marked by pulsation of the dura mater.

Both surgical outcomes and postoperative recovery were strongly associated with the occurrence of complications. Sun et al. [29] reported that the most common complications of spinal surgery were dural tears and CSF leakage because of adhesion or ossification of the dural mater, which can lead to CSF pseudocyst, respiratory obstruction, wound dehiscence, and meningitis. Dural adhesion made it difficult to directly remove the ossified mass by traditional surgical methods, which resulted in a high incidence of postoperative cerebrospinal fluid leakage [30]. The incidence of dural tear or CSF leakage was 32% and the incidence of patients who had dural ossification with CSF leakage was highly to 78.8% [29]. Early neurological deterioration was not uncommon in traditional surgery [30]. Hou et al. [14] have reported that the complication of thoracic spine surgery for ossification of ligamentum flavum were as follows: CSF leakage (32%)(78.8% had ossified dura), neurological deterioration (21%), infection (5%), dehiscence (3%), deep venous thrombosis (1%) and death (1%). Takahata et al. [31] have revealed that decompression and posterior instrumented fusion surgery was a reliable surgical procedure with stable long-term clinical outcomes. They found 15 patients (60%) experienced late neurological deterioration, and 10 patients had a relapse of myelopathy due to OLF in the region outside the primary operative lesion. The causes of early neurological impairment were postoperative epidural hematoma and direct intraoperative spinal cord injury [32]. The causes of late neurological deterioration or paralysis may include ischemia-reperfusion injury, microthrombi and changed perfusion due to internal recoil of the spinal cord structure after decompression, which were four patients among the results of the Li's study [21]. Kanno et al. [33] have reported that two extremely rare cases successfully treated by revision surgery for a recurrent of ossification of ligamentum flavum at the same intervertebral level in the thoracic spine after the primary surgery. Postoperative complications in this study included dural tears in 3 cases (9.7%), defects in 1 case (3.2%), and cerebrospinal fluid leaks in 3 cases (9.7%), which were close to other conventional or novel procedures. All dural complications are due to the removal of the dural ossification along with the adhesion of the ossified ligamentum flavum. There was no recurrence of ossification, infection and postoperative thoracic vertebra deformity in patients with aggravated neurological injury. A study by Stroup et al. [34] reported that 6 out of 22 patients had advanced neurological degeneration, but the authors did not specifically define the term "late neurological deterioration". Chen et al. [35] reported a case of acute neurological deterioration caused by an epidural hematoma, but after the hematoma was cleared, the neurological deficit completely disappeared. Yoon et al.'s study did not report any late complications, such as deformities or recurrences, during the 53.2-month follow-up period [36].

The advantages of our new technique were as follows: (1) Before longitudinally cutting the vertebral plate where the ligamentum flavum was ossified, the upper and lower vertebral plates were partially resected and fenestrated to reveal the dura mater. Since the operation was performed in the normal space, the ossified mass was not dissociated, so the fenestration process would not cause shock to the ossified mass, which was very safe. (2) The spinal cord can be partly decompressed after the exposure of the upper and lower dural mater, which increased the space of concession space of the spinal cord at the compression site and made subsequent operation safer. (3) The depth and boundary of the dural mater can be seen after laminectomy at the upper and lower margins, which can provide reference for the location and depth of the incision when making longitudinal osteotomy incision of the lamina with ossified ligamentum flavum. (4) When the lamina of the calcified ligamentum flavum was longitudinally incised, which can be gently lifted and shaken left and right to check whether the lamina was completely free, the ossification of the ligamentum flavum became a floating island. Dural mater was gently pulled upward without pulling the spinal cord.

However, the limitations of our new technique in this study are as follows: (1) The number of patients is small and the sample size is small. (2) The short follow-up period, which provides a poor assessment of long-term efficacy. (3) lack of control group. The above limitations may lead to deficiencies in further clinical efficacy and safety of the floating island laminectomy technique, limiting the dissemination of the procedure and potentially affecting the validity of the long-term outcomes of the technique. Therefore, further studies with larger sample sizes, longer follow-up times, and laminectomy as control group are needed to recognize our new technique.

Conclusion

This study emphasizes a safe and effective technique, the floating island laminectomy technique, for the treatment of severe thoracic spinal stenosis and myelopathy caused by ossification of the ligamentum flavum, which can decrease the risk of spinal cord and nerve injury. Most patients with symptomatic TOLF have more satisfactory clinical improvements after surgery.

Abbreviations

mJOA modified Japanese Orthopaedic Association
TOLF Thoracic Ossification of the Ligamentum Flavum
OLF Ossification of the Ligamentum Flavum
SSEPs Somatosensory Evoked Potentials
MEPs Motor Evoked Potentials
CSF Cerebrospinal Fluid
NI Neurological Impairment
SSI Surgical Site Infection

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Author contributions

Cheng Zhong and Peng Xiu were the major contributors in writing the manuscript. Hua Chen and Tao Li helped collected and analyzed the patient clinical data. Yueming Song, Jiancheng Zeng and Tao Li provided supervision and direction in the revision of the manuscript, including the figures and tables. All authors reviewed and approved the manuscript.

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Data availability

The datasets generated and/or analysed during the current study are not publicly available due to protect study participant privacy, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of West China Hospital of Sichuan University. Informed consents were obtained from all patients in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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