Journal of Investigative Surgery

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/iivs20

Treatment of Thoracic Ossification of Posterior Longitudinal Ligament with One-Stage 360 Degree Circumferential Decompression Assisted by Piezosurgery

Peng Yang , Rile Ge , Zhong-qiang Chen & Bing-tao Wen

JOURNAL OF INVESTIGATIVE SURGERY
https://doi.org/10.1080/08941939.2020.1839149

Taylor & Francis
Taylor & Francis Group

Check for updates

ORIGINAL RESEARCH

Treatment of Thoracic Ossification of Posterior Longitudinal Ligament with One-Stage 360 Degree Circumferential Decompression Assisted by Piezosurgery

Peng Yang, Rile Ge, Zhong-qiang Chen, and Bing-tao Wen

Department of Orthopedics, Peking University International Hospital, Beijing, China

ABSTRACT

Objectives: To evaluate the safety and clinical efficacy of One-Stage 360 degree circular decompression for thoracic ossification of the posterior longitudinal ligament (TOPLL) assisted by piezosurgery.

Materials and methods: The present study enrolled 36 patients with TOPLL between August 2016 and February 2019. The average intraoperative bleeding volume of all 36 patients in this study is 1058.61 ±737.66 ml.

Results: All patients did not experience any intraoperative complications such as spinal cord and nerve injuries, and 22 other complications related to decompression of OPLL cited in other literature; all of which were relieved after treatment. The resection time of single laminectomy was 3.43 ±0.49 min, and circular decompression was 42.06 ±14.22 min. At the last follow-up, the modified Japanese Orthopaedic Association (mJOA) score was 8.89 ±1.56, the recovery rate of spinal cord function was 64.2 ±21.2%, and the number of cases of spinal cord function deterioration was 0 (0%). The mJOA score of the last follow-up was negatively correlated with the time of circular decompression ($r = 0.368$, $p < 0.01$) and age ($r = 0.412$, $p = 0.026$). The recovery rate of the spinal cord function was negatively correlated with the operation time of circular decompression ($r = -0.325$, $p = 0.041$) and the amount of intraoperative blood loss ($r = -0.555$, $p = 0.028$).

Conclusions: The use of piezosurgery can safely and effectively complete one-stage simple posterior TOPLL with 360-degree circular decompression. The incidence of complications is not high, and a good outcome can be obtained.

ARTICLE HISTORY
Received 14 July 2020
Accepted 13 October 2020

KEYWORDS
piezosurgery; ossification of thoracic posterior longitudinal ligament; circular decompression; JOA

Introduction

Thoracic ossification of the posterior longitudinal ligament (TOPLL) is a common disease middle-aged with a reported incidence of 0.44% to 8.92% in Chinses population [1]. The widely proliferative posterior longitudinal ligament could compresses the spinal cord and/or nerve root due to, resulting in sensory and motor disorders of the limbs and dysfunction of the visceral autonomic nervous system [2]. Its pathogenic mechanism is not precise but is most likely multifactorial, including age, sex, developmental malformation, genetic inheritance pattern and other factors. It is generally believed that it is caused by heterotopic ossification of chondrocytes. However, some scholars argue that it is related to fibrocartilage and intramembranous ossification, and that degenerative intervertebral disk can affect the formation of ossification of posterior longitudinal ligament [3,4].

Simple thoracic laminectomy used to be a safe surgical method [5,6]. However, this technique could hardly obtain sufficient decompression for patients with severe ventral spinal cord compression, ossification of the beak posterior longitudinal ligament or severe kyphosis [4]. Direct resection of OPLL obtains the adequate spinal cord decompression, but an anterior approach to a ventral spinal cord decompression involves a complex operation process. Moreover, its complications were relative higher, such as sizeable surgical trauma, pulmonary dysfunction, making its application is limited [7].

One-stage posterior circular decompression (CD) of the thoracic spine has been widely recognized due to its effectiveness in removing the compression around the spinal cord [8]. However, using traditional surgical instruments such as high-speed grinding drill and bone knife for the treatment of thoracic OPLL is highly invasive [9]. Imagama et al. [4] report that the incidence of motor paralysis of both lower limbs after posterior fusion was 32.2% and takes an average of 2.5 months for the motor function of lower limbs to recover to the preoperative level. Ito et al. [9] reviewed 156 patients with thoracic OPLL who were operated using traditional instruments, of which 23 (14.7%) developed postoperative paraplegia. Yang et al. [10] retrospectively reviewed 21 patients who underwent one stage CD. Their study noted this technique is effective for TOPLL but causes complications which need to be proactively prevented and treated. If treated properly, most complications can be recovered with satisfactory outcomes. Similar outcomes were also proved by Head et al. [11] and Bernstein et al. [12].

CONTACT Bing-tao Wen bingtaowen_binter@126.com Department of Orthopedics, Peking University International Hospital, No. 1, Life Park Road, Zhongguancun Life Science Park, Beijing 102206, China.

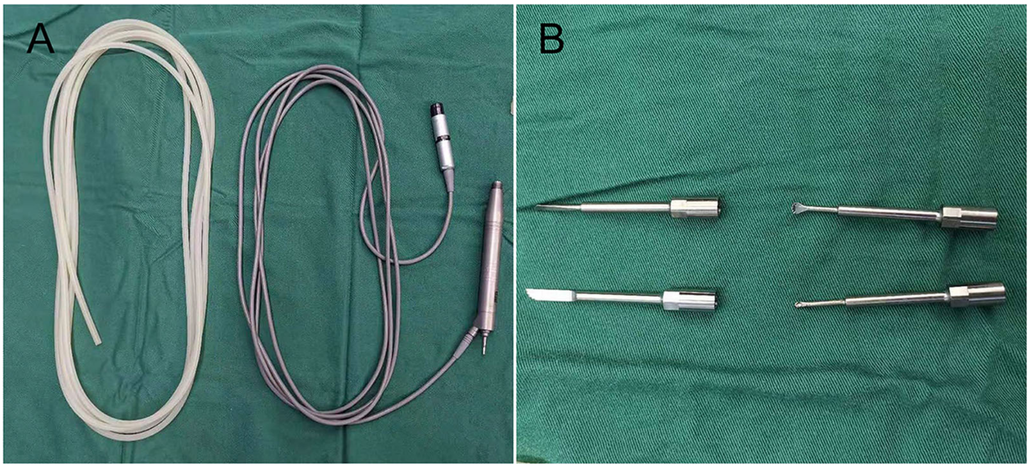

Figure 1. SMTP ultrasonic bone dynamic system. (A) Ultrasonic scalpel handle, connecting line, water pipeline (from left to right). (B) Ultrasonic cutter.

Piezosurgery is an innovation in orthopedic surgery, primarily utilizing high-frequency ultrasonic drilling to destroy bone tissues and cut through osseous structures. It also has a hemostatic effect on the bone cross-section. Direct damage to the blood vessels and nerve tissue is prevented in piezosurgery, which significantly improves the accuracy and safety of spinal surgery. At present, the application of piezosurgery in spinal laminectomy has achieved favorable surgical outcomes [13,14]. However, few reports exist on the application of piezosurgery in circular decompression surgery. In this study, we explored the application of piezosurgery to remove the posterior wall of thoracic spinal canal and localized resection of OPLL via facet joint approach to achieve a 360-degree circular spinal cord decompression.

Materials and methods

Subjects

This study was approved by the institutional review board committee of our hospital (2018YFB1307600). Data obtained in all TOPLL patients surgically treated by one-stage 360 degree circumferential decompression assisted by piezosurgery between August 2016 and February 2019 were retrospectively reviewed. The patients enrolled in the study include those who have compression of the thoracic ventral spinal cord caused by an ossified mass on the thoracic posterior longitudinal ligament diagnosed by thoracic magnetic resonance imaging (MRI) and total spinal computed tomography (CT); and those with clinical manifestations of thoracic spinal cord compression (lower limb or trunk sensory disturbance, lower limb motor dysfunction, sphincter dysfunction). Patients who have previous thoracic surgery history, tumor history, spinal deformity, and spinal infection are excluded from the study.

Surgical methods

Surgical equipment

The piezosurgery. The surgical devices used for this study were a piezosurgery medical device with different tips, a neuroelectrophysiological monitoring instrument and an internal fixation instrument. The piezosurgery uses SMTP XD860A ultrasonic bone power system (Shuimu Tianpeng Medical, Beijing, China. Figure 1A) and is equipped with four kinds of ultrasonic heads (Figure 1B): sheet, hook, spoon and the rake heads. During the operation, the maximum output power of piezosurgery was 68 W (the output power was automatically adjusted with bone hardness), and the water flow rate was 30 mL/min.

Spinal cord monitoring. Spinal cord functionality of patients was performed and assessed with intraoperative neuroelectrophysiological monitoring instruments (Intraoperative Neurophysiological monitoring, XLTEK Protekor32, Natus, USA) with a baseline stimulation of 200 v.

Internal fixation instruments. All patients were also treated with internal fixation instruments by implanting autogenous bone fragments into the intervertebral space. The system used was Poly A pedicle screw system (USS II Polyaxial, Synthes GmbH, CH made by Johnson Company).

Surgical procedures

The surgical procedure for each case in our center was performed by a single surgical team while monitoring somatosensory evoked potentials and motor evoked potentials. After complete exposure of the spine, pedicle screws were placed bilaterally at the intended fusion levels. Contralateral temporary fixation performed before pedicle and facet joint osteotomy to avoid spinal cord shortening. Then, osteotomies were performed. Firstly, the surgeon must uncover the posterior wall of the thoracic spinal canal assisted by ultrasound bone knife for resection. The bilateral vertebral laminae of the decompression segment were cut longitudinally with the piezosurgery (Figure 2A-a), after which, the head and tail vertebral lamina of the decompression segment were transversely sectioned (Figure 2A-b). The posterior wall of the thoracic spinal canal was entirely resected by the uncovering method (Figure 2A-c). Transfacet osteotomy, assisted by an ultrasound bone knife, was done. The facet joint can be partially or entirely removed with piezosurgery

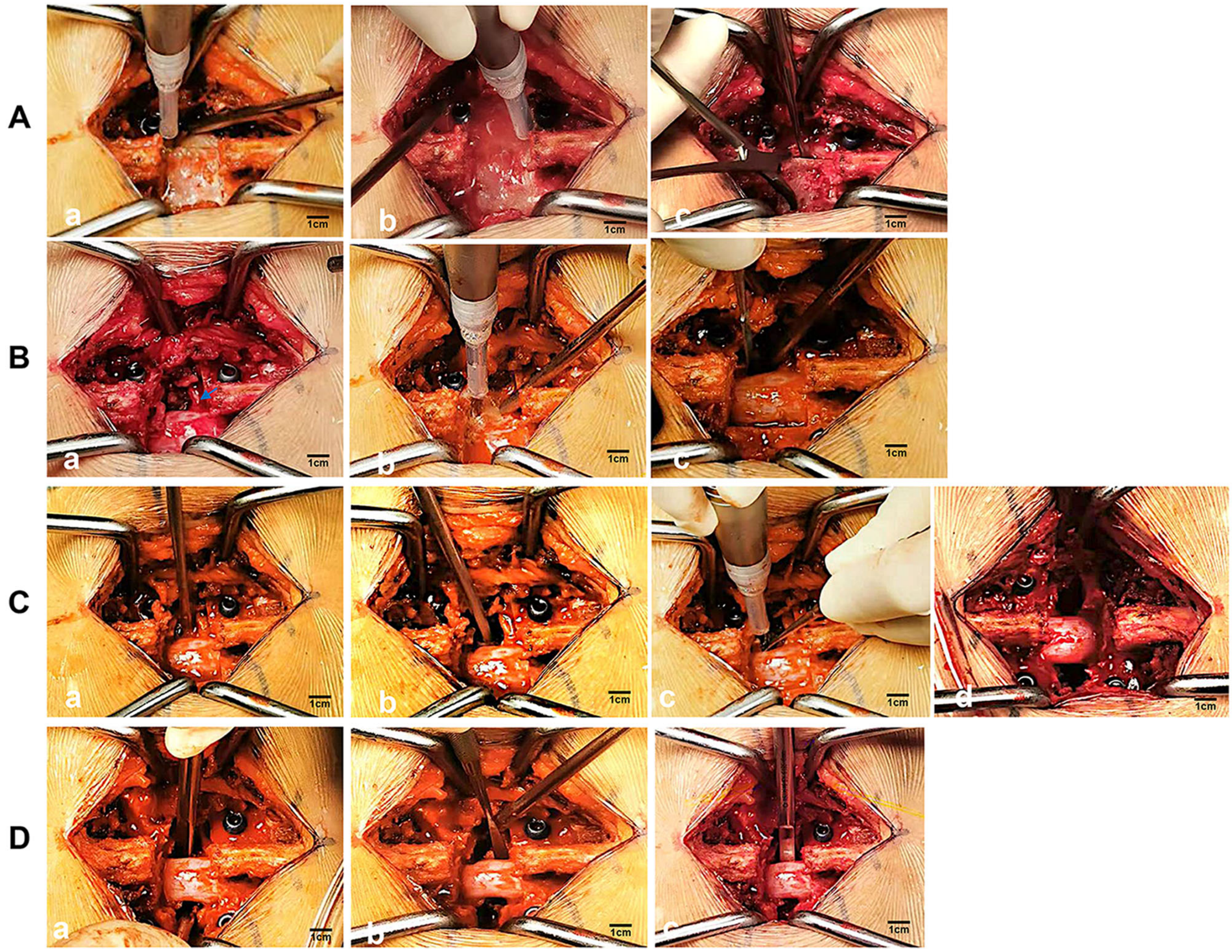

Figure 2. Ultrasound bone knife assisted 360-degree circular decompression of the thoracic spinal canal. (A) En-bloc posterior wall resection of thoracic spinal canal with piezosurgery. (B) Osteotomy of facet joint with piezosurgery. (C) Separation of ossification mass of posterior longitudinal ligament with piezosurgery (The blue curve is the boundary of OPLL.). (D) Resection of ossification of posterior longitudinal ligament (The blue curve is the boundary of ossification mass of posterior longitudinal ligament.).

(Figure 2B-a) to expose the nerve root and the lateral intervertebral disk of OPLL (Figure 2B-b).

Furthermore, the extent of OPLL invasion was explored along the longitudinal axis of the spinal canal at the planned annular decompression segment to identify the "safe triangle" (posterior edge of the vertebral body, the cephalo-caudal boundary of OPLL, potential space surrounded by the ventral dural sac) (Figure 2B-c). Next, OPLL dissociation was done and assisted by piezosurgery. First lateral OPLL disks were removed on one side (Figure 2C-a), followed by the removal of the ventral OPLL disks (Figure 2C-b). The piezosurgery head was inserted into the safe triangle, and the base of the head and tail of OPLL was cut horizontally going inwards (Figure 2C-c). A contralateral operation was also done until the ossification block is dissociated on both sides (Figure 2C-d). Lastly, the OPLL was removed by prying the free OPLL with a bone knife (Figure 2D-a). When the OPLL was utterly suspended, the adhesion was then separated between the OPLL and the dural sac (Figure 2D-b). The suspended OPLL was pushed ventrally into the intervertebral space (Figure 2D-c), finally removing it from the back of the side to complete the circular decompression.

Data collection

The general data collected from the patients include the patient's age, sex, course of the disease, OPLL type, clinical symptoms, and long follow-up period. Intraoperative data, spinal cord monitoring, early warning standard-setting, complications, and functional evaluation were recorded.

Intraoperative data

For the intraoperative data, the distribution of OPLL segment and circular decompression segment, operation time (min.), circular decompression time (min.) (from the completion of resection of the posterior wall of the spinal canal to the complete resection of OPLL), operation time of single laminectomy (mL) and the amount of blood loss (mL) were all documented.

Spinal cord monitoring

In terms of the spinal cord monitoring, the early warning events of CSEP (Cortical Somatosensory Evoked Potential) and TES-MEP (Transcranial Electrical Stimulation-Motor Evoked Potential), were recorded, as well.

Table 1. General information of enrolled patients.

	Age	52.8 (27–80)
	Female/Male	13/23
	Merged with COPLL	8 (22.2%)
	Merged with OTLF	5 (13.9%)
Type of OPLL	Continuous	9 (25%)
	non-Continuous	27 (75%)
	Duration of onset, Mon	7.4 (0.5–36)
	Length of follow-up, Mon	23.8 (12–45)
	Sensory disturbance	31 (86.1%)
Clinical manifestation	Lower extremity dyskinesia	22 (61.1%)
	Sphincter dysfunction	6 (16.7)

Note: COPLL: Ossification of cervical posterior longitudinal ligament. OTLF: Ossification of ligamentum flavum of thoracic spine.

Early standard warning setting

With regards to the early warning standard-setting, the CSEP amplitude drop is more than 50%, or the latency is longer than 10%. The ETS MEP early warning standard is that the amplitude drop is higher than 50%. Meeting the first warning criteria, one or both of them are defined as intraoperative neuroelectrophysiological early warning events. For 0 minute or the onset of operation, no early warning event assignment; for assignment 1, it is deemed as the single early warning event training for CSEP; assignment 2 refers to the TESMEP single early warning event, and finally, assignment 3 is for the joint early warning event. When SSEP and MEP showed early warning signs, the operations were suspended and the ultrasonic scalpel was withdrawn slowly to check whether there was any direct spinal cord injury. If this was confirmed as “warning event”, dexamethasone was given during the operation and then the operation was continued.

Complications

Intraoperative and postoperative complications were observed and subsequently treated. The follow-up was arranged at 1-, 3-, 6-, 12 months after the operation, and finally, reexamined every year.

Functional evaluation

Lastly, the functional evaluation of the thoracic spinal cord function was accomplished with the use of the mJOA score, whereas the spinal cord function improvement rate was evaluated according to the Hirabayashi system, using the following as the ratings: excellent (75%–100%), good (50%–74%), fine (25%–49%), and poor (0–25%).

Statistical analysis

The data were then analyzed by SPSS 24.0 software, and the charts were made by GraphPad Prism 7.0 software. Descriptive statistical methods were used to evaluate the general data, operational data, early warning events and functional evaluation of the patients. Average ± standard deviation was used to express the data. General data and operation-related data from Spearman correlation were used to analyze the correlation between mJOA score and spinal cord function improvement rate in the last follow-up. $p <$ 0.05 was considered to be statistically significant.

Results

General data

A total of 36 patients (13 female and 23 male) with mean age of 52.8 years old (range, 27–80 years) were included in this study. The duration of onset was 7.4 (0.5/36) months with a follow-up period of 23.8 (12/45). The OPLL and clinical symptoms are detailed in Table 1.

Data related to the operation

Intraoperative data

With regards to the intraoperative data, a total of 81 segments of the thoracic lamina and 36 segments of circular decompression were resected. The average number of posterior wall resection segments was 2.25. The total operation time lasted for 176.73 ± 82.23 min. Circular decompression was completed in 42.06 ± 14.22 min, while the duration of a single laminectomy was 3.43 ± 0.49 min. The amount of blood loss was 1058.61 ± 737.66 mL.

Spinal cord monitoring

The spinal cord monitoring system documented nine neuroelectrophysiological early warning events, including four cases of CSEP single early warning event, five cases of CSEP and TES-MEP combined early warning event. No TES-MEP single early warning event, as shown in Table 2. Post-operatively, the average period of the patient’s hospital stay was at 11.8 days (5–33 days) (Table 2 and Figure 3).

Complications

There were no direct nerve root and spinal cord injuries during the operation. However, cerebrospinal fluid leakage did occure in seven patients, of which three cases were complicated with ossification of ligamentum flavum, and dural tear occurred during laminectomy—the other cases developed OPLL dural adhesion and ventral tear of dural sac during separation. Temporary lower limb myodynamia occurred in six patients, of which four cases recovered to the preoperative level within one week after the operation, and the other two cases recovered to the preoperative level half a year after the operation. Furthermore, wound infection was suspected in two patients who developed a high fever and chilled one week after the operation. Infection index screening and wound MRI examination were subsequently performed for these patients. The body temperature and infection index returned to normal after two weeks of Vancomycin plus Shupu. Five patients developed severe intercostal neuralgia, with a VAS score of more than seven and the postoperative complications were only relieved after intercostal nerve blocking treatment in our hospital. Ultrasonic knife head was broken and needed to be replaced

Table 2. Operation data of enrolled patients.

	Operation time (min)	Circular decompression time (min)	Operation time of single laminectomy (min)	Blood loss (mL)	Mean number of segments removed from posterior wall	Warning events
n = 36	176.73 ± 82.23 (80, 340)	42.06 ± 14.22 (22, 83)	3.43 ± 0.49 (2.70, 5.10)	1058.61 ± 737.66 (150, 3500)	2.25 (1, 8)	9 (CSEP single warning 4, joint warning 5)

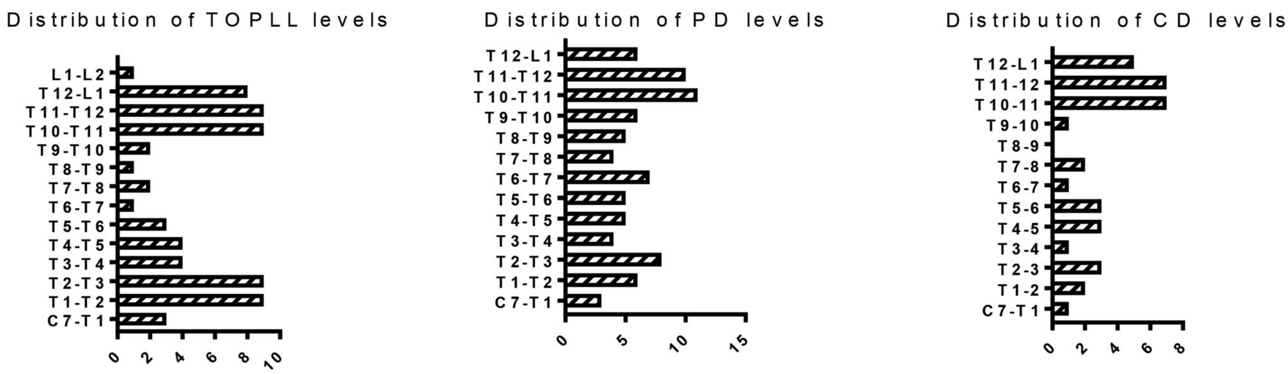

Figure 3. Distribution of segments of TOPLL, laminectomy of thoracic spinal canal, and circumferential decompression.

Table 3. Statistics of complications (SSI: Surgical Site Infection).

	Cerebrospinal fluid leakage	Nerve injury	Surgical Wound Infection	Temporary postoperatively decreased muscle strength	Intercostal neuralgia	Ultrasonic scalpel fracture
n = 36	7 19.4%	0 0%	2 5.6%	6 16.7%	5 13.9%	2 5.6%

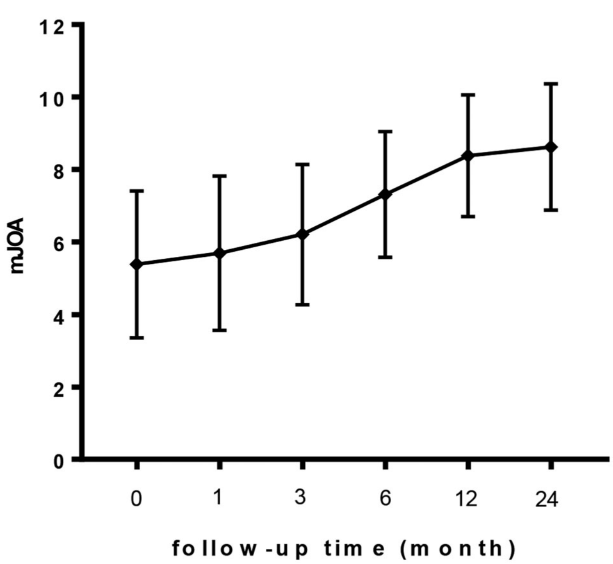

Figure 4. Follow up results of mJOA score.

in 2 patients during laminectomy. The operation was completed after the replacement of the knife head (Table 3).

Functional evaluation

Finally, the preoperative, follow-up and recovery rates were recorded during the functional evaluation according to the mJOA association scale. The preoperative JOA score was 5.28 ± 2.07, and the last follow-up JOA score was 8.89 ± 1.56. The average spinal cord function recovery rate was 64.21% ± 21.20%, of which 30 patients (83.3%) reached the peak JOA recovery 12 months after operation (Figure 4). Spearman analysis (Table 4) showed that the mJOA score at the last follow-up was negatively correlated with the circular decompression time ($r = 0.368$, $p < 0.01$) and age ($r = 0.412$, $p = 0.026$), and positively correlated with the preoperative mJOA score ($r = 0.454$, $p = 0.013$). The improvement rate of spinal cord function was negatively correlated with the operation time of circular decompression (ringing color 0.325) and the amount of intraoperative blood loss (rpm 0.325) and intraoperative blood loss (0.028). The results reflected the negative correlation of the improvement rate of spinal cord function with the time of circular decompression and the amount of blood loss during operation. There were no significant correlation between intraoperative neuroelectrophysiological monitoring early warning events and postoperative spinal cord function improvement rate and the last follow-up mJOA score. However, in this study, four of the five patients with CSEP and TES-MEP combined early warning events had temporary muscle strength decrease after the operation. The temporary decrease in muscle strength after the operation had a negative effect on the recovery of spinal cord function (rpm 0.289) (0.022).

Discussion

One-stage posterior CD has become a mainstay of treatment for TOPLL due to its effectiveness in removing the ossified

Table 4. Spearman correlation analysis on the factors influencing the recovery of spinal cord function after operation (* $p < 0.05$).

		Age	BMI	circular decompression segment	Pre-mJOA	operation time	circular decompression time	Blood loss	Warning events	Temporary postoperatively decreased muscle strength
The last follow-up mJOA	r	−0.412*	0.082	0.275	0.454*	−0.353	−0.368*	−0.334	−0.338	−0168
	P	0.026	0.673	0.148	0.013	0.061	0.049	0.077	0.424	0.335
Spinal cord function improvement rate	R	−0.340	0.038	0.032	0.193	−0.222	−0.325*	−0.555*	−0.217	−0.289*
	P	0.072	0.847	0.869	0.315	0.247	0.041	0.028	0.443	0.022

lesions and decompress the spinal canal [5,6]. However, as the dura mater in the ventral spine and the dorsal subarachnoid space are relatively fragile components, any slight retraction or compression may lead to catastrophic consequences related to the spinal cord [9]. Recently, piezosurgery technique has been introduced in patients with TOPLL [13,14]. The current study retrospectively reviewed 36 patients with TOPLL who underwent decompression with piezosurgery. Our findings demonstrated that the use of piezosurgery can safely and effectively complete one-stage posterior CD.

Intraoperative piezosurgery technique could effectively reduce the incidence of spinal cord injury after CD decompression. Due to the high incidence of spinal cord injury, there may be a hesitation among surgeons with regards to choice of decision making. Yamazaki et al. [15] reported that the incidence of spinal cord injury can reach 18.8%. Hanai et al. [16] also reported similar complication rates. In the current study, a total of nine electrophysiological early warning events, of which seven cases occurred in the process of ventral adhesion separation of dural sac and bone knife prying OPLL, the two other cases were single early warning events of CSEP, which occurred immediately after laminectomy. During follow-up, no patients complain about neurology deficit.

Additionally, excellent health-related quality of life has been found after decompression surgery. Previous studies reported significant neurological deterioration after circular decompression [1,17]. Yamazaki et al. [15] report that neurological deterioration might appear as a tough problem after posterior laminotomy decompression. In the current study, the improvement rate of spinal cord function after the last follow-up was 64.2%. Around 88.8% of the patients had an excellent and good rate of spinal cord function improvement according to the Hirabayashi system. Although six patients (16.7%) had temporary myodynamia after the operation, satisfactory clinical results were obtained after conservative treatment. The improvement rate of spinal cord function of patients with piezosurgery-assisted posterior thoracic circular decompression was much better, and the probability of spinal cord function deterioration is significantly reduced than previous literature outcomes [1,15].

It should be noted that limitations of piezosurgery technique also existed. Hu et al. [14] used piezosurgery to perform spinal osteotomy in 128 patients with spinal diseases, of which two patients had cerebrospinal fluid leakage directly related to piezosurgery, indicative of its risk despite not causing significant nerve injury. All piezosurgery cutting planes are carbonized to varying degrees which allows for continuous cooling of flowing water in bone cutting (Figure 5). However, a large amount of heat is still produced despite carbonization. Despite its reported thermogenic effect, there was no direct damage to the nerve structure of the patients in the study because the surgeons repositioned the ultrasonic tool head from time to time to reduce thermal damage. Therefore, piezosurgery did not increase the risk of nerve structure in this study. There were also no abnormal signals in neuroelectrophysiological monitoring. Moreover, the occurrence of postoperative intercostal neuralgia also noted in the current study (13.9%), which was consistent with previous literature reports [10].

In terms of intraoperativeblood loss, our study did not demonstrate greater outcomes when compared with previous studies [1,10,18]. The current study suggests that piezosurgery has no visible hemostatic effect during OPLL resection because of the large amount of bleeding. It can be attributed to the hemostatic mechanism of thermal coagulation in piezosurgery. Piezosurgery can effectively reduce bleeding in laminectomy alone, whereas, the bleeding during circular decompression is mainly venous plexus bleeding in the spinal canal and intervertebral space. This study lacks statistical analysis for the current data because of the inherent difficulty in obtaining accurate statistics regarding the amount of bleeding during OPLL resection.

For continuous TOPLL, it is still uncertain whether circumferential osteotomy is needed or not as well as the range of decompression. Ando et al. [19] introduced treatment of continuous TOPLL with Ponte osteotomy. The improvement rate of nerve function in their results was 56%. However, this procedure is not suitable for patients with high spinal canal encroachment rate of ossification mass, especially "peak type" TOPLL. Tokuhashi et al. [20] suggested circular decompression more than posterior wall resection alone for TOPLL patients with ossification convex angle greater than 23 degrees. In the current study, all patients underwent all patients underwent single circumferential osteotomy and satisfactory outcomes were noted during follow-up. Surgeons need to be aware that too many segments of circumferential osteotomy may potentially increase the risk of neurological complications. Takahata et al. [21] reported that the total proportion of neurological deterioration for circumferential osteotomy was 33%. Liu et al. [22] also reported that the use of multi segmental 360° thoracic spinal cord annular decompression was associated with poor improvement rate of thoracic spinal cord function. Therefore, i it is necessary to reduce the number of circular decompression segments on the basis of ensuring adequate decompression. Here, 9 of 36 patients was diagnosed with continuous TOPLL. All of them underwent one level circular decompression. Additionally,

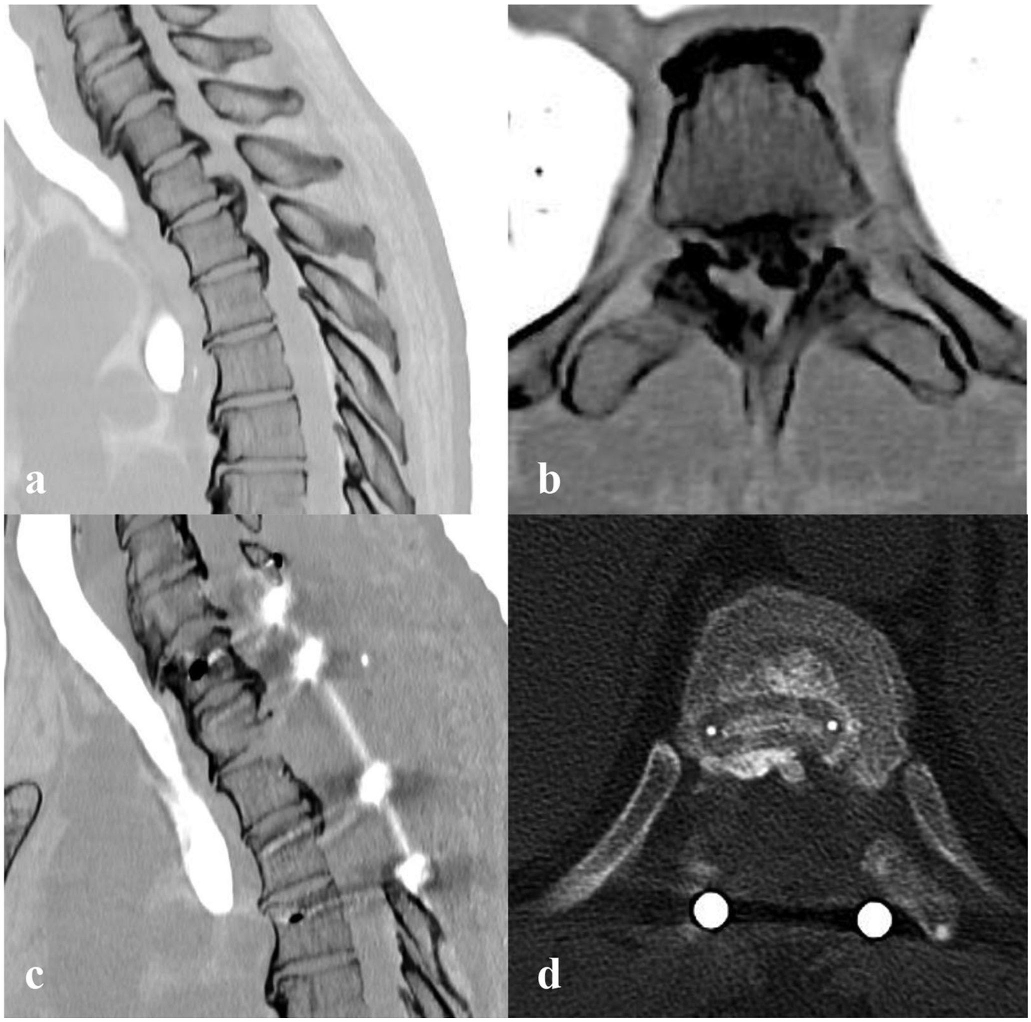

Figure 5. Radiographs showing a 50-year-old female with severe TOPLL (a); axial CT scans showed severe ossification in T2/3 segments (b); After decompression surgery with piezosurgery technique, the ossification was removed (c); and the intraspinal area was significantly enlarged (d).

16 of 36 patients underwent single level laminectomy and 20 patients underwent multi segmental laminectomy. The purpose of multi-level laminectomy was to provide enough space for spinal cord to move backward to obtain sufficient decompression.

The clinical relevance of the current study related to the surgical details of OPLL block resection with piezosurgery technique. During a laminectomy, reduction in the spinal cord interference should be performed when the ossification block was separated and removed. This method ensured that the lateral intervertebral space could be widened before facilitating the operation. The ossification block then floated completely and was removed with less spinal cord interference. There were some cases with adhesions between the ossification block and the dura mater. To address such cases, the ossification mass without adhesions was treated first, before proceeding to the more difficult part. If necessary, the dura mater with partial adhesion or ossification can be removed. Based on the findings and limitations of piezosurgery technique, we propose that surgeons should be careful when operating the ultrasonic knife head because of its likelihood to break during the bone cutting process. In complicated cases of OPLL resection, it is also preferable to use the hook, spoon or rake knife heads to grind and divide the OPLL. Moreover, in order to mitigate the thermogenic effect, the ultrasonic knife head must remain parallel to the cutting cross-section, but the knife head should not be kept in the same position for a long time as it produces excessive amounts of heat.

There were also some limitations in the current study. First, although this study is a prospective study, it lacks the control group of traditional instruments, and the data are analyzed by descriptive statistics, which can only be compared with the data reported from the previous literature. Second, this study did not include the morphometric data of the ossification block of the posterior longitudinal ligament. Third, the type of ultrasonic knife head used during the procedure is a cause of concern since it was relatively fixed, and the personalized ultrasonic knife head was not designed according to the specific shape of the patient's ossification block.

In conclusion, Piezosurgery-assisted 360-degree circular decompression of the thoracic spinal canal achieved an overall good improvement rate of spinal cord function and reduced the probability of postoperative deterioration of spinal cord function than traditional circular decompression techniques reported in previous literature. However, clinical evidence is still insufficient to prove that piezosurgery can reduce the total blood loss of the operation.

Disclosure of interest

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are available from the corresponding author.

References

1. Xu ZW, Hu YC, Sun CG, et al. Treatment for thoracic ossification of posterior longitudinal ligament with posterior circumferential decompression. *Orthop Surg*. 2017;9(2):206–214.
2. Endo T, Takahata M, Koike Y, et al. Clinical characteristics of patients with thoracic myelopathy caused by ossification of the posterior longitudinal ligament. *J Bone Miner Metab*. 2020;38(1):63–69. doi:10.1007/s00774-019-01026-8.
3. Kim SY, Hyun SJ, Kim KJ, et al. Surgical outcomes according to dekyphosis in patients with ossification of the posterior longitudinal ligament in the thoracic spine. *J Korean Neurosurg Soc*. 2020;63(1):89–98.
4. Imagama S, Ando K, Takeuchi K, et al. Perioperative complications after surgery for thoracic ossification of posterior longitudinal ligament: a nationwide multicenter prospective study. *Spine*. 2018;43(23):E1389–E1397.
5. Kato S, Murakami H, Demura S, et al. Indication for anterior spinal cord decompression via a posterolateral approach for the treatment of ossification of the posterior longitudinal ligament in the thoracic spine: a prospective cohort study. *Eur Spine J*. 2020;29(1):113–121. doi:10.1007/s00586-019-06047-5.
6. Matsuyama Y, Yoshihara H, Tsuji T, et al. Surgical outcome of ossification of the posterior longitudinal ligament (OPLL) of the thoracic spine: implication of the type of ossification and surgical options. *J Spinal Disord Tech*. 2005;18(6):492–497; discussion 8. doi:10.1097/01.bsd.0000155033.63557.9c.
7. Morishita S, Yoshii T, Okawa A, et al. Perioperative complications of anterior decompression with fusion versus laminoplasty for the treatment of cervical ossification of the posterior longitudinal ligament: propensity score matching analysis using a nation-wide inpatient database. *Spine J*. 2019;19(4):610–616.
8. Li M, Meng H, Du J, et al. Management of thoracic myelopathy caused by ossification of the posterior longitudinal ligament combined with ossification of the ligamentum flavum-a retrospective study. *Spine J*. 2012;12(12):1093–1102. doi:10.1016/j.spinee.2012.10.022.
9. Ito Z, Matsuyama Y, Ando M, et al. Postoperative paralysis from thoracic ossification of posterior longitudinal ligament surgery risk factor of neurologic injury: nationwide multiinstitution survey. *Spine*. 2016;41(19):E1159–E1163. doi:10.1097/BRS.0000000000001585.
10. Yang B, Wang Y, He X, et al. Treatment for thoracic ossification of posterior longitudinal ligament with posterior circumferential decompression: complications and managements. *J Orthop Surg Res*. 2016;11(1):153.
11. Head J, Rymarczuk G, Stricsek G, et al. Ossification of the posterior longitudinal ligament: surgical approaches and associated complications. *Neurospine*. 2019;16(3):517–529. doi:10.14245/ns.1938222.111.
12. Bernstein DN, Prong M, Kurucan E, et al. National trends and complications in the surgical management of ossification of the posterior longitudinal ligament (OPLL). *Spine*. 2019;44:1550–1557.
13. Hazer DB, Yaşar B, Rosberg HE, et al. Technical aspects on the use of ultrasonic bone shaver in spine surgery: experience in 307 patients. *Biomed Res Int*. 2016;2016:8428530. doi:10.1155/2016/8428530.
14. Hu X, Ohnmeiss DD, Lieberman IH. Use of an ultrasonic osteotome device in spine surgery: experience from the first 128 patients. *Eur Spine J*. 2013;22(12):2845–2849. doi:10.1007/s00586-013-2780-y.
15. Yamazaki M, Mochizuki M, Ikeda Y, et al. Clinical results of surgery for thoracic myelopathy caused by ossification of the posterior longitudinal ligament: operative indication of posterior decompression with instrumented fusion. *Spine*. 2006;31:1452–1460.
16. Hanai K, Ogikubo O, Miyashita T. Anterior decompression for myelopathy resulting from thoracic ossification of the posterior longitudinal ligament. *Spine*. 2002;27:1070–1076.
17. Hu P, Yu M, Liu X, et al. A circumferential decompression-based surgical strategy for multilevel ossification of thoracic posterior longitudinal ligament. *Spine J*. 2015;15(12):2484–2492.
18. Ma X, An HS, Zhang Y, et al. A radical procedure of circumferential spinal cord decompression through a modified posterior approach for thoracic myelopathy caused by severely impinging anterior ossification. *Spine J*. 2014;14(4):651–658. doi:10.1016/j.spinee.2013.06.091.
19. Ando K, Imagama S, Ito Z, et al. Ponte osteotomy during dekyphosis for indirect posterior decompression with ossification of the posterior longitudinal ligament of the thoracic spine. *Clin Spine Surg*. 2017;30(4):E358–e62. doi:10.1097/BSD.0000000000000188.
20. Tokuhashi Y, Matsuzaki H, Oda H, et al. Effectiveness of posterior decompression for patients with ossification of the posterior longitudinal ligament in the thoracic spine: usefulness of the ossification-kyphosis angle on MRI. *Spine*. 2006;31(1):E26–E30.
21. Takahata M, Ito M, Abumi K, et al. Clinical results and complications of circumferential spinal cord decompression through a single posterior approach for thoracic myelopathy caused by ossification of posterior longitudinal ligament. *Spine*. 2008;33:1199–1208.
22. Wang YQ, Liu XG, Jiang L, et al. Intraoperative ultrasonography in "cave-in" 360° circumferential decompression for thoracic spinal stenosis. *Chin Med J*. 2011;124:3879–3885.