



OPERATIVE TECHNIQUE

Angled Ultrasonic Bone Curette-Assisted Circumferential Decompression for Thoracic Myelopathy Caused by Severely Anterior Ossification

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Objective: Thoracic myelopathy caused by severe anterior ossification is often progressive and fails to respond to conservative treatment. Removal of the compressing ossification is the most effective method but is hard to operate. In this study, we describe a novel one-stage posterior circumferential decompressive procedure assisted by an angled ultrasonic bone curette (UBC) for thoracic myelopathy caused by severe anterior ossification and evaluate its safety and efficacy.

Methods: The current study enrolled 15 consecutive patients (five men and 10 women) with thoracic myelopathy caused by severely anterior ossification between January 2017 and December 2019. All patients underwent posterior circumferential decompression assisted by angled UBC and segmental instrumentation with interbody fusion. At the time of surgery, the average age was 58.6 ± 6.3 years (47–70 years). Before and after surgery, the patient data, clinical manifestation, operative levels, blood loss, operative time, perioperative complications, Japanese Orthopaedic Association (JOA) score were recorded and analyzed retrospectively.

Results: All patients had successful one-stage posterior circumferential decompression to remove anterior ossifications directly. There were 12 cases of OPLL, two cases of a calcified giant herniated disc, and one case of osteophyte. The average operation time was 153.4 ± 53.4 min (77–242 min), with a mean blood loss of 463.5 ± 155.8 mL (240–780 mL). The average length of stay in the hospital was 14.3 ± 4.7 days (9–25 days) and the mean follow-up duration was 20.8 ± 8.8 months (12–39 months). Almost all patients had subjective improvement in motor power and gait. The average preoperative JOA score was 4.5 ± 1.6 , which improved to 9.0 ± 1.8 at the final follow-up. Postoperative differences in the overall JOA scores showed significant improvement ($F = 105.446$, $p < 0.01$). The overall recovery rate at the final examination scored $70.9\% \pm 25.0\%$. According to Hirabayashi's classification, eight cases were rated as excellent, four as good, two as fair, and one as unchanged. No patient was graded as deteriorated. Two patients (13.3%) experienced intraoperative cerebrospinal fluid leakage, while two cases (13.3%) experienced unilateral intercostal neuralgia, and only one (6.7%) encountered acute neurological deterioration. All these patients were treated conservatively and their neurological function improved significantly. At the follow-up, there was no evidence of neurological deterioration.

Conclusion: Circumferential decompression assisted by angled UBC can preserve more posterior elements of the involved levels, maintaining an intact pleura and reducing the operation time and blood loss for thoracic myelopathy caused by severe anterior ossification. It is a safe, effective, and technically feasible method to provide surgeons with a new option for thoracic spinal circumferential decompression.

Key words: Anterior ossification; Circumferential decompression; Surgical technique; Thoracic myelopathy; Ultrasonic bone curette

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Introduction

Progressive thoracic myelopathy caused by severe anterior ossification such as ossification of the posterior longitudinal ligament (OPLL). Calcified giant herniated disc or osteophyte is generally considered the result of heterotopic ossification of chondrocytes. It is a rare disease that causes sensory and motor disorders of the extremities and dysfunction of the visceral autonomic nervous system. Compared to the cervical and lumbar spinal canals, the thoracic spinal canal is usually smaller in volume, leaving little room for the spinal cord to escape in the event of nerve compression, for which it has a poor response to conservative treatment and surgical intervention is indicated if signs of neurologic dysfunction develop¹⁻³. To date, various surgical procedures have been developed to treat thoracic myelopathy caused by anterior ossification. However, promising outcomes are not always attained, and the most optimal surgical treatment of thoracic anterior ossification remains highly debatable.

Indirect decompression, including posterior laminectomy or laminoplasty, is considered a safe method. Yet, for patients with severe anterior spinal cord compression, beak-type OPLL, and segments with a predominant kyphosis, satisfactory efficacy is not always achievable because of the poor posterior shift of the spinal cord⁴⁻⁶. To obtain adequate decompression, it is sometimes necessary to remove anterior compression directly^{5,7}. Anterior decompression *via* an anterior approach has been developed but involves a demanding process. Moreover, its clinical application is limited due to the great trauma it causes, significant interference with pulmonary function, and a high incidence of intraoperative spinal cord and nerve injury⁸. In recent years, minimally invasive thoracoscopic techniques were performed by some surgeons to treat a single lesion type of thoracic myelopathy. However, thoracoscopic surgery has a long learning curve in general, and the small number of patients with thoracic spinal stenosis caused by anterior compression limits the familiarity with this approach^{9,10}. Furthermore, two-stage posterior and anterior decompression has been shown to have favorable surgical outcomes¹¹, despite the challenges posed by the need for two separate operations, such as the high degree of induced trauma and the risk of secondary injury to the thoracic spinal cord, which increase the morbidity and medical expenses.

Because of its effectiveness in explicitly removing the ventral spinal cord lesions without additional incisions or staging operations, one-stage posterior circumferential decompression has been accepted as the most effective method to relieve pressure on the spinal cord with the development of surgical techniques^{1,12}. Even for experienced surgeons, direct removal of the anterior plaque-causing compression is technically challenging and poses a significant risk to the patient. Complications, such as spinal cord injury, aggravation of symptoms, cerebrospinal fluid (CSF) leakage, and infection, occur in a range of 9.6% to 40.8%^{6,13,14}. One explanation is that the dura mater in the ventral spine and the dorsal subarachnoid space is a relatively fragile component, and a slightly greater backward traction of the spinal

cord may cause catastrophic consequences¹⁵. Another reason is that the processes of both ventral adhesion separation of the dural sac and traditional surgical instruments prying thoracic anterior ossifications usually cause electrophysiological early warning events that significantly increase the risk of spinal cord injury^{16,17}. Furthermore, the total resection of the posterior elements is needed to achieve sufficient space to perform the ventral spinal operation under direct vision in practice in almost all circumferential decompression surgeries that have been reported previously, increasing the incidence of complications, such as long operation times, massive blood loss, and even instrument-related adverse events^{18,19}. As a result, there is an urgent need for a standard procedure or technique to decompress the spinal cord safely and effectively.

Since 1947, when the first ultrasonic aspirator was introduced in clinical practice, ultrasonic instruments expanded into many other fields. The ultrasonic bone curette (UBC) is a relatively novel orthopaedic surgical device, primarily utilizing different ultrasonic frequencies to selectively cut hard tissues while the dural mater and blood vessels are left intact. Advantages of this device, such as precision safety, self-irrigation cooling system, soft tissue protection, and better hemostasia, make it a useful instrument for treating various spinal disorders without causing excessive mechanical and thermal injury^{20,21}. Especially for patients with thoracic myelopathy caused by severely anterior ossification, the application of UBC could effectively reduce the probability of spinal cord injury after circumferential decompression and improve the recovery rate of spinal cord function in comparison with conventional instruments^{16,22}.

Despite advancements in instruments and techniques, thoracic circumferential decompression has remained a difficult procedure due to its unfavorable outcomes and high incidence of complications⁶. To the best of our knowledge, no consistent surgical procedures have yet been established. As a result of our clinical experience with ultrasonic bone curettes (UBCs), we redesigned the structure of the UBC head and modified the circumferential decompression procedure to treat thoracic myelopathy caused by severely anterior ossification. The purposes of this study were: (i) to summarize the current status of traditional circumferential decompression procedure for thoracic myelopathy caused by anterior ossification; (ii) to analyze the advantages and pitfalls of the novel one-stage circumferential decompression surgery for directly removing anterior compressing ossification assisted by angled UBC; and (iii) to evaluate the safety and efficacy of the technique.

Materials Methods

Inclusion and Exclusion Criteria

Inclusion Criteria

The following were the inclusion criteria: (i) typical spinal cord compression symptoms; (ii) single-level thoracic OPLL,

calcified herniated disc, or osteophyte without ossification of the ligament flavum (OLF); (iii) complete clinical data and regular follow-ups.

Exclusion Criteria

The exclusion criteria were as follows: (i) suffering from heart, brain, kidney, and other essential organ diseases; (ii) having coexisting contraindications such as infection and tumor; and (iii) being unable to tolerate the operation.

Patient Population

Informed consent was obtained from the patients enrolled in this study. The study protocol was approved by the Institutional Review Board of the Shengjing Hospital of China Medical University(2020PS487K). This novel technique was successfully performed in 15 consecutive patients (five men and 10 women) with thoracic myelopathy caused by severely anterior ossification between January 2017 and December 2019. Twelve cases had OPLL, two cases had a calcified herniated disc, and one case had an osteophyte. The average age was 58.6 ± 6.3 years (47–70 years) at the time of surgery. All patients underwent single-level anterior spinal cord decompression with an angled UBC and instrumented fusion *via* a posterior approach (Table 1. Demographics and Clinical Data of the 15 patients).

Surgical Instruments

An ultrasonic surgical system (Beijing Sonicmed Technologies Co., Ltd., China) (Figure 1A:Ultrasonic scalpel handle equipped with an angled head, connecting line, and water pipeline) was used during surgery, which was equipped with two types of angled heads made of medical titanium alloys (Figure 1B:Angled ultrasonic cutter).The angled ultrasonic cutter consists of a straight cutter body and an angled cutter head with a sharp surface and the angle formed by the axis of both ends of the cutter bar ranges from 120° to 150° (Figure 2:Ultrasonic scalpel handle with an angled head [120°]). [A] A lateral view of the angled head, as well as an enlarged image of it. [B] front view and an enlarged image of the angled head. Figure 3:Ultrasonic scalpel handle equipped with an angled head [150°]. [A] A lateral view of the angled head, as well as an enlarged image of it. [B] front view with an enlarged image of the angled head). The output power range is 0–150 W with a 250 μm maximum vibration amplitude at a frequency of 40 kHz, which was selected on the control panel with a digital display according to the situation. Both two types of angled heads would be selectively used when removing thoracic anterior compressing ossification such as OPLL, calcified giant herniated disc, or osteophyte. The angled head (120°) is suitable for all types of anterior ossification, while the angled head (150°) is better for central ventral ossification. As the possibility of the angled ultrasonic cutter head fracture increases with the angle, it should be applied intermittently to reduce fatigue.

Surgical Procedures

Preparation and Exposure

Under general anesthesia, the patient was placed in a prone position and the posterior elements of the stenotic segment were exposed through a midline incision.

Posterior Laminectomy

A high-speed burr was used to prepare the boundary of the involved laminae after pedicle screws were placed bilaterally at the intended fusion levels (Figure 4A: Prepare the boundary of the involved laminae with a high-speed burr). Then, a straight UBC head was used to remove the remaining ventral portion of the lamina that clung to the inner wall of the pedicle followed by an en bloc laminectomy. Afterward, the inferior facet joints of the upper vertebra, the inner wall of the bilateral pedicles, and the partial superior facet joints of the lower vertebra were resected (Figure 4B: Remove the remaining ventral portion of the lamina that clung to the inner wall of the pedicle using a straight UBC head, followed by an en bloc laminectomy [the red region]). Resect the inferior facet joints of the upper vertebra, the inner wall of the bilateral pedicles, and the partial superior facet joints of the lower vertebra [the blue region]) to create sufficient space for the succedent anterior decompression.

Anterior Semi-Circumferential Decompression

According to the preoperative three-dimensional computed tomography (CT), a nerve hook was used to probe the boundary of the lesion and its adhesion to the dura mater. For the ossification beyond the outer edge of the spinal cord under direct vision, a straight UBC was used to remove it directly to the posterior wall of the vertebral body (Figure 4B: Remove the ossification beyond the outer edge of the spinal cord under direct vision [orange box] with a straight UBC). Afterward, the visible posterior vertebral wall was regarded as a reference, and the compressing lesion was ground from the basal part by an angled UBC to the middle line, whose types were selected by the surgeon based on the situations (Figure 4C: Resect the basal part of the anterior ossification [orange box] to the middle line using an angled UBC with the reference of the visible posterior wall of the vertebral body). The same surgical procedure was performed if there was still ossification pressing on the spinal cord on the contralateral side. After the cuttings from both sides, they were connected on the midline, and the rest of the ossified mass could be eradicated by a nerve hook with caution (Figure 4D2: Remove the rest of the ossified mass in cases with nonadherent ossification). In cases where the ossification extended to the dura mater or even with dural ossification, dissect of the adhesion between the ossification and the dura mater. Therefore, the floating ossification adhered to the ventral dura mater was ground carefully with an appropriate angled UBC, and then retained the residual ossification that extended to the ventral dura mater (Figure 4D1: Retain the ossification adhered to the ventral dura mater in

TABLE 1 Demographics and clinical data of the 15 patients

Case	Age (years) /sex	Type of MAO	Involved levels	Symptomatic duration (mon)	Posterior decomp level	Anterior decomp level	U time (mon)	JOA score			LOS (days)	Complications	
								Preop.	Final	Recovery rate (%)			
1	47/F	OPLL	T3-T7	1	T2-T7	T6-T7	12	5	6	17	580	20	CSF leaks
2	63/F	OPLL	T1-T2, T4-T6	48	T1-T2, T4-T7	T1-T2	13	2	6	44	780	14	None
3	52/M	Disc*	T8-T9	120	T8-T9	T8-T9	16	7	11	100	240	15	None
4	56/F	OPLL	T3-T4	12	T2-T5	T3-T4	14	6	10	80	500	13	None
5	60/M	OPLL	T5-T7	6	T6-T8	T6-T7	20	1	8	70	350	9	None
6	56/F	OPLL	T2-T3, T4-T5	12	T2-T5	T2-T3	15	6	10	80	410	13	None
7	70/F	OPLL	T4-T5	4	T4-T6	T4-T5	25	4	7	43	280	10	None
8	67/M	Osteophyte	T10-T11	72	T10-T11	T10-T11	22	5	9	67	600	12	None
9	66/F	Disc*	T9-T10	84	T9-T10	T9-T10	32	4	11	100	480	12	None
10	56/M	OPLL	T10-T11	168	T10-T11	T10-T11	17	5	8	50	400	10	None
11	54/F	OPLL	T4-T6	4	T1-T4	T3-T4	17	4	11	100	670	25	CSF leaks
12	62/F	OPLL	T9-T11	3	T9-T11	T10-T11	30	6	11	100	500	11	None
13	62/M	OPLL	T3-T4	12	T3-T5	T3-T4	28	4	8	57	300	12	None
14	55/F	OPLL	T6, T7	36	T5-T7	T6-T7	24	3	9	75	320	17	None
15	53/F	OPLL	T11-T12, L1-L2	22	T11-L2	T11-T12	39	6	10	80	570	22	None

MAO, massive anterior ossification; F-U, follow up; decomp., decompression; JOA, Japanese Orthopaedic Association; Preop., preoperative; LOS, length of stay in hospital; Disc*, Calcified herniated disc. Recovery rate (%) = (Final JOA score - Preoperative JOA score) × 100/(Full score (11) - Preoperative JOA score).

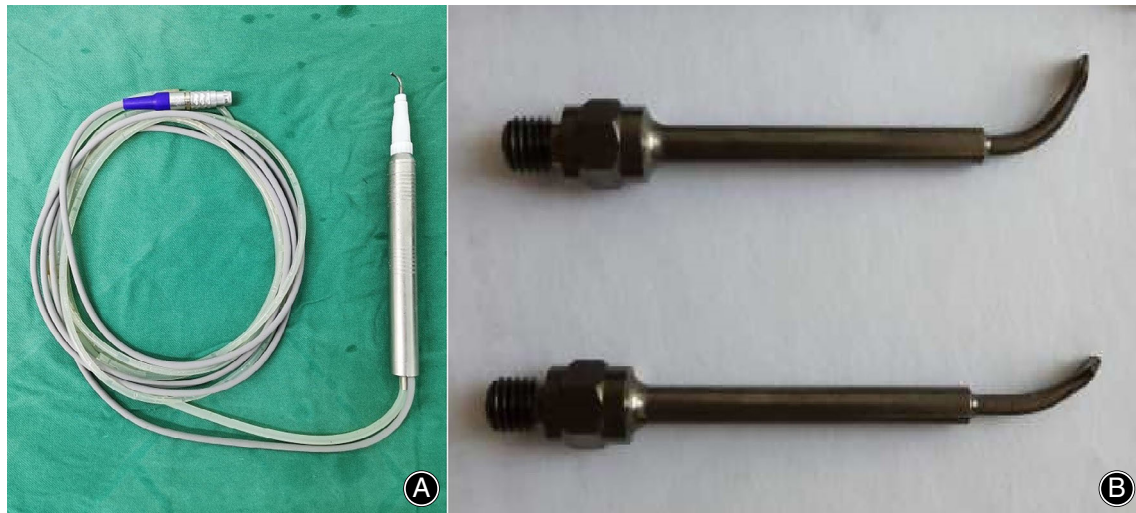


Fig. 1 (A) Ultrasonic scalpel handle equipped with an angled head, connecting line, and water pipeline. (B) Angled ultrasonic cutter

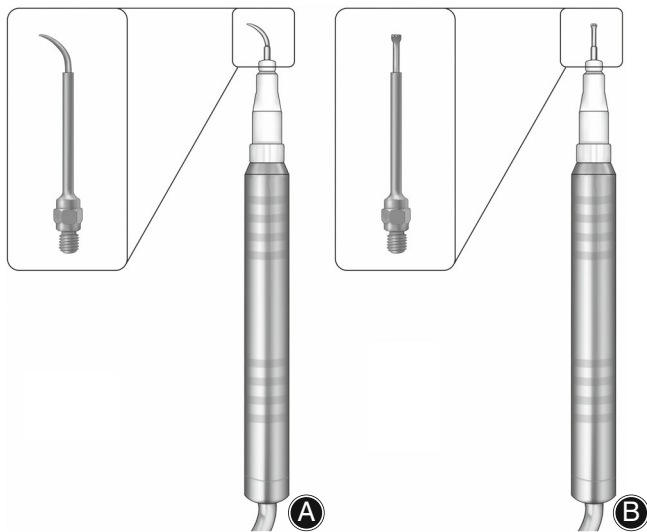


Fig. 2 Ultrasonic scalpel handle equipped with an angled head (120°). (A) Lateral view and enlarged picture of the angled head. (B) Front view and enlarged picture of the angled head

cases that ossification extended to the dura mater or with dural ossification). A set of intraoperative images are shown in Figure 5 (Intraoperative images of anterior ossification resection. [A] Resect the inferior facet joints of the upper vertebra, the inner wall of the bilateral pedicles, and the partial superior facet joints of the lower vertebra. [B–D] Remove the anterior ossification with an angled UBC). All the procedures were performed under intraoperative neurological monitoring.

Close

Finally, the screws were connected firmly to bilateral prebent rods, surgical drains were placed, and the incision was closed in layers.

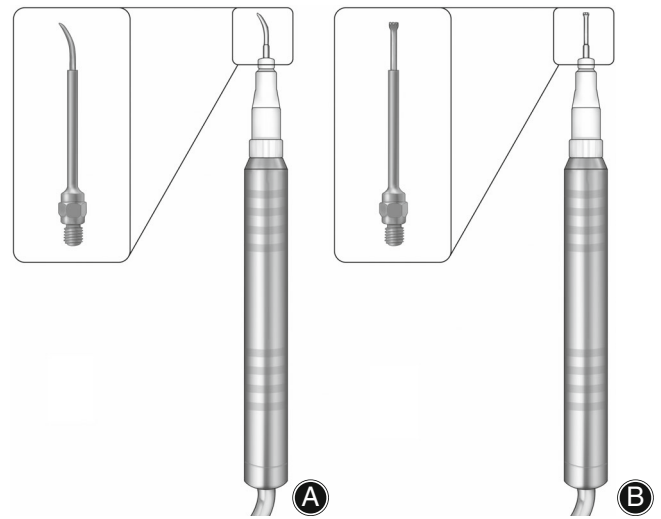


Fig. 3 Ultrasonic scalpel handle equipped with an angled head (150°). (A) Lateral view and enlarged picture of the angled head. (B) Front view and enlarged picture of the angled head

Evaluation and Follow-Up

All patients were followed up at 3, 6, and 12 months after surgery, and then annually until the final follow-up visit. The neurological statuses were evaluated according to the modified JOA scoring system, with a maximum score of 11 points. The recovery rate was calculated using Hirabayashi's Method (recovery rate (%) = (Postoperative JOA score - Preoperative JOA score) × 100 / (Full score (11) - Preoperative JOA score)).

JOA Scoring System

The modified JOA scoring system was used to evaluate the neurological status. The JOA scoring system includes four

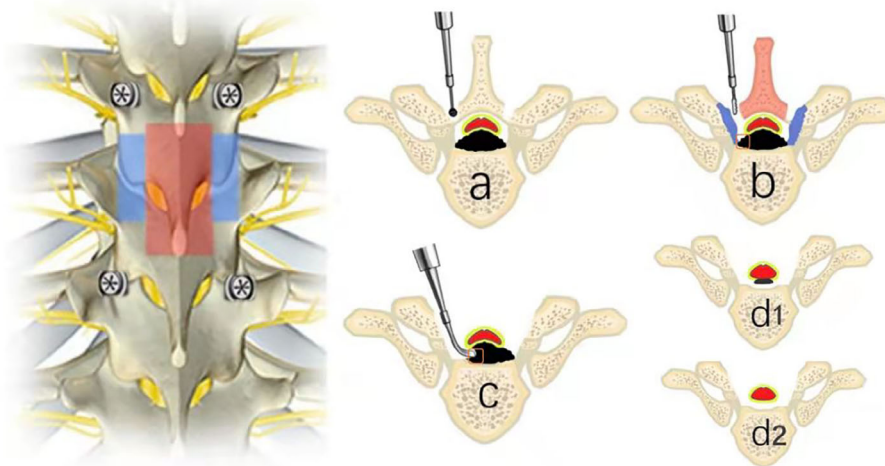


Fig. 4 Schematic diagrams of circumferential decompression for anterior ossification resection. (A) Prepare the boundary of the involved laminae with a high-speed burr. (B) Remove the remaining ventral portion of the lamina that clung to the inner wall of the pedicle using a straight UBC head, and followed by an en bloc laminectomy (the red region). Resect the inferior facet joints of the upper vertebra, the inner wall of the bilateral pedicles and the partial superior facet joints of the lower vertebra (the blue region). Remove the ossification beyond the outer edge of the spinal cord under direct vision (orange box) by a straight UBC. (C) Resect the basal part of anterior ossification (orange box) to the middle line using an angled UBC with the reference of the visible posterior wall of the vertebral body. (D) Retain the ossification adhered to the ventral dura mater in cases that ossification extended to the dura mater or with dural ossification (D1). Remove the rest of the ossified mass in cases with nonadherent ossification (D2)

sections: lower-limb motor dysfunction, lower-limb sensory deficit, trunk sensory deficit, and sphincter dysfunction. The maximum score of 11 indicates normal function. The recovery rate was calculated as recovery rate (%) = (Postoperative JOA score - Preoperative JOA score) \times 100/ (Full score (11) - Preoperative JOA score). The surgical outcome was then classified as excellent (100%–75%), good (74%–50%), fair (49%–25%), unchanged (24%–0%), or deteriorated (score <0%) based on the recovery rate.

Statistical Analysis

SPSS 24.0 (SPSS, Chicago, IL, USA) was used to analyze the data described using means with standard deviations and ranges. Repeat analysis of variance measurements was used to assess the statistical significance of both preoperative and postoperative JOA score changes. A p -value <0.05 was considered statistically significant.

Results

Intraoperative Results

After partial resection of the intended facet joint and the inner wall of the pedicle using a high-speed burr and a straight UBC, the edge of the dura mater and the outward extended ossification can be fully exposed. Then, the ventral compression was gradually removed by an angled UBC under direct vision, after which the retracted spinal cord and reduced dural tension can be observed.

Clinical Outcomes

The mean operation time was 153.4 ± 53.4 min (77–242 min), with a mean intra-operative blood loss of 465.3 ± 155.8 ml (240–780 ml). The average hospital stay time was 14.3 ± 4.7 days (9–25 days) and the mean follow-up duration was 20.8 ± 8.8 months (12–39 months).

Functional Results

The Japanese Orthopaedic Association (JOA) score was used to quantitatively evaluate postoperative neurological improvement. The mean preoperative JOA score was 4.5 ± 1.6 in the series. At the last follow-up, the mean JOA score improved to 9.0 ± 1.8 , representing a significant improvement over the preoperative score ($F = 105.446$, $p < 0.01$). According to Hirabayashi's classification, eight cases were rated as excellent, four as good, two as fair, and one as unchanged. The average recovery rate was 70.9%.

Illustrative Case Presentation

Calcified Giant Herniated Thoracic Disc (T8–9)

A 51-year-old man (case 3) had a 1-year history of numbness and weakness in both lower extremities. His symptoms gradually developed in the 6 months and he presented with gait disturbance. A neurologic examination revealed grade 3 lower extremity muscle strength, bilateral patellar, Achilles tendon hyperreflexia, and a bilaterally positive Babinski sign. CT and magnetic resonance imaging (MRI) showed a giant

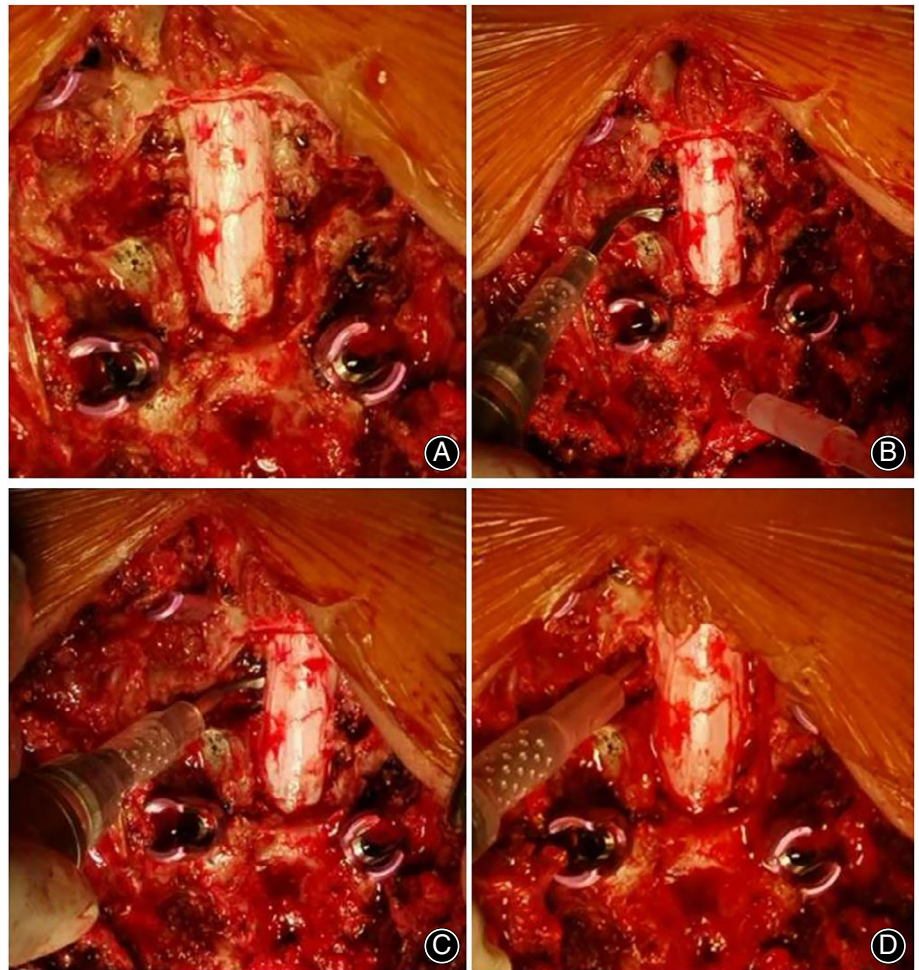


Fig. 5 Intraoperative images of anterior ossification resection. (A) Resect the inferior facet joints of the upper vertebra, the inner wall of the bilateral pedicles and the partial superior facet joints of the lower vertebra. (B–D) Remove the anterior ossification with an angled UBC

thoracic disc herniation with calcification at the T8–9 segment. A standard surgical procedure was performed as described in the method section, and the lesion showed calcium deposition. The neurological symptoms of the patient improved after the operation, and the JOA score increased from 7 points before the operation to 11 points at the last follow-up (Figure 6: Illustrative case presentation. Preoperative sagittal bone window [A], axial bone window [B], and axial soft tissue window [C] CT images showing massive thoracic disc herniation with calcification and calcium deposition at the T8–9 segment. Preoperative sagittal [D] and axial [E] MRI scans [T2] demonstrating spinal cord compression at the T8–9 segment. Postoperative sagittal [F] and axial [G] CT images demonstrating complete resection of the calcified giant disc and calcium deposition at the T8–9 segment. CT scan [H], sagittal [I], and axial [J] MRI scans [T2] at 12 months postoperatively showing sufficient decompression and bony fusion at the T8–9 segment).

Severe Ossification of the Posterior Longitudinal Ligament (T6–7)

A 54-year-old woman (case 5) presented with severe gait disturbance and incomplete bladder incontinence for 4 months. When she was admitted to the hospital, her JOA score was

1 point. Imaging studies revealed continuous OPLL from T5 to T7, compressing the spinal cord anteriorly, especially at T6–7. While physical examination demonstrated decreased muscle strength in lower limbs, hypoesthesia below the navel, and hyporeflexia of knee jerks. Laminectomies and circumferential decompression were planned at T6–8 and T6–7 via a posterior approach. She underwent the same surgical procedure as in case 3, followed by a posterolateral fusion in the T6–11 segment due to osteoporosis. After surgery, the patient's neurological symptoms significantly improved, with a JOA score of 8 at the last follow-up (Figure 7: Illustrative case presentation. Preoperative sagittal [A] and axial [B] CT images showing continuous OPLL at the T6–T7 level. [C] A preoperative sagittal MRI scan [T2] demonstrated severe spinal cord compression at the T6–7 level. Postoperative sagittal [D] and axial [E] CT images demonstrating complete removal of the OPLL at the T6–7 level. [F] CT scan at 12 months postoperatively showing sufficient decompression and bony fusion at the T6–7 segment).

Severe Ossification of the Posterior Longitudinal Ligament (T11–12)

A 53-year-old woman (case 15) was referred to our hospital with a 22-month history of progressive numbness in the

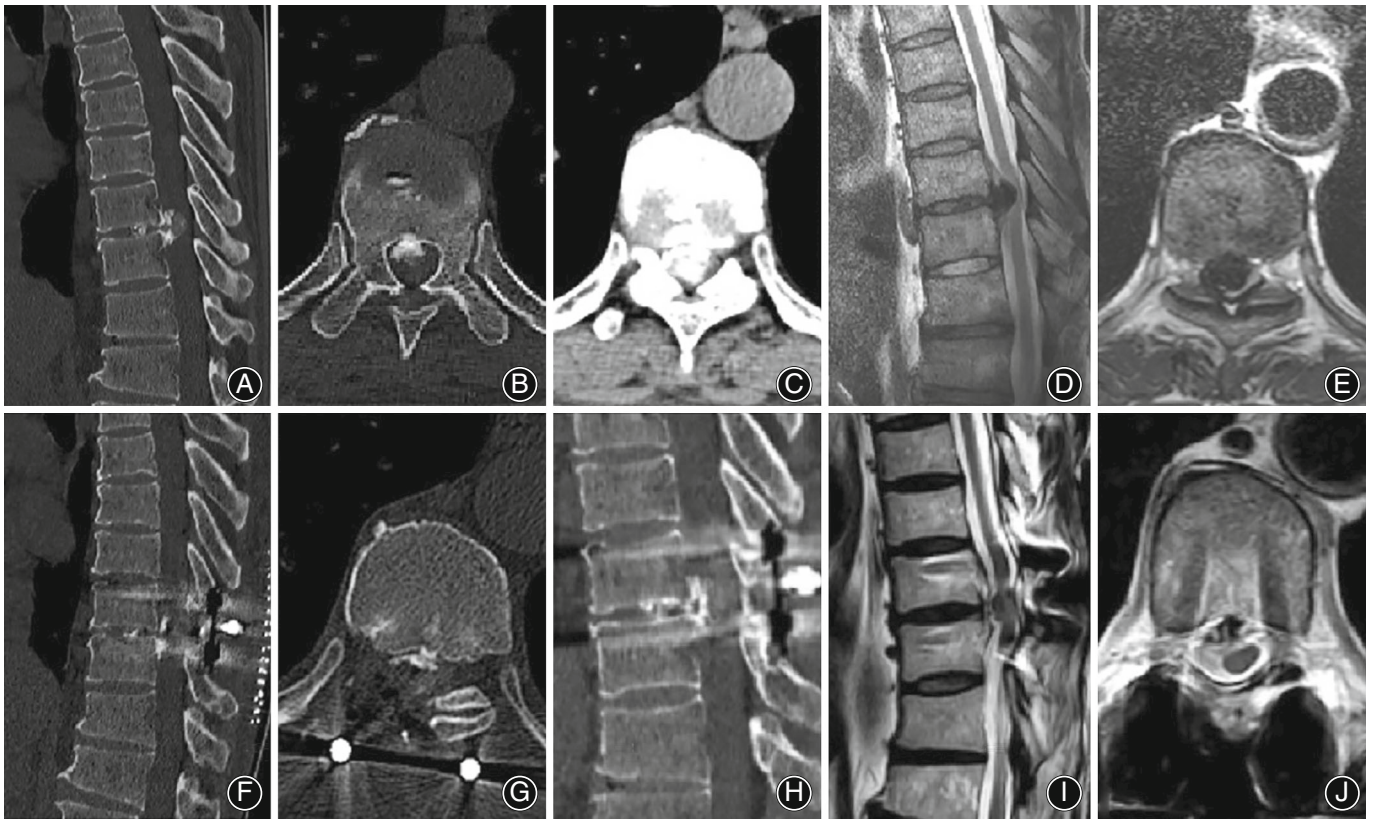


Fig. 6 Illustrative case presentation (case 3). Preoperative sagittal bone window (A), axial bone window (B), and axial soft tissue window (C) CT images showing massive thoracic disc herniation with calcification and calcium deposition at the T8-9 segment. Preoperative sagittal (D) and axial (E) MRI scans (T2) demonstrating spinal cord compression at the T8-9 segment. Postoperative sagittal (F) and axial (G) CT images demonstrating complete resection of the calcified giant disc and calcium deposition at the T8-9 segment. CT scan (H), sagittal (I), and axial (J) MRI scans (T2) at 12 months postoperatively showing sufficient decompression and bony fusion at the T8-9 segment

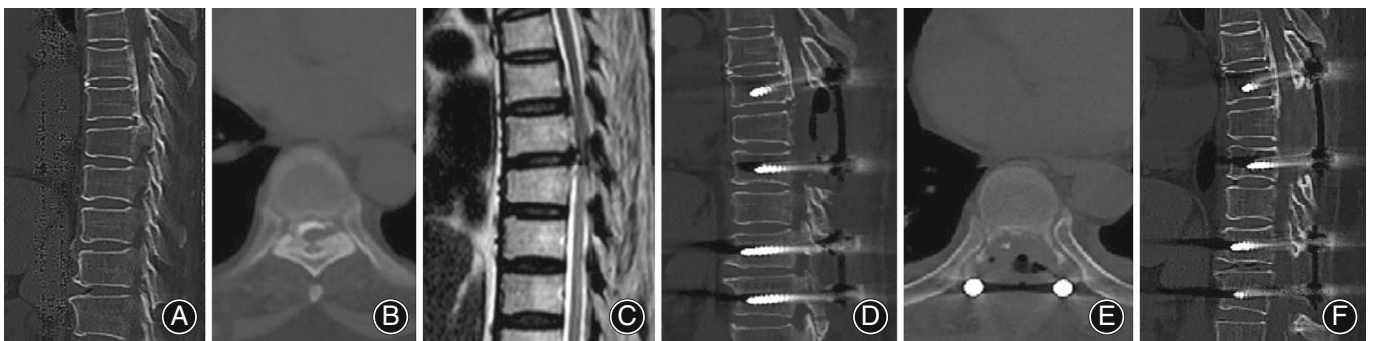


Fig. 7 Illustrative case presentation (case 5). Preoperative sagittal (A) and axial (B) CT images showing continuous OPLL at the T6-7 level. (C) A preoperative sagittal MRI scan (T2) demonstrated severe spinal cord compression at the T6-7 level. Postoperative sagittal (D) and axial (E) CT images demonstrating complete removal of the OPLL at the T6-7 level. (f) CT scan at 12 months postoperatively showing sufficient decompression and bony fusion at the T6-7 segment

right lower limb. She felt weak when walking for 10 months. Examination revealed slightly decreased muscle strength and hypermyotonia of the right lower extremity. CT and MRI

showed scattered OPLL at T11-12 and L1-L2 segments and spinal cord compression. Laminectomies at T11-L2 and circumferential decompression as described above at T11-12

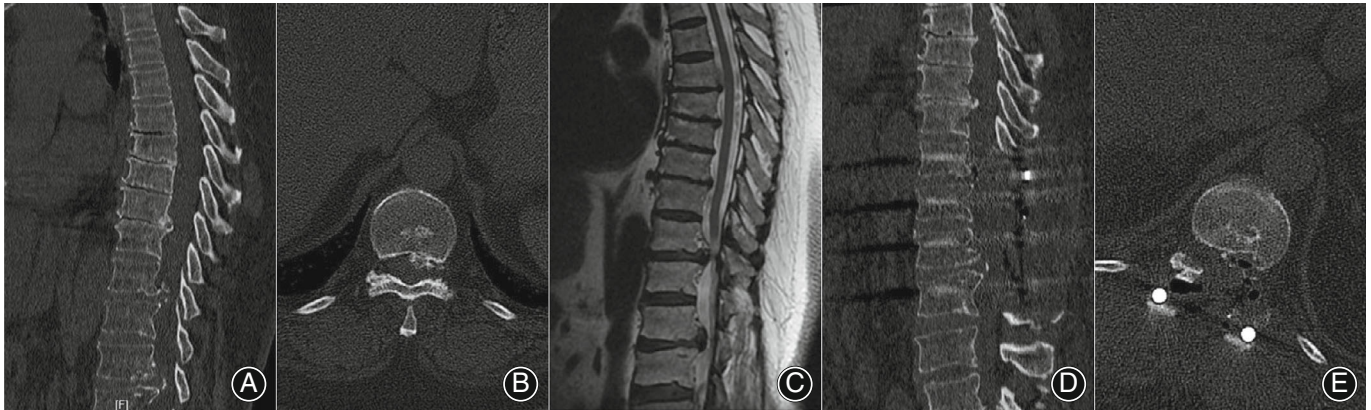


Fig. 8 Illustrative case presentation (case 15). Preoperative sagittal (A) and axial (B) CT images showing scattered OPLL at T11–T12 and L1–L2 segment. (C) Preoperative sagittal MRI scan (T2) showing significant compression at the T11–T12 segment. Postoperative sagittal (D) and axial (E) CT images showing the ossified PLL at the T11–T12 segment has been removed

were carried out. After surgery, the patient's neurological symptoms improved and the JOA score increased from 6 points preoperatively to 10 points until the last follow-up (Figure 8: Illustrative case presentation. Preoperative sagittal [A] and axial [B] CT images showing scattered OPLL at T11–12 and L1–L2 segments. [C] Preoperative sagittal MRI scan [T2] demonstrating significant compression at the T11–12 segment. Postoperative sagittal [D] and axial [E] CT images showing the ossified PLL at the T11–12 segment have been removed).

Complications

There was no direct nerve root or spinal cord injuries during the operation. Intraoperative CSF leakage occurred in two of 15 cases (13.3%), evidenced by pale blood and large drainage, in which both exhibited dural tears due to the severe adhesion between the ossification and the dura mater. Those two patients were treated with bed rest and compressive dressing after removing drainage on the twelfth day postoperatively. CSF leakage did not result in any neurologic degradation. Still, it was associated with patient discomfort, such as dizziness, headache, nausea, and/or vomiting, which mostly occurred 2–5 days after the operation and lasted approximately 3–5 days. Two patients (13.3%) had apparent unilateral intercostal neuralgia, which may be attributed to the traction of the nerve roots. The symptoms disappeared completely within 2 months.

Acute neurological deterioration was encountered postoperatively in one patient (6.7%). Hyperbaric oxygenation and methylprednisolone were intravenously administered immediately; muscle strength gradually improved in 5 days and reached the preoperative level half a year after the surgery. There was no evidence of late postoperative neurologic deterioration or persistent aggravation of paralysis. There were no vascular complications or pleural damage.

Discussion

Since the 1990s, circumferential decompression has been widely used to treat various spinal disorders. It results in favorable surgical outcomes compared to other procedures due to its effectiveness in removing the anterior ossification^{1,12}. To our knowledge, no consensus about the standard surgical procedure for thoracic circumferential decompression has been achieved.

Current Status of Traditional Circumferential Decompression

Technically, to get enough space for the operation, almost all traditional circumferential decompressions involve the process of resecting bilateral pedicles, the transverse processes, the medial ribs, and part of the posterior vertebral body. Afterward, a “culvert” is generated after resecting part of the posterior vertebral body with a high-speed burr^{19,23,24}, allowing greater operational space and providing an oblique angle to perform the ventral spinal operation without retracting the dura. To directly visualize the targeted ossification, the ligated thoracic nerves may need to be lifted²⁴. These processes significantly increase the operating time, blood loss, and surgical risk.

With the application of the ultrasonic bone curette (UBC) for circumferential decompression, the improvement rate of spinal cord function in patients was much better, and the probability of spinal cord function deterioration was significantly reduced^{13,19}. However, as a result of ventral adhesion separation of the dural sac and the surgical instrument prying anterior ossification, electrophysiological early warning events occurred sometimes^{16,17}. Sun *et al.* augmented the surgical procedure by maintaining the last thin layer of ossification rather than penetrating it, reducing the incidence of UBC-related nerve root injuries significantly²², while Tang *et al.* suggested breaking the distal end of the plaque to press it down slightly and separating the adhesion with direct

vision under the microscope to minimize disturbance to the spinal cord¹⁷. Despite this, surgical instruments are still used to gouge or rotate the ossification beneath the spinal cord.

Advantages and Pitfalls of the Novel Circumferential Decompression

Making use of the structural features of the angled UBC, there are several advantages to this surgical approach: (i) by partial resecting the facet joints and the inner wall of the pedicles, the angled head was able to remove the ventral ossification in a smaller space while the transverse processes, costotransverse joints, medial ribs, and posterior vertebral body of the involved levels are all preserved, which helps to maintain spinal stability and an intact pleura, further reducing the operation time and blood loss; (ii) the angled inserts are effective in cutting ossification beneath the spinal cord, which cannot be achieved with conventional rotating burrs at such rare angles. Regarding the adhesion between ossification and the ventral aspect of the dura mater, an appropriate angled UBC was used to grind the ossified lesions as thin as possible instead of exfoliating them; thus, the probability of dural tear and spinal cord injury is significantly reduced; (iii) the spinal cord disturbances could be significantly reduced because no processes were prying or rotating the ossification on the ventral side of the spinal cord.

Despite these, this technique was accompanied by several difficulties and pitfalls: (i) it sometimes lacked sufficient visual field for the operation since the posterior structures of the vertebral body were only partially removed, especially when the ossification was located in the middle of the ventral part of the spinal cord. If necessary, the thoracic nerve root could be ligated to increase the visual field; (ii) special attention must be paid to operating the angled ultrasonic knife head because of its greater likelihood of breaking than the straight one during the bone-cutting process. Furthermore, it is preferable to use appropriate heads to grind and divide the ossification in complicated cases as the circumstances may require; (iii) it is highly recommended that the curette be used intermittently to dissipate the heat that stimulates the dura mater of the spinal cord.

Efficacy and Safety of the Novel Circumferential Decompression

Neurological deterioration is a severe complication of thoracic spine decompression surgery. In some previous reports, in patients who underwent circumferential decompression and fusion, the rate of neurological deterioration was 33% (10 of 30 patients)¹⁸ and 34.6% (nine of 26 patients)¹³. However, we encountered only one (6.7%) who experienced transient neurological deterioration and gradually recovered after discharge. The event might be related to the spinal cord ischemia–reperfusion injury resulting in the degradation of functional recovery capacity. Studies have shown that CSF leakage was an independent predisposing factor for poor neurological recovery, which may be another explanation as the patient had an intraoperative dural tear by accident^{15,25}.

Nevertheless, the rate in this study is lower than in the above-mentioned studies.

It is noteworthy that CSF leakage in circumferential decompression commonly occurs. Hu *et al.* reported that the total proportion of CSF leakage during circumferential decompression was 38.5%. Hu *et al.*¹³ reported that the total proportion of CSF leakage for circumferential decompression was 38.5%. Chen *et al.*¹⁵ found that 33.3% of patients who underwent a novel “IV + V + VI” technique developed CSF leakage. In our study, only two out of 15 patients had CSF leakage, leading to an incidence of 13.3%, which is significantly lower than in previous literature.

In this study, the mean blood loss was 463.5 ± 155.8 mL with an average operation time of 153.4 ± 53.4 min, which was significantly decreased compared with previous studies^{19,23}. It can be attributed to the less bone removal that no resection of the middle and posterior spinal column as well as transverse processes, costotransverse joints, and medial ribs during the operation, while the clotting effect of UBS worked a lot. To achieve significant hemostasis, we found that the flexible application of hemostatic gauze, a gelatin sponge, and particularly bipolar coagulation was much more important.

In terms of neurological recovery, around 80% of the patients had an excellent or good rate of improvement in spinal cord function, and only one experienced temporary neurological deterioration but obtained acceptable clinical results after conservative treatment. Before surgery, the average JOA score improved from 4.5 ± 1.6 to 9.0 ± 1.8 at the last follow-up. The average recovery rate was 70.9%, higher than the results reported in previous circumferential decompression surgeries^{8,13,14,18,19,26}.

Limitations

First, we present a retrospective study that lacks randomization between procedures and no control group. Second, this study did not include the morphometric data of the anterior ossification block, and the indications of surgical procedures for different conditions were not discussed. Third, regardless of the number of laminectomy segments, we only recruited patients who underwent one level of circumferential decompression to illustrate this surgical approach. Thus, the selection bias of patients may lead to significant differences in recovery rates. Fourth, the sample size in this study was relatively small. Future studies with more patients are warranted to fully elucidate the potential advantages and complications of the technique.

Conclusion

Circumferential decompression assisted by angled UBC is a safe, effective, and technically feasible method for improving thoracic myelopathy resulting from severe anterior ossification. The procedure preserved more posterior elements of the involved levels, maintaining an intact pleura and reducing the operation time and blood loss. Furthermore, using UBC allowed for greater intraoperative control and improved safety when cutting around the spinal cord.

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