Prospective Study

CT-Guided Posterolateral Full-Endoscopic Ventral Decompression for Single-Level Cervical Spondylotic Myelopathy

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Background: Percutaneous full-endoscopic surgery was recently developed for the treatment of cervical foraminal stenosis and posterolateral disc herniation. However, there are no studies involving endoscopic surgery to treat cervical spondylotic myelopathy (CSM).

Objectives: To observe the safety, feasibility, and efficacy of posterolateral full-endoscopic ventral decompression (PLEVD) via computed tomography (CT)-guided surgery in patients with single-level CSM.

Study Design: A prospective cohort study.

Setting: The First Affiliated Hospital of Gannan Medical College.

Methods: From May 2018 to August 2019, 21 patients with single-level CSM underwent CT-guided PLEVD. The posterolateral angle was measured during surgery. The neurologic condition was evaluated via the Japanese Orthopaedic Association (JOA) score and recovery rate, and a Visual Analog Scale (VAS) was used to measure pain relief. The maximum spinal canal diameter (MSCD) was measured on pre- and postoperative CT images.

Results: The mean length of follow-up was 11.3 ± 5.3 months. The average posterolateral angle was 36.0° ± 5.6°. The mean VAS score of limbs significantly decreased after surgery. The mean JOA score improved during the follow-up period. Nineteen of the 21 patients achieved good or excellent outcomes, and 2 patients had fair outcomes according to the JOA score 6 months after surgery. The average MSCD was enlarged from 0.55 ± 0.15 cm preoperatively to 1.02 ± 0.18 cm postoperatively.

Limitations: This study was nonrandomized and provides only preliminary clinical results for single-level CSM.

Conclusion: Under appropriate indications, PLEVD under CT guidance is an available and safe technique for treating single-level CSM.

Key words: CT-guided, posterolateral, full-endoscopic, cervical spondylotic myelopathy

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In recent decades, minimally invasive cervical spine surgical techniques have been introduced, including microendoscopic and full-endoscopic techniques (1-3). As reported in previous studies, both microendoscopic (4-6) and full-endoscopic techniques (7-9) have several merits, including reduced trauma, decreased hospital stays, and rapid recovery rates, and comparable results have been achieved with endoscopic surgery compared with traditional surgery (10-12). With the refinement of endoscopes and surgical instruments in recent years, the indications for full-endoscopic procedures are expanding. However, cervical spondylotic myelopathy (CSM) caused by central disc herniation and osseous stenosis is still recognized as a contraindication.

We have had extensive experience using computed tomography (CT)-guided posterior full-endoscopic cervical surgery since February 2016. After reviewing the cervical anatomy, in conjunction with applying a flexible, high-speed drill, we altered the angle of the traditional approach and proposed posterolateral full-endoscopic ventral decompression (PLEVD) under CT guidance to treat single-level CSM (Fig. 1). We expect to preliminarily evaluate the feasibility, safety, and efficacy of this new endoscopic surgery for single-level CSM patients.

Methods

Patient Population

This study was approved by our institutional review board, and all patients voluntarily enrolled in this clinical study and signed the informed consent form to participate. The cohort consisted of 21 consecutive single-level CSM patients who underwent CT-guided PLEVD at our institution between May 2018 and August 2019. There were 9 men and 12 women, with a mean age of 49.9 years (range, 37–66 years). The clinical symptoms greatly coincided with CSM (Fig. 2), and the mean duration of symptoms was 10.4 months (range, 0.3–60 months). The characteristics of the enrolled patients are shown in Table 1. All patients underwent CT-guided PLEVD performed by the same experienced senior surgeon. The principal inclusion and exclusion criteria are presented in Table 2. All patients were followed by outpatient review.

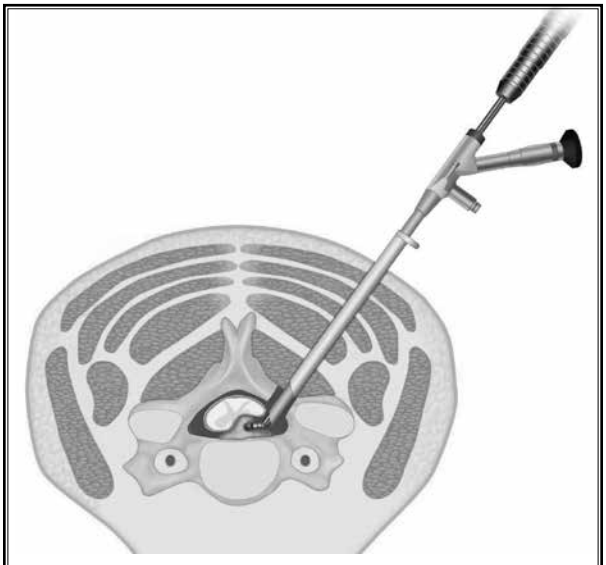

Fig. 1. *Schematic diagram. The flexible, high-speed drill was gradually advanced to the ventral side of the dural sac along the designated surgical path angle between the outside of the dural sac and the underside of the nerve root.*

Surgical Technique

Surgical Path Design with CT Guidance

The patient was admitted to the operating room and placed in the prone position on the CT bed panel. Latex pads were placed under the patient's shoulders, abdomen/thorax, and joints to make the patient comfortable and keep the head slightly flexed in a neutral position. A CT scan was performed, and the posterolateral puncture path to the central spinal target lesion, as well as the lamina targeted for removal, were identified and confirmed using timely CT images. A low dose of intravenous dexmedetomidine (0.5–1.0 μg/kg/h) was administered to ensure that the anesthesia regimen was satisfactory, and the patient could be easily awakened.

After local anesthesia was applied, a puncture needle was inserted into the designed puncture path under CT guidance. The bone into which the puncture needle is inserted can vary depending on the patient's situation; however, it is commonly inserted near the junction of the superior edge of the inferior lamina and the facet joint. The optimal location is defined as that which can achieve adequate ventral decompression, which was confirmed on CT images taken during the procedure. A skin incision approximately 7 mm in length was made to access the work channel, and the target dilators were inserted parallel to the puncture. A CT scan was performed to confirm the location of the work channel (Fig. 3A). Then, the endoscope was inserted, and a long-tip bipolar cautery device was used to coagulate and remove the remaining muscle and soft tissue overlying the lamina.

A part of the lamina near the V point (i.e., the inner edge of the facet joint, the inferior edge of the superior lamina, and the superior edge of the inferior lamina) was excised using a flexible, high-speed drill (DK-O-MVS [abrasive head], bit diameter: 3 mm, head drill length variable: 15 mm, angle range: 0°–40°, Xi Shan, China). The scope of bone abrasion depended on the CT-based design established before surgery. Soft tissue, such as the ligamentum flavum or fiber bundles adhered to the dural sac, was excised using bipolar radiofrequency, a disc rongeur, and a Kerrison rongeur through the laminar bone window (Fig. 3C). The flex-

ible, high-speed drill was gradually advanced to the ventral side of the dural sac along the designated surgical path angle, between the outside of the dural sac and the underside of the nerve root. Central lesions, including disc herniation and osteophytes, were removed with the flexible, high-speed drill or a clamp, and ventral decompression of the spinal cord was achieved. A CT scan was then conducted to ensure that the decompression performed during surgery was adequate (Fig. 3B, D).

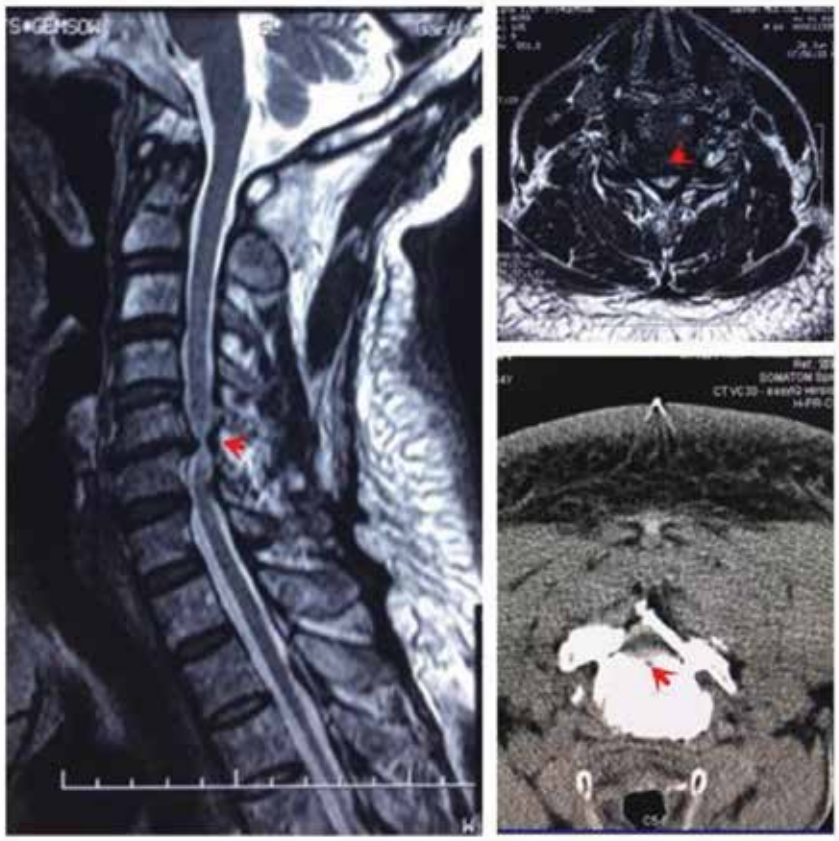

Fig. 2. *A preoperative sagittal MRI shows C5-6 central spinal stenosis and spinal cord injury. The coronal CT and MRI scans demonstrate central hyperostosis and disc herniation compressing the spinal cord.*

Assessment of Outcomes

The relief of arm pain was assessed according to the Visual Analog Scale (VAS) score (0 = no pain, 10 = worst pain). Pre- and postoperative neurologic conditions were evaluated using the Japanese Orthopaedic Association (JOA) myelopathy score. The recovery rate was calculated as follows: recovery rate (%) = [(postoperative JOA score - preoperative JOA score) / (17 - preoperative JOA score)] * 100. Rates ≥ 75%, 50% to 74%, 25% to 49%, and < 25% were considered excellent, good, fair, and poor, respectively. Any surgery-related complications were recorded.

Radiographic Evaluation

The maximum spinal canal diameter (MSCD) was defined as the length of the midline between the pathology and the posterior spinal canal and was used to measure the degree of spinal canal stenosis on pre- and postoperative CT images (Fig. 4).

Statistical Analyses

The data were analyzed using SPSS 22.0 software (IBM Corporation, Armonk, NY). Continuous variables are presented as the means ± standard deviations, and categorical data are presented as numbers and percentages. Continuous data were compared using the Student t-test. A P value < 0.05 was considered statistically significant.

Results

Surgery was successful in all patients. Two patients underwent surgery on C3-4, 5 patients underwent surgery on C4-5, 11 patients underwent surgery on C5-6, and 3 patients underwent surgery on C6-7. The average course of disease was 10.4 months (range, 0.3–60 months). In 6 of the 21 patients, CSM was caused by central disc herniation only; in the other 15 patients, CSM was caused by both disc protrusion and osteophytes. The duration of surgery averaged 169.3 ± 49.8 minutes (range, 105–255 minutes). The average posterolateral angle was 36.0° ± 5.6° (range, 29.5°–47.6°).

All patients were followed for an average of 11.3 ± 5.3 months (range, 6–25 months). The mean VAS score significantly decreased after surgery from 5.5 ± 1.66

preoperatively to 3.0 ± 0.80 at 1 day, 1.1 ± 0.85 at 1 week, 0.5 ± 0.6 at 1 month, and 0.4 ± 0.5 at 6 months after surgery (Fig. 5A). The mean JOA score improved from 10.0 ± 1.66 preoperatively to 12.0 ± 1.16, 13.0 ± 1.02, 13.6 ± 0.87, 14.0 ± 0.92, 14.7 ± 1.06, and 15.9 ± 1.6 at 1 day, 1 week, 1 month, 3 months, 6 months, and 12 months after surgery, respectively (Fig. 5B). According to the JOA recovery rate, 5 patients had a poor outcome and 16 had a fair outcome 1 day after surgery. Three of the 5 patients with a poor outcome received a cervical nerve block with 5 mg dexamethasone and 5 mL lidocaine 0.5% on the third day after surgery, and the other 2 patients underwent cervical intraspinal catheterization to inject 5 mg dexamethasone and 5 mL lidocaine 0.5% via epidural for 1 week. All 5 poor outcome cases recovered to a fair outcome within 1 week after surgery. The JOA recovery rate gradually improved during follow-up; 19 of the 21 patients (90.5%) achieved a good or excellent outcome, and 2 patients had fair outcomes according to the JOA score 6 months after surgery (Fig. 5C).

Table 1. *Characteristics of the patients.*

Patients	Gender	Age (years)	Surgery Level	Duration of Symptoms (months)	Surgical Time (minutes)	Follow-Up Time (months)
1	Female	45	C3/4	1	255	17
2	Male	64	C5/6	60	195	16
3	Male	66	C4/5	6	255	18
4	Male	43	C6/7	1	135	18
5	Female	45	C5/6	1	225	25
6	Male	49	C5/6	0.5	165	12
7	Male	46	C5/6	1.5	135	12
8	Female	52	C5/6	3.5	225	12
9	Male	44	C5/6	1	135	12
10	Female	51	C5/6	0.3	135	12
11	Male	41	C4/5	60	225	6
12	Female	39	C3/4	6	135	6
13	Male	37	C5/6	12	135	12
14	Female	60	C6/7	12	120	12
15	Female	44	C6/7	0.3	135	12
16	Female	64	C4/5	24	255	6
17	Female	44	C5/6	0.3	105	6
18	Female	44	C4/5	2	165	6
19	Female	61	C5/6	12	135	6
20	Male	55	C4/5	12	135	6
21	Female	53	C5/6	1	150	6

The MSCD was significantly enlarged after surgery, and the spine achieved complete decompression. The average MSCD was enlarged from 0.55 ± 0.15 cm preoperatively to 1.02 ± 0.18 cm postoperatively (Fig. 5D). The postoperative magnetic resonance imaging (MRI) shows the lesion has been removed, and the spinal cord has been decompressed and recovered (Figs. 6 and 7).

There were no complications, including intraoperative bleeding, hematomas, neural structure injury, spinal cord damage, or paralysis. However, 2 patients

Table 2. *Inclusion and exclusion criteria for the cohort.*

Inclusion criteria
1. 20 years < Age ≤ 66 years.
2. Single-level cervical spinal central stenosis or multilevel cervical spinal central stenosis but only one level is responsible for the symptoms as determined by cervical nerve root block test.
3. Diagnosis of CSM as evidenced by cervical myelopathy symptoms and physical examination.
4. Cervical spinal central stenosis due to cervical disc herniation or hyperostosis as diagnosed on cervical CT or MRI.
5. No cervical spine instability.
Exclusion criteria
1. Age ≤ 20 years, Age > 66 years.
2. Unable to identify the obligation segment with multilevel cervical spinal central stenosis.
3. Lateral or foraminal stenosis or disc herniation as evidence on cervical spondylotic radiculopathy, CT, or MRI.
4. Cervical spine instability or a history of open cervical surgery.
5. Intolerance to surgery.

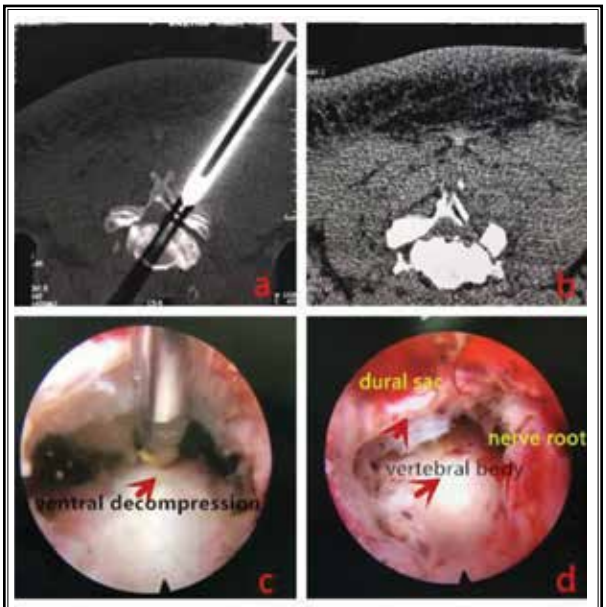

Fig. 3. *Images taken during the operation: (A) the posterolateral work path was established during the operation. (B) Ventral decompression was achieved, which was confirmed via CT scan immediately after surgery. (C, D) Ventral decompression from an endoscopic view.*

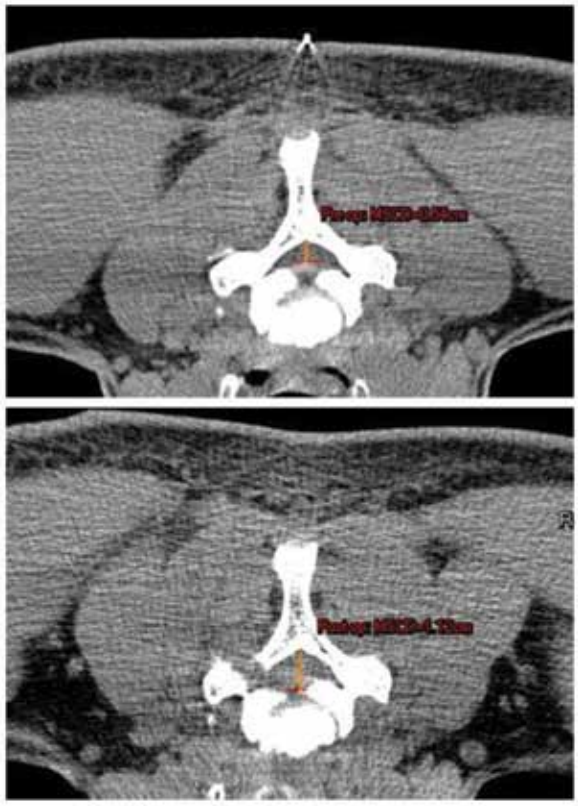

Fig. 4. *Pre- and postoperative CT images show that the average MSCD was enlarged from 0.68 ± 0.13 cm before surgery to 1.08 ± 0.24 cm after surgery ($P < 0.01$).*

presented transient bradycardia during surgery: one underwent surgery on C4-5, and the other underwent surgery on C5-6. One patient experienced C5 nerve root injury syndrome. Other complications, such as infection, spondylodiscitis, recurrent disc herniation, and cervical instability, were not observed.

Discussion

Minimally invasive surgery, including both anterior and posterior approaches, has been proposed in recent decades, and favorable results equivalent to those of open procedures have been obtained for appropriate indications (1-3,6-15). Compared with traditional open procedures, minimally invasive endoscopic (MIE) decompression techniques involve minimal skin incisions, limited tissue dissection, and improved visualization (7,9,16).

Recently, several investigations have attempted to take advantage of MIE techniques for the treatment of cervical spondylosis. Minamide et al (9) compared cervical microendoscopic laminotomy (CMEL) with conventional expansive laminoplasty (ELAP) in the treatment of CSM, and patients were followed for 5 years. The results showed similar neurologic recovery between the 2 groups (JOA recovery rate 57.6% in CMEL vs. 55.5% in ELAP); however, the CMEL group had decreased postoperative axial pain and improved subaxial cervical lordosis, and 2 patients in the CMEL group and 1 patient in the ELAP group had complications of C5 nerve root injury during surgery. Deng et al (15) reported a patient with C4-5 massive central disc herniation treated by percutaneous endoscopic cervical discectomy with an anterior transcorporeal approach. The patient achieved complete recovery without complications. Chu et al (17) and Du et al (13) described similar anterior approaches to treat single-level cervical central or mediolateral soft herniation in 5 and 36 patients, respectively. All of these patients achieved satisfactory results without any surgery-related complications, although both authors excluded CSM patients.

Indeed, there is currently no minimally invasive full-endoscopic surgical treatment for CSM.

With our experience performing CT-guided MIE surgery and learning the cervical anatomy on radiography, we have identified the characteristics of the cervi-

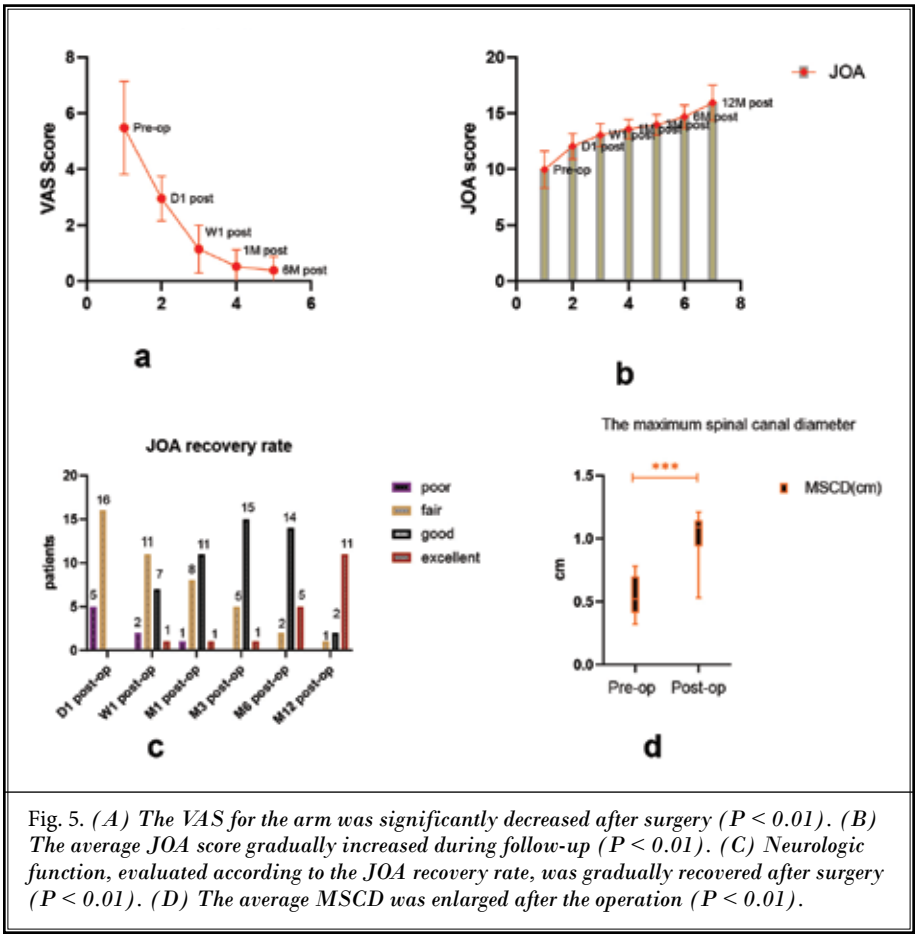

Fig. 5. *(A) The VAS for the arm was significantly decreased after surgery ($P < 0.01$). (B) The average JOA score gradually increased during follow-up ($P < 0.01$). (C) Neurologic function, evaluated according to the JOA recovery rate, was gradually recovered after surgery ($P < 0.01$). (D) The average MSCD was enlarged after the operation ($P < 0.01$).*

cal spine in CT-guided MIE surgery to be as follows: first, the site of the cervical nerve root originates from the dural sac, usually above the level of the cervical disc. Second, a safety triangle district exists between the nerve root and the dural sac, called the nerve root axillary triangle (outer/superior border is the nerve root, inner border is the dural sac). Third, there are no large blood vessels that may cause uncontrollable bleeding in the ventral dural sac, especially in front of the posterior longitudinal ligament. Based on this theory, we propose an increase in the posterior MIE surgical angle, combined with CT guidance and a variable angle, high-speed drill, to treat single-level CSM.

In this study, the average posterolateral angle of the 21 patients was 36.0° ± 5.6°. The posterolateral angle can provide a reasonable path to the ventral side of the spinal cord. Central disc protrusion can be removed directly, and osteophytes can be abraded using a flexible, high-speed drill. Complete ventral decompression of the spinal cord can be achieved with endoscopic visualization during this operation.

The optimum endoscopic work channel location and appropriate posterolateral angle were the premise of performing PLEVD for selective single-level CSM patients. CT guidance shows the precise location of the spinal cord, nerve root and protrusion during the operation, which is strongly necessary for performing PLEVD. Moreover, the puncture needle and work channel can be adjusted to the optimum location near the V point based on the CT images.

The MSCD was significantly enlarged after the operation, and the spine achieved complete decompression. The average MSCD was enlarged from 0.55 ± 0.15 cm before surgery to 1.02 ± 0.18 cm after surgery.

An appropriate surgical route and safe surgical space are the key points to successfully conducting PLEVD. The flexible drill, with angles ranging from 0° to 40°, combined with the surgical angle can provide a working angle that reaches approximately 76°. In addition, fine tuning the direction of the work channel during the operation and while drilling can help achieve ventral decompression. The appropriate exposure under an endoscopic view is expected to completely show the nerve root axillary triangle area, which includes an upper view of the nerve root, downward view of the upper edge of the vertebral pedicle, and inner view of the dural sac. After exposure, the nerve root axillary triangle area is relatively safe, and the view of the nerve root or dural sac in the endoscope is clear. It is safe to bypass the spinal cord or nerve root and remove the ventral pathology viewed via endoscope.

Surgery near the spinal cord and nerve root should be performed gently, and the patient's consciousness should be maintained under local anesthesia. It is crucial to closely observe the patient's heart rate fluctuations, limb sensation, and muscle strength changes during the operation, as the basis for avoiding spinal cord and nerve injury.

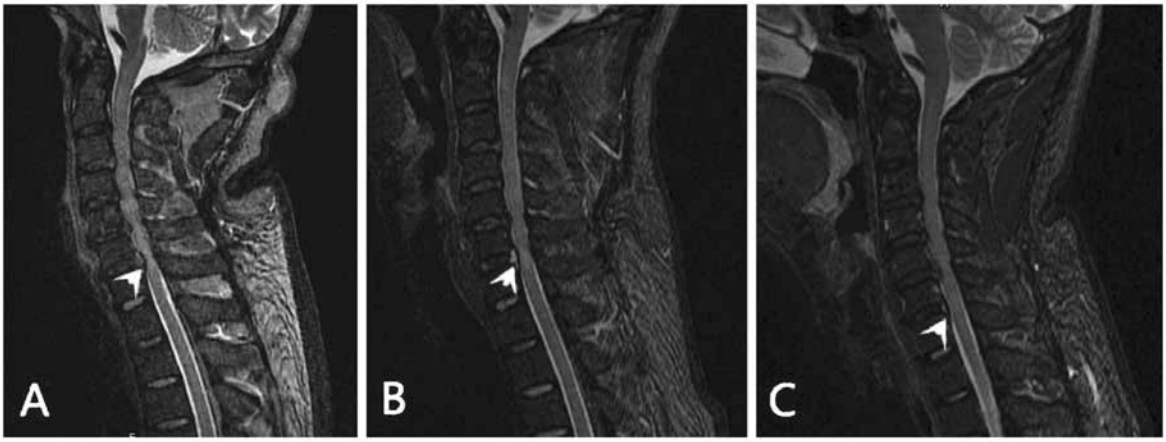

Fig. 6. *A 42-year-old man who was diagnosed with CSM underwent PLEVD. (A) Preoperative sagittal MRI shows an intraspinal lesion at C6-7 that is obviously compressing the spinal cord. (B, C) One-week and 6-month postoperative sagittal MRI show that the lesion has been removed, and the spinal cord has been decompressed.*

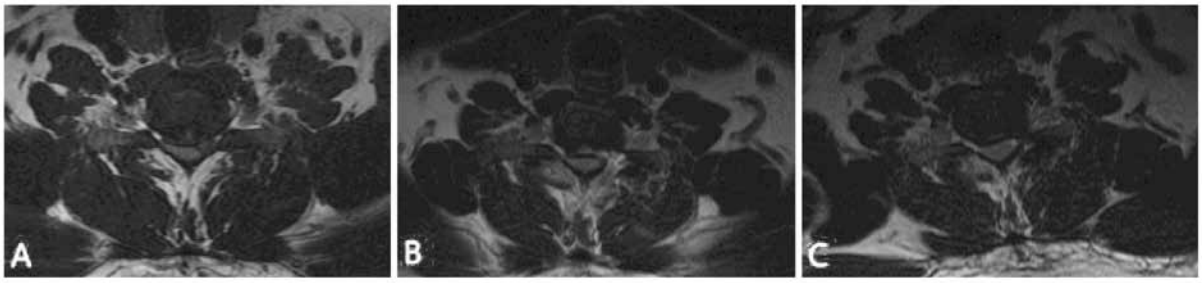

Fig. 7. *(A) Preoperative transverse MRI shows a lesion at the central and central-left areas of the intraspinal region. (B, C) One-week and 6-month postoperative transposition MRI show that the lesion has been removed, and the spinal cord and nerve root have been decompressed.*

In the present study, 21 single-level CSM patients successfully underwent PLEVD surgery. No complications, such as spinal cord or nerve root injury, dural sac tear, or uncontrollable bleeding, occurred during the surgeries. Arm pain was significantly relieved after surgery, as indicated by VAS scores. Neurologic function gradually recovered during the follow-up period; 19 of the 21 patients (90.5%) achieved excellent outcomes, and 2 patients had fair outcomes according to the JOA score 6 months after surgery. A full-endoscopic anterior cervical discectomy and fusion study conducted by Yao et al (6) in 2011 presented a similar excellent/good rate (86.6%) in 67 patients followed for 5 years; however, among these cases, only 21 patients (31%) had CSM, and one patient required revision surgery due to an adjacent segment disc herniation 6 years after surgery. In the current study, 2 patients presented persistent mild sensory and myodynamia abnormalities in the extremities at 12 and 25 months after surgery, respectively. Potential reasons to consider for these 2 cases could be an extensive pathology that included disc herniation with osteophytes, a large area with a high T2 signal on MRI, or a relatively shorter follow-up time.

Bleeding during PLEVD is minimal and can be controlled. The surgical area includes the nerve root, axilla, and ventral posterior longitudinal ligament, with no abundant arteries. Venous bleeding can be blocked by the pressure of washing away fluid and fine bone debris created by the drill. Bipolar radiofrequency hemostasis is feasible for bleeding in the field of vision. In cases of uncontrollable bleeding, the work channel can be blocked for approximately 10 minutes to stop the bleeding by relying on the physiological coagulation function.

The limitations of this study are as follows: (1) it had a small sample size and a short follow-up period. (2) Although it was designed as a prospective study, there was no contrast group or randomization. (3) All of the patients in the present study had single-level surgery for multilevel cervical stenosis; for severe bilateral spinal bony stenosis and severe central bony stenosis cases, there was a lack of operator experience with this technique.

Conclusion

Under appropriate indications, PLEVD performed under CT guidance is an available and safe technique for treating single-level CSM.

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