CLINICAL ARTICLE

Circumferential Decompression *via* a Modified Costotransversectomy Approach for the Treatment of Single Level Hard Herniated Disc between T₁₀–L₁

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Objective: To describe a novel surgical strategy for circumferentially decompressing the T₁₀–L₁ spinal canal when impinged upon by single level hard thoracic herniated disc (HTHD) *via* a modified costotransversectomy approach.

Methods: This is a retrospective review of 26 patients (17 men, 9 women; mean age at surgery 48.5 years, range 20–77 years) who had undergone single level HTHD between T₁₀–L₁ by circumferential decompression *via* a modified costotransversectomy approach. The characteristics of the approach are using a posterior midline covered incision, which keeps the paraspinal muscle intact and ensures direct visualization of circumferential spinal cord decompression of single level HTHD between T₁₀–L₁.

Results: The average operative time was 208 ± 36 min (range, 154–300 min), mean blood loss 789 ± 361 mL (range, 300–2000 mL), mean preoperative and postoperative mJOA scores 5.2 ± 1.5 and 9.0 ± 1.3, respectively ($t = 19.7$, $P < 0.05$). The rate of recovery of neurological function ranged from 33.3% to 100%. The ASIA grade improved in 24 patients (92.3%) and stabilized (no grade change) in two (7.7%). MRI indicated that the cross-sectional area of the dural sac at the level of maximum compression increased from 45.0 ± 5.8 mm² preoperatively to 113.5 ± 6.1 mm² postoperatively ($t = 68.2$, $P < 0.05$). Anterior tibialis muscle strength of the 15 patients with foot drop had a mean recovery rate of 95% at final follow-up. One patient who resumed work early after the surgery showed a significantly augmented Cobb angle. One patient had transient postoperative cerebrospinal fluid leakage. No patients showed neurological deterioration.

Conclusions: This procedure achieves sufficient direct visualization for circumferential decompression of the spinal cord *via* a posterior midline covered costotransversectomy approach with friendly bleeding control and without muscle sacrifice. It is a reasonable alternative treatment option for thoracic myelopathy caused by single level HTHD between T₁₀–L₁.

Key words: Circumferential decompression; Hard thoracic herniated disc; Modified costotransversectomy approach

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Introduction

Herniated thoracic discs (HTDs) are a rupture of the fibrocartilaginous material (annulus fibrosis) that surrounds the thoracic intervertebral discs. Asymptomatic thoracic disc herniation is common, with a prevalence of 7%–15%¹ whereas symptomatic HTDs are relatively rare in comparison with cervical and lumbar herniated discs, accounting for only 0.25%–0.57% of all disc herniations.^{1–4} Because of the variety of symptoms and lack of a characteristic presentation pattern, the diagnosis of this condition is often unexpected or delayed.⁵ Patients with HTDs may be mistakenly diagnosed with cholecystitis, pancreatitis, or cardiac or intrathoracic disorders.^{5,6} Thus, by the time the diagnosis is confirmed, the patients are often at advanced stage of the disease and the discs are often gigantic or hard or both.⁵ HTD is classified as hard if there is evidence of at least partial calcification either on imaging studies or intraoperatively, and soft if there is no evidence of calcification.² Hard thoracic herniated discs (HTHD) occur most frequently during the fourth and fifth decades of life and there is a marked female predominance.^{1,7–10} CT scans and MRI show an ossified or calcified herniation or both. Pathologic examination may show either lamellar bone organized in trabeculae containing predominantly fatty marrow or the presence of calcium deposits.¹⁰ These lesions may be adherent to and even erode through the dural sac over time.¹¹ For this reason, thoracic myelopathy caused by HTHD is often progressive and responds poorly to conservative treatment.^{12,13}

Furthermore, HTHDs occurs frequently at T₁₀–L₁.^{1,7,10,14–19} The typical characteristics of their gross pathological structure include direct anterior cord compression, usually accompanied by posterior vertebral endplate osteophytes, and wedge-shaped vertebrae.^{10,12,14,20–23} Technical challenges in the decompression of HTHD are therefore accessing the anterior border of the vertebrae for anterior decompression while ensuring safe decompression of the spinal cord and control of copious epidural venous bleeding under direct visualization, and avoiding late recompression from progressive kyphosis.^{12,21,24,25}

To date, a variety of surgical approaches have been described to treat symptomatic HTHD, including posterior (laminectomy), posterolateral (costotransversectomy and transpedicular), anterior (transthoracic), anterolateral (lateral extracavitary) and video-assisted thoracoscopic surgical procedures. These surgeries do not always achieve satisfactory results and have potential morbidities.^{5,10,12,14,20,21,26}

In 1934, Mixter and Bar were the first to report operative treatment of HTHD by laminectomy; a standard laminectomy approach has since been abandoned because its results are disappointing, with major morbidity rates of 18%–75% and mortality rates of up to 50%.^{27,28,49} Although a conventional costotransversectomy approach can achieve anterior decompression, it cannot ensure safe decompression

of the spinal cord, control of copious epidural venous bleeding under direct visualization or avoidance of late recompression from progressive kyphosis.^{16,29,30} Simpson *et al.* evaluated the results of surgery *via* a modified costotransversectomy approach and concluded that the current costotransversectomy approach minimizes or avoids most of these possibilities while providing adequate visualization of the pathology and neural structures.²⁹ The anterior approach carries potential morbidity associated with thoracotomy, such as pneumothorax, pleural effusion, chylothorax, atelectasis, and prolonged mechanical ventilation; however, it does provide direct visualization.¹¹ Arts *et al.* recently compared the outcomes of patients with symptomatic thoracic disc herniations treated *via* an anterolateral mini-transthoracic approach (TTA) versus posterior transpedicular discectomy.⁴⁴ They reported that only 50% of the patients treated by mini-TTA and 37% of the transpedicular group had postoperative improvement by at least one grade on the ASIA scale. The duration of surgery, blood loss, hospital stay and complication rate were significantly greater in patients treated with mini-TTA and were mainly related to the size and consistency of the herniated disc. These findings are consistent with those of others.³¹ Gille *et al.* retrospectively reported unsatisfactory results in a series of 18 HTHDs operated on by thoracoscopy.¹⁰ No separating plane was found during surgery in 11 of these patients. Surgery was complicated by a dural tear, which is associated with a high risk of cerebrospinal fluid (CSF) fistula, in seven patients and four of these seven required surgical revision. Thoracoscopic discectomy is therefore indicated only for small lateral and soft disc herniations.^{11,32} Cho *et al.* introduced a minimally invasive oblique paraspinal approach using 3-D navigation and tubular retractors with the aid of robotic holder, which they considered unsuitable for sequestered, calcified or hard disc herniations.³³ Similarly, the posterior transdural approach reported by Moon *et al.* offers a surgical option for patients with thoracic paracentral soft discs but may also be unsuitable for HTHDs³⁴: HTHDs usually require direct and extensive visualization.

Unlike the modified costotransversectomy approach used by Simpson *et al.*, we herein modified the conventional costotransversectomy approach by using a posterior midline covered incision, which keeps the paraspinal muscle intact and ensures direct visualization of circumferential spinal cord decompression of single level HTHD between T₁₀–L₁.

The purposes of this present study were: (i) to introduce a new surgical strategy for circumferentially decompressing the T₁₀–L₁ spinal canal impinged on by single level HTHD *via* a modified costotransversectomy approach; (ii) to evaluate and analyze the outcomes of these modifications; (iii) to compare it with other strategies by evaluating its advantages and disadvantages; and (iv) to determine whether it is an effective procedure for the treatment of single level HTHD between T₁₀–L₁.

Materials and Methods

Patients

Data on all patients with thoracic myelopathy caused by HTHD who had undergone our modified surgical procedure, circumferential decompression *via* a modified costotransversectomy approach, between January 2005 and December 2012 in Tianjin Medical University General Hospital were retrospectively reviewed. The following exclusion criteria were applied: thoracic myelopathy involving more than one level, diagnosis of soft thoracic herniated disc, surgery *via* an anterior approach, circumferential spinal cord decompression through a posterior approach, history of trauma and history of spinal tumor. In all, 26 patients (17 men and 9 women) met the criteria. All were diagnosed as having single level HTHDs between T₁₀–L₁. According to radiographic data, 20/26 lesions were centrally located and six were paracentral. Five patients had lesions at T₁₀–T₁₁, 11 at T₁₁–T₁₂ and 10 at T₁₂–L₁. Fifteen patients with single level HTHD between T₁₀ and L₁ had associated foot drop (unilateral in six cases and bilateral in nine). The mean age of the patients at surgery was 48.5 years (range, 20–77 years). The mean duration of follow-up was 46.1 months (range, 30–60 months).

Neurodiagnostic Studies and Imaging Data

The diagnosis of thoracic myelopathy was determined by thorough neurological examinations and subsequent imaging studies, including plain radiography, CT and MRI. Local kyphosis was evaluated by the Cobb angle in MRI sagittal views before surgery, 3 months after surgery and at the final follow-up (mean, 46.1 months). The cross-sectional area of the dural sac at the level of compression was quantified preoperatively and postoperatively with surface-rendering software.

Surgical Technique

Under general anesthesia, the patient was placed in a lateral decubitus position with vertical bolsters on the involved vertebra to help in achieving sufficient lateral exposure.²⁰ The choice of left or right lateral decubitus position was made on the basis of neurological symptoms, localization and consistency of the herniated disc, presence of spinal deformity and presence of osteophytes. Patient-related factors such as body habitus and other medical comorbidities could also influence the choice of approach.^{5,14} Spinal cord activity was recorded with transcranial electric motor and somatosensory evoked potentials. The appropriate surgical level was confirmed by intraoperative radiography.

Surgical Approach

A curved incision ranging from the third vertebral cephalic level to the third vertebral caudal level and centered at the herniated level, was made lateral to the vertebral column. The high apex of the curve was about 10 cm lateral to the posterior midline at the herniated disc level (Figs 1A and 2A). The skin flap was retracted contralaterally just beyond the spinous processes. The attachments of the trapezius and

latissimus muscles on the incision side were separated from the spinous processes and then retracted laterally (Figs 1B and 2B). The residual bilateral paraspinal muscles within the length of the incision were detached from the lamina and articular joints, after which the paraspinal muscles on the incision side were thoroughly detached from the vertebral arch (Figs 1C and 2C). After medial traction of the erector spinae on the incision side, the two ribs and transverse processes adjacent to the herniated disc were resected, thus completing the surgical approach (Figs 1D and 2D).

Circumferential Decompression

Circumferential spinal cord decompression was performed in two steps: posterior semi-circumferential spinal cord decompression by en bloc resection of upper facet joints and anterior semi-circumferential spinal cord decompression by discectomy with vertebral wedged resection.

Upper facet joints en bloc resection was performed as reported previously.^{35,36} In brief, to achieve posterior exposure, the erector spinae were retracted laterally bilaterally, after which posterior decompression was achieved as follows: the spinous processes, inferior facet joints, and laminae of the involved segments were resected, then the bony junction between the pedicle and upper facet joint was detached with a bone rongeur or motor burr *via* the pedicle-ossification tunnel. Next, the ligamentum flavum together with the upper facet joint was gently lifted en bloc from the dura mater using a nerve stripper.³⁵ After that, the dural sac in the herniated disc level bulged posteriorly, having been freed from the posterior bony structures (Figs 1E and 2E). Posterior semi-circumferential spinal cord decompression was thus completed.

For the anterior semi-circumferential spinal cord decompression, the paraspinal muscles on the incision side were medially retracted to achieve anterolateral exposure and anterior decompression performed as follows. First, the sharply protruding HTHD and its compressed lateral aspect of the dura was exposed (Fig. 1F). Curettage into the mid-portion of the disc was performed, undermining the nucleus pulposus and annulus, but provisionally preserving the hard shell of the HTHD, which was adherent to the dural sac. Next, just beneath the posterior cortex of the lower and upper vertebrae attached to the herniated disc, two posterior wedge-shaped bony elements were resected under direct visualization. This thoroughly undermined the hard shell of the HTHD and the integrated two adjacent bony spurs. The junction between the spur and posterior cortex of the two involved vertebrae was then disrupted, the spur resected and the hard shell of the HTHD thoroughly freed (Fig. 1G). Adhesions between the hard shell of the HTHD and the dura were dissected gently and sharply, and the bleeding meticulously controlled. With the resultant complete separation between the hard shell of the HTHD and the dura, anterior semi-decompression was completed and circumferential decompression was achieved (Figs 1H and 2F).

In cases in which the bony deficiency was more than a quarter of the vertebral endplate, the autogenous ribs were

Fig. 1 Case 24 (57-year-old woman). Intraoperative photographs of circumferential spinal cord decompression via a modified costotransversectomy approach. (A) A curved incision (black line) is made. (B) The trapezius (white arrow) and latissimus muscles (black arrow) are separated and retracted laterally. (C) The paraspinal muscles (white arrows) are detached bilaterally. (D) Following medial traction on the paraspinal muscle, the ribs (white arrow) adjacent to the herniated disc are exposed and then resected. (E) After achieving posterior semi-circumferential decompression, the dural sac (white arrow) bulges posteriorly and can be observed directly. (F) The protrude HTHD (white arrow) and its compressed lateral aspect of the dura (black arrow) are exposed by medial traction on the paraspinal muscle (black triangle). (G) After resecting the spur, the hard shell of HTHD (white arrow) is thoroughly freed. (H) The white tube (white arrows) shows that circumferential spinal cord decompression has been achieved.

resected and implanted to promote the bony fusion. If financially feasible, instrumentation such as pedicle screw systems was used to avoid progressive kyphosis.

Closure and Drainage

Meticulous closure of the paraspinal muscles, deep fascia and skin was performed with continuous pressure on the wound. An epidural drain was always placed for posterior wounds, the drains being removed on the second postoperative day.

Postoperative Evaluation

Postoperative follow-up ranged from 30 to 60 months (mean, 46.1 months). Outcomes were evaluated according to a recovery scale based on the modified Japanese Orthopedic Association (mJOA) scoring system (full score = 11 points; Table 1) and ASIA grading system (A = complete; B, C, D = incomplete, E = normal; Table 2). The scores were calculated

before surgery, 3 months after surgery, and at the final follow-up visit. The degree of recovery was calculated using the following formula: recovery ratio (%) = (postoperative score – preoperative score)/(11 – preoperative score) × 100%. The recovery rate was then used to define the surgical outcome as follows: excellent (≥75%), good (50% to 75%), fair (25% to 50%), or poor (<25%).

We used the Manual Muscle Test to evaluate the anterior tibialis muscle strength according to the Medical Research Council scale (Table 3).³⁷ Briefly, foot drop was defined as when TA muscle strength was graded as <3 of a possible 5. TA strength was evaluated in a standardized way before surgery, 3 months after surgery and at the final follow-up by three experienced independent orthopedic surgeons in an independent, blinded manner. The weaker strength was used for analysis in patients with bilateral foot drop. Surgical outcomes were classified according to the postoperative muscle strength of the TA as excellent when

Fig. 2 Diagrammatic representation of circumferential spinal cord decompression *via* a modified costotransversectomy approach. (A) A curved incision (black line) is made. (B) The trapezius (white arrow) and latissimus muscles (black arrow) are separated and retracted laterally. (C) The paraspinal muscles (black arrows) are detached bilaterally. (D) Following medial traction of the paraspinal muscle, the ribs (white arrow) adjacent to the herniated disc are exposed and then resected. (E) Posterior semi-circumferential decompression. The spinous processes, inferior facet joints and laminae of the involved segments are resected. (F) Anterior semi-circumferential decompression. (i) A curettage is made into the midportion of the disc; (ii) two posterior wedge-shaped bony elements are resected; (iii) the posterior spur is resected and (iv) adhesions between the hard shell of the HTHD and dura are dissected.

TABLE 1 Summary of the mJOA scoring system

Neurological status	Score
Motor function of lower extremity	
Cannot walk	0
Needs cane or aid on flat ground	1
Needs cane or aid only on stairs	2
Can walk without cane or aid, but slowly	3
Normal	4
Sensory deficit in lower extremity	
Apparent sensory loss	0
Mild sensory loss	1
Normal	2
Sensory deficit in trunk	
Apparent sensory loss	0
Mild sensory loss	1
Normal	2
Sphincter dysfunction	
Unable to void	0
Severe disturbance	1
Mild disturbance	2
Normal	3

muscle strength had recovered to grade 4 or 5, good when it had recovered to grade 3, fair when it had improved but remained below 3, and poor when there was no improvement in muscle strength at the final follow-up.³⁸ The recovery rate of muscle strength was evaluated as follows: recovery ratio (%) = (grade at final follow-up) – (grade before operation)/(5 – grade before operation) × 100%. Grade 3 was treated as grade 2.5 in this equation.³⁸

Statistical Analysis

Statistical analysis was performed using Student's *t*-test. *P* values <0.05 were considered statistically significant. Results are presented as the mean ± standard deviation (SD). All data were analyzed using SPSS for Windows.

Results

Between January 2005 and December 2012, circumferential spinal cord decompression *via* a modified costotransversectomy approach was performed on all 26 study

TABLE 2 American Spinal Injury Association impairment scale

Grade	Characteristic
A	Complete: No motor or sensory function is preserved in the sacral segments S4–S5
B	Incomplete: Sensory, but not motor, function is preserved below the neurological level and includes the sacral segments S4–S5
C	Incomplete: Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3
D	Incomplete: Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more
E	Normal: Motor and sensory function is normal

TABLE 3 Manual muscle test according to the Medical Research Council scale³⁷

Grade	Characteristic
0	No contractility
1	Evidence of slight contractility. No joint motion
2	Complete range of motion without gravity
3	Partial range of motion against gravity
4	Complete range of motion against gravity
5	Complete range of motion against some resistance
5	Complete range of motion against full resistance

subjects. All required data were recorded before surgery, 3 months after surgery and at the final follow-up (mean, 46.1 months).

General Results

The average operative time was 208 ± 36 min (range, 154–300 min) and mean blood loss 789 ± 361 mL (range, 300–2000 mL). Autogenous resected ribs grafts were used to assist bony fusion in 16 patients and instrumentation was used to avoid worsening the Cobb angle in 18 patients.

One case had a lesion that was considered to be intradural by the surgeon, a dural tear having occurred during resection of the herniated disc. In 12 cases the HTDHs were adherent to the dura sac. The lesions were successfully separated in 12 cases, dural tears being avoided by removing the herniated disc meticulously under direct visualization and by preserving a bony fragment of the interface of the herniated disc with the dura mater if they were too strongly adherent to separate safely. In all cases, spinal-cord decompression was verified by both intraoperative and postoperative imaging.

No patients had exacerbation of radiculopathy or myelopathy postoperatively; indeed, initial symptoms, including

paraparesis, sensory changes and truncal or back pain were significantly alleviated postoperatively.

Radiographic Improvement

Preoperative plain radiography changes, included disc space narrowing, osteophytic spurs, disc space calcification and/or evidence of calcified disc material within the canal, were found in all cases. Preoperative CT and MRI showed ossified herniations in 15 cases and calcified herniations in 11. Preoperative MRI showed single-level areas of low signal intensity in the herniated thoracic discs in all case. Postoperative plain radiography and CT showed both complete resection of the lesions and adequate fixation in all cases. According to MRI, the cross-sectional area at the level of maximum compression of the dural sac increased from 45.0 ± 5.8 mm² preoperatively to 113.5 ± 6.1 mm² postoperatively ($t = 68.2$, $P < 0.05$) (Table 4). Preoperative and postoperative MRI indicated that surgery had achieved adequate decompression of the dural sac in all cases (Figs 3 and 4).

Improvement in Neurological Function

During follow-up, the neurological status of the 26 patients improved from a mean mJOA score of 5.2 ± 1.5 points (range, 2–8 points) preoperatively to 9.1 ± 1.3 points (range, 5–11 points) postoperatively ($t = 19.7$, $P < 0.05$; Table 4). The ASIA grade improved in 24 patients (92.3%), stabilized (no grade change) in two (7.7%) and worsened in none (0%). The rate of improvement in neurological function ranged from 33.3% to 100% ($68.75\% \pm 15.79\%$). The surgical outcome was excellent in 11 patients (42.30%), good in 14 (53.85%) and fair in one (3.85%). Thus, the outcomes indicated that surgical decompression had been achieved (Table 5).

TABLE 4 Clinical outcomes of 26 patients treated surgically for hard herniated thoracic disc (mean $\pm$ SD)

Variable	Pre	Post
Area (mm ²)	45.0 ± 5.8	113.5 ± 6.1
mJOA score	5.2 ± 1.5	9.1 ± 1.3
Cobb angle(instrumentation, °)	17.3 ± 2.7	18.0 ± 3.2
Cobb angle (no instrumentation, °)	18.0 ± 3.2	24.4 ± 8.6

mJOA, modified Japanese Orthopedics Association; post, post operation at final follow-up visit; pre, before surgery

Fig. 3 Case 24 (57-year-old woman). Preoperative (A) plain X-ray film, (B) axial CT, (C) sagittal CT, (D) axial T₂-weighted, (E) sagittal T₁-weighted and (F) sagittal T₂-weighted images of the HTHD (red arrows) are presented, showing the dural sac has been impinged upon by the protruding HTHD. Postoperative (G) plain X-ray film, (H) axial CT, (I) sagittal CT, (J) axial T₂-weighted, (K) sagittal T₁-weighted and (L) sagittal T₂-weighted images showing satisfactory decompression (red arrows).

Improvement in TA Muscle Strength

Tibialis anterior muscle strength preoperatively and at the final follow-up is shown in Table 6. Muscle strength improved by at least two grades in all patients and all patients with foot drop (15 cases, 100%) recovered to better than grade 3. In terms of functional motor recovery, overall surgical outcomes were as follows: excellent for 13 patients (86.67%), good for two (13.33%), and fair or poor for none (0%). The overall rate of recovery was 86%.

The mean values for pre- and postoperative kyphosis of the involved vertebrae in patients in whom instrumentation was used were $17.3^\circ \pm 2.7^\circ$ (range, 12.7° – 22.1°) and $17.5^\circ \pm 2.9^\circ$ (range, 12.8° – 22.1°), respectively; the mean

increase being only $0.2^\circ \pm 0.5^\circ$ ($t = 1.73$, $P > 0.05$). However, the mean values in patients who did not require instrumentation were $18.0^\circ \pm 3.2^\circ$ (range, 13.2° – 22.6°) and $24.4^\circ \pm 8.6^\circ$ (range, 16.8° – 44.3°), respectively; the mean increase being $6.4^\circ \pm 6.2^\circ$ ($t = 2.9$, $P < 0.05$, Table 4). Thus, all cases had satisfactory surgical outcomes and no patient had neurological deterioration.

Complications

In the one patient with postoperative CSF leakage, as reported previously, the drainage tube was removed on the second postoperative day. Transient CSF leakage usually stops after 8–10 days of conservative treatment with local

Fig. 4 Case 11 (20-year-old man). (A) Preoperative MRI showing the dural sac is compressed by a single-level thoracic herniated disc and bony fragments (red arrow). (B) Postoperative MRI showing the surgery has achieved adequate decompression of the dural sac (black arrow).

pressure. Only one patient, who resumed work early after the surgery, had a significantly augmented Cobb angle (Fig. 5). Because sufficient maximum decompression had been achieved and bony fusion was achieved later, there was no associated neurological deterioration in spite of the augmented Cobb angle.

At the final follow-up evaluation, no patients had wound infections, meningitis, recurrence of ossification in the operated segments or deterioration in initial symptoms (paraparesis, sensory changes and or truncal or back pain). All patients demonstrated bone fusion within 3–6 months postoperatively and had satisfactory neurological recovery, all being able to walk without a cane within a year.

Discussion

The surgical treatment of HTHDs between T₁₀–L₁ is challenging for many reasons, including frequently delayed or mistaken diagnosis because of the variety of symptoms and lack of a characteristic presentation pattern, the particularities of anatomic structures between T₁₀–L₁, and the multiplicity of surgical approaches.^{2,5,10,12–14,20,21,26,32,34,39,40} Furthermore, the direct anterior cord compression from the HTHD, adhesions between the HTHD and dural sac, posterior vertebral endplate osteophytes and wedge-changed vertebrae increase the surgical difficulties.^{10,12,14,20–23}

We have therefore introduced circumferential decompression via a modified costotransversectomy approach to treat single level HTHD between T₁₀–L₁. The initial symptoms were significantly alleviated postoperatively in all study subjects. Preoperative and postoperative MRI indicated that the surgery had achieved sufficient decompression of the dura sac. The mJOA scores and ASIA grades also showed that surgical decompression had been achieved.

In addition, only one patient, who had resumed work early, had a significantly augmented Cobb angle (Fig. 5).

Because sufficient maximum decompression had been achieved and bony fusion was achieved later, there was no associated neurological deterioration in spite of the augmented Cobb angle. Thus, this patient illustrates that bony fusion can be achieved after disc resection, even if the Cobb angle has been augmented. In our study, maximum decompression was attained in all cases and no patients showed neurological deterioration. We recommend that patients exercise with brace protection for 3 weeks, until bony fusion has been achieved.

As we have reported previously, foot drop can be caused by a single-level herniated disc between T₁₀ and L₁; our findings are consistent with those of Tokuhashi *et al.*, who reported three cases of T₁₂–L₁ disc protrusion with foot drop.^{38,41} In the present study, all patients with foot drop associated with single-level hard disc herniation between T₁₀ and L₁ showed excellent surgical outcomes after decompression, suggesting that this procedure provides satisfactory outcomes.

Traditional laminectomy and its modifications have gradually been abandoned because they do not completely decompress the spinal cord and can have unsatisfactory final outcomes because of the high early complication rate and recurrence of compression in some patients.^{21,36} Additionally, laminectomy involves some manipulation of the HTHD

TABLE 5 American Spinal Injury Association Scale categories of 26 patients surgically treated for hard herniated thoracic disc

Pre	Post					Total
	A	B	C	D	E	
A	0	0	1	1	0	2
B	0	0	0	3	1	4
C	0	0	2	9	6	17
D	0	0	0	0	3	3
E	0	0	0	0	0	0
Total	0	0	3	13	10	26

Post, post operation at the final follow-up visit; Pre, before surgery

TABLE 6 Anterior tibialis muscle strength of 15 patients surgically treated for hard herniated thoracic disc with foot drop

Pre	Post						Total
	0	1	2	3	4	5	
0	0	0	0	2	2	1	5
1	0	0	0	0	1	3	4
2	0	0	0	0	2	3	5
3	0	0	0	0	0	1	1
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
Total	0	0	0	2	5	8	15

Post, post operation at the final follow-up visit; Pre, before surgery

Fig. 5 Case 5 (28-year-old man). Postoperative MRI showing adequate circumferential decompression (red arrows). However, this patient, who resumed worked early, showed a significantly augmented Cobb angle with no associated neurological deterioration.

which, while being insufficient to cause mechanical damage, may interfere with blood supply to the cord.²⁹ Maiman *et al.* reported that it is difficult to remove a mass anterior to the spinal cord *via* a posterior approach.²¹ Although costotransversectomy, transpedicular, lateral extracavitary and video-assisted thoracoscopic approaches allow resection of anterior HTHD, this procedure cannot be performed smoothly and easily *via* these approaches, especially in subjects with central HTHD, because they provide limited visualization.^{10,21,26,29,42,43} The transpedicular approach is not been commonly performed because it has three potential drawbacks: (i) lack of direct visualization of decompression; (ii) inability to remove hard or central discs; and (iii) potential instability after removal of the pedicle.^{14,26,37} Similarly, traditional costotransversectomy, lateral extracavitary and video-assisted thoracoscopic approaches also provide limited visualization of decompression, which increases the potential risk of dural tears and copious epidural venous bleeding; hence, many surgeons favor anterior approaches.^{10,14,20,21,26,29} The transthoracic approach is recommended for treating thoracic disc herniations, especially in subjects with centrally located herniation.^{5,28,44} However, because of the particularities of the anatomy of the lower thoracic spine (T₁₀–T₁₂), it has a potential risk of pulmonary complications.^{14,21,45}

In our procedure, we modified the conventional costotransversectomy approach by using a posterior midline covered incision, which keeps the paraspinal muscle intact and ensures direct visualization of circumferential spinal cord decompression of single level HTHD between T₁₀–L₁.

Compared with other strategies for achieving anterior decompression of the dural sac, the modified costotransversectomy approach provides wide and direct visualization, which facilitates and simplifies the procedure. The direct visualization ensures safe spinal cord decompression and ability to control copious epidural venous bleeding. This approach not only preserves the paraspinal muscle, but also enables careful separation of the associated veins and arteries. To avoid late recompression from progressive kyphosis, we recommend using instrumentation to insure stability of kyphosis.

As is well known, direct anterior decompression by removing the entire HTHD and surgical outcomes are closely interrelated. However, few surgical approaches can achieve thorough and circumferential decompression.^{14,27,29,30,39,44,46–48} In our procedure, we have modified the conventional costotransversectomy approach for treating single level HTHDs, achieving both posterior semi-circumferential spinal cord decompression of upper facet joints by en bloc resection and anterior semi-circumferential spinal cord decompression by discectomy with wedged vertebral resection. We attribute the satisfactory neurological recovery in part to the adequate circumferential spinal cord decompression achieved.

Another technical challenge in surgical treatment is controlling copious epidural venous bleeding under direct visualization to ensure safe spinal cord decompression. As reported by Barbanera *et al.*, direct visualization of the dura is of paramount importance when dealing with giant discs, particularly if they are calcified.¹³ In our procedure, after achieving posterior semi-circumferential spinal cord decompression, we can perform anterior removal of an entire HTHD and osteophytes at a single level under direct visualization, thus achieving anterior semi-circumferential decompression of the dura without resistance from the posterior semi-wall. It is therefore easy to identify the bleeding points and to apply a gelatin sponge or electrocoagulation for hemostasis to reduce the amount of intraoperative blood loss.

Simpson *et al.* proposed that progressive kyphosis is responsible for late neural recompression.²⁵ Our procedure resulted in neurologic recovery in all study subjects. Patients in whom instrumentation was used had smaller Cobb angle changes than those in whom it was not used.

Our procedure achieves adequate direct visualization for the circumferential decompression of the spinal cord via a modified costotransversectomy approach, facilitating control of bleeding and preserving paraspinal muscles. We believe it is a reasonable alternative treatment option for thoracic myelopathy caused by single level HTHD between T₁₀–L₁.

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