CLINICAL ARTICLE

# Anterior Cervical Discectomy and Fusion Combined with Foraminotomy Assisted by High-Definition 3-Dimensional Exoscope in the Treatment of Cervical Spondylotic Radiculopathy Secondary to Bony Foraminal Stenosis

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**Objective:** To evaluate the outcomes of cervical spondylotic radiculopathy secondary to bony foraminal stenosis treated with anterior cervical discectomy and fusion (ACDF) combined with anterior cervical foraminotomy (ACF) assisted by High-Definition 3-Dimensional Exoscope.

**Methods:** In this retrospective study, a total of 19 consecutive patients (12 males and seven females, with an average of 49.2 years, range from 40 to 59 years) with spondylotic radiculopathy caused by bony foraminal stenosis underwent ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope in our hospital between January 2019 and December 2019 were included in this study. All patients signed the consent form before the surgery. The patient baseline information such as gender, age, body mass index (BMI), surgery time, blood loss, hospital stay, lesion segment, side, follow-up time and postoperative complications were recorded. The Japanese Orthopedic Association (JOA), Neck Disability Index (NDI), and Visual Analogue Scale (VAS) were measured and compared before surgery, 1 months and final follow-up after surgery. The radiographic outcomes were evaluated using the $C_2$-$C_7$ angel, disc height, foraminal height, superior diagonal distance, inferior diagonal distance, and foraminal area.

**Results:** The involved levels included $C_4$-$C_5$ (six cases), $C_5$-$C_6$ (10 cases), $C_6$-$C_7$ (three cases). The mean duration of the surgery, mean blood loss, mean hospital stay, and mean follow-up were $100 \pm 11.10$ min, $19.4 \pm 7.05$ mL, $7.1 \pm 0.99$ days, and $12.1 \pm 2.25$ months, respectively. The average preoperative JOA score was $11.9 \pm 1.31$, then improved to $15.7 \pm 0.73$ ($t = -13.45$, $P < 0.001$) and $16.2 \pm 0.74$ ($t = -14.39$, $P < 0.001$) at 1 month after operation and at last follow-up, respectively. The average preoperative NDI score was $27.3 \pm 3.36$, then decreased to $5.1 \pm 1.79$ ($t = 20.63$, $P < 0.001$) and $4.5 \pm 1.21$ ($t = 25.53$, $P < 0.001$) 1 month after operation and at last follow-up, respectively. The average preoperative VAS score was $6.7 \pm 0.93$, then decreased to $2.4 \pm 0.69$ ($t = 15.05$, $P < 0.001$) and $1.9 \pm 0.78$ ($t = 16.40$, $P < 0.001$) 1 month after operation and at last follow-up, respectively. As compared with the condition before surgery, there was a significant improvement in the $C_2$-$C_7$ angel, disc height, foraminal height, and foraminal area ($P < 0.05$). None of the patients developed postoperative vascular injury, nerve injury, loosening and rupture of the internal fixation, displacement of interbody fusion cage, and pseudarthrosis.

**Conclusion:** ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope is effective and safe for the treatment of CSR caused by secondary to bony foraminal stenosis.

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**Key words:** Bony foraminal stenosis; Cervical spondylotic radiculopathy; Foraminotomy; High-Definition 3-Dimensional Exoscope

## Introduction

Cervical Spondylotic radiculopathy (CSR) is the most common type of cervical spondylosis, accounting for about 50%–60%. It is mainly manifested as pain, numbness, stiffness, and limitation of movement of the affected upper limb, which seriously affects human normal work and life. The main pathogenic factors are the compression of nerve roots by herniated disc and hyperplastic osteophytes, because exiting cervical nerve roots are closely related to the posterior aspect of the uncovertebral joint, osteophytes arising from the uncinate process and herniated disc from the lateral portion can produce foraminal stenosis resulting in cervical radiculopathy[1]. Conservative treatment is the first choice for CSR, but for patients with intractable upper limb pain, decreased myodynamia and ineffective conservative treatment, surgical treatment is feasible to relieve clinical symptoms. Posterior or anterior cervical foraminotomy (PCF or ACF) is classic treatment for CSR caused by a lateral herniated disc or secondary to foraminal stenosis, but they have some limitations, such as the progression of kyphosis and postoperative neck pain[2]. Anterior cervical discectomy and fusion (ACDF) has been considered the standard treatment for CSR caused by central, paramedian and even lateral discs and osteophytes at one or two levels, but it is difficult to remove the bony foraminal stenosis, and there is a risk of nerve root injury and vertebral artery injury[3]. Therefore, ACDF combined with ACF may be a preferably treatment for CSR secondary to bony foraminal stenosis when ineffective by conservative treatment, it can directly and effectively remove nerve root compression, reconstruct the segmental stability of the lesions and improve the physiological curvature of cervical vertebrae[4,5].

Although ACDF is the gold standard for the treatment of CSR, the incidence of surgical complications or adverse events is still high[6]. The reason may be that the operation position is deep, the operation space is narrow, insufficient lighting and poor visual field are easy to occur, and the decompression range of CSR. But for the CSR secondary to bony foraminal stenosis, the decompression range is larger and more difficult, which makes it difficult to remove the compression, resulting in incomplete decompression and a higher risk of nerve, dura mater and vertebral artery injury[7]. With the development of surgical equipment, this problem may be solved. At present, High-Definition 3-Dimensional Exoscope (Sanying, Tokyo, Japan) has the characteristics of three-dimensional images, good light and clear display of subtle lesions under the field of magnification several times, which can provide a field of vision similar to the perception of surgeons. Moreover, this new technology has obvious advantages in ergonomics and operability[8]. ACDF combined with ACF under the assistance of High-Definition 3-Dimensional Exoscope can not only effectively decompress, but also provide a clear surgical field under the magnification of several times, which is conducive to ensuring the accuracy and safety of all intraoperative operations. Therefore, it may be an alternative treatment for CSR secondary to bony foraminal stenosis. However, there are few reports on the application of High-Definition 3-Dimensional Exoscope in this field.

Therefore, in this study, patients with CSR secondary to bony foraminal stenosis that were treated with ACDF combined with ACF assisted by High Definition 3-Dimensional Exoscope were retrospectively reviewed. The purpose of this study was: (i) to describe ACDF combined with ACF assisted by High Definition 3-Dimensional Exoscope for the treatment of CSR secondary to bony forminal stenosis; (ii) to follow-up and analyze the clinical outcomes of Japanese Orthopedic Association (JOA), Neck Disability Index (NDI), Visual Analogue Scale (VAS), the $C_2$-$C_7$ angel, disc height, foraminal height, superior diagonal distance, inferior diagonal distance, and foraminal area; and (iii) to evaluate the efficacy and feasibility of the ACDF combined with ACF assisted by High Definition 3-Dimensional Exoscope.

## Materials and Methods

### *Inclusion and Exclusion Criteria*

The inclusion criteria included: (i) patients had been diagnosed with CSR through medical history, symptoms, physical examination, and CT or MRI examination who were not responded to conservative treatment; (ii) patients were treated with ACDF combined with ACF assisted by High Definition 3-Dimensional Exoscope; (iii) comparison of preoperative and postoperative status; (iv) evaluation of surgical procedure and postoperative status; and (v) retrospective study. Exclusion criteria were as follows: (i) CSR caused by soft disc herniation; (ii) CSR of foramen stenosis caused by hypertrophy of the posterior facet; (iii) Patients with other cervical spine disease; and (iv) incomplete data or missing patients.

### *Study Design*

From January 2019 to December 2019, 19 consecutive patients with CSR secondary to bony foraminal stenosis were treated with ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope in our hospital were analyzed retrospectively. Demographic data were collected and shown in Table 1.

## *Surgical Procedures*

Anesthesia and Surgical Position

After general anesthesia, the patients were placed in prone position.

*Approach and Exposure*

The internal oblique edge of the right sternocleidomastoid muscle and the anterior cervical transverse incision were taken, the skin, subcutaneous tissue and the platysma muscle were cut in turn, the carotid sheath and esophageal tracheal were obtuse separated to the anterior cervical edge, and the target intervertebral space was identified by C-arm X-ray fluoroscopy, and the anterior vertebral space was fully exposed by using a special retractor.

*Processing of the Decompression*

The procedures were performed for spinal pathologies using the High-Definition 3-Dimensional Exoscope (Fig. 1), the intervertebral disc and its hyperplastic ligament tissue and osteophyte were removed, reaching the Luschka joints on both sides, lifting and cutting the posterior longitudinal ligament, exposing the dural sac, and exploring the ossification of the posterolateral margin of the vertebral body and the stenosis of the intervertebral foramen, vertebral joint with ultrasonic osteotome excision osteophyte. Exploration showed that the dural sac and nerve root were relaxed without compression. Select a suitable size interbody fusion cage to install bone particles into the intervertebral space, select the appropriate length of titanium plate segment fixation, C-arm X-ray shows that the fusion cage and titanium plate internal fixation position is great, wash the wound, carefully

**TABLE 1 General result**

| Case | Age(y) | Gender | BMI | Surgery time(min) | Blood loss(ml) | Hospital stay(day) | Lesion segment | Side | Follow-up (months) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 40 | M | 23.11 | 120 | 10 | 6 | $C_5$-$C_6$ | L | 14 |
| 2 | 51 | F | 23.88 | 110 | 20 | 7 | $C_5$-$C_6$ | L | 13 |
| 3 | 44 | M | 29.55 | 100 | 20 | 8 | $C_4$-$C_5$ | R | 8 |
| 4 | 47 | M | 22.86 | 100 | 30 | 9 | $C_5$-$C_6$ | L | 9 |
| 5 | 54 | M | 20.04 | 90 | 20 | 7 | $C_5$-$C_6$ | L | 14 |
| 6 | 48 | F | 24.39 | 90 | 10 | 6 | $C_6$-$C_7$ | R | 16 |
| 7 | 49 | F | 25.78 | 80 | 20 | 7 | $C_4$-$C_5$ | R | 10 |
| 8 | 55 | M | 21.34 | 90 | 10 | 5 | $C_5$-$C_6$ | R | 12 |
| 9 | 56 | F | 27.34 | 100 | 20 | 6 | $C_5$-$C_6$ | L | 14 |
| 10 | 59 | M | 18.94 | 110 | 30 | 7 | $C_5$-$C_6$ | R | 9 |
| 11 | 43 | M | 19.98 | 100 | 30 | 8 | $C_4$-$C_5$ | L | 10 |
| 12 | 42 | F | 25.39 | 90 | 20 | 8 | $C_6$-$C_7$ | L | 12 |
| 13 | 46 | M | 21.56 | 120 | 20 | 8 | $C_5$-$C_6$ | R | 14 |
| 14 | 47 | M | 24.65 | 110 | 30 | 7 | $C_4$-$C_5$ | L | 13 |
| 15 | 52 | M | 24.61 | 90 | 20 | 7 | $C_5$-$C_6$ | L | 12 |
| 16 | 54 | F | 21.21 | 100 | 10 | 6 | $C_5$-$C_6$ | L | 15 |
| 17 | 51 | F | 25.71 | 110 | 10 | 7 | $C_6$-$C_7$ | L | 11 |
| 18 | 50 | M | 22.03 | 100 | 20 | 8 | $C_4$-$C_5$ | R | 10 |
| 19 | 47 | M | 23.73 | 90 | 20 | 8 | $C_4$-$C_5$ | L | 13 |

BMI, body mass index; F, female; M, male; L, left; R, right.

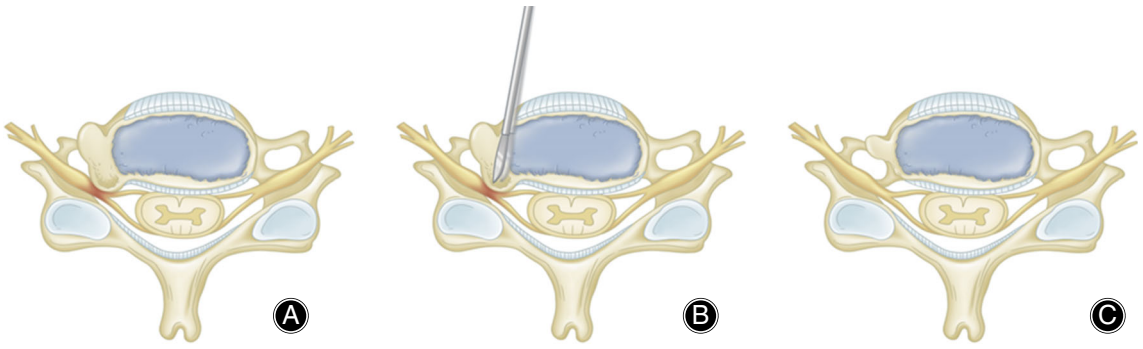


**Fig 1** (A, B and C) surgical diagrams: (A) the location of bone foramen stenosis; (B) osteotome excision osteophyte; (C) the nerve root were relaxed without compression.

stop the bleeding, place the drainage tube, suture and close the wound layer by layer.

*Intraoperative Management*

Routine electrophysiological monitoring of the nerves of the extremities is taken during the operation to know whether the operation to be carried out will stimulate the nerve root or spinal cord. If there is an abnormal waveform during decompression, we will operate carefully to avoid injury.

### *Outcome Measures*

*Japanese Orthopedic Association (JOA)*

The JOA was used to evaluate the neurological status, which was assessed at preoperative, 1 month after surgery, and at the final follow-up. The maximum score was 17 points, which includes four sections: four limbs motor dysfunction, four limbs sensory deficit, trunk sensory deficit, and sphincter dysfunction.

*Neck Disability Index (NDI)*

The NDI was used to evaluate neck-specific disability. It contains 10 items, including: pain intensity, personal care, lifting, reading, headache, concentration, work, driving, sleeping, and recreation. Each items is scored from zero (no disability) to five (full disability).

*Visual Analogue Scale (VAS)*

The VAS was used to measure the degree of pain, which was self-assessed by the patients. The scale ranged from zero (no pain) to ten (very severe pain).

**TABLE 2 Clinical outcomes**

| | JOA | NDI | VAS |
|---|---|---|---|
| Preop | 11.9 ± 1.31 | 27.3 ± 3.36 | 6.7 ± 0.93 |
| Postop-1 month | 15.7 ± 0.73* | 5.1 ± 1.79* | 2.4 ± 0.69* |
| Final follow-up | 16.2 ± 0.74* | 2.4 ± 0.69* | 1.9 ± 0.78* |

*There is significant different between preoperative,postoperative 1 month and final outcome ($P < 0.05$). JOA, Japanese Orthopedic Association; NDI, Neck Disability Index; VAS, Visual Analogue Scale.

*$C_2$-$C_7$ Angel (Cervical Curvature)*

The $C_2$-$C_7$ angel (cervical curvature) was measured using the tangential method from $C_2$ to $C_7$ on lateral radiographs in neutral position[9].

*Disc Height (Height of Lesion Segmental Intervertebral Space)*

The disc height (height of lesion segmental intervertebral space) was measured using the mean value of the anterior disc height and the posterior disc height on lateral radiographs in neutral position.

*Foraminal Height*

The foraminal height was measured using the distance between the midpoint of the upper edge of the pedicle and the midpoint of the lower edge of the pedicle.

*Superior Diagonal Distance*

The superior diagonal distance was measured using the distance between the posterior lower margin of the upper vertebral body and the inner upper margin of the lower articular surface.

*Inferior Diagonal Distance*

The inferior diagonal distance was measured using the distance between the posterior upper margin of the lower vertebral body and the inner lower margin of the superior articular surface.

*Foraminal Area*

The foraminal area was measured using the area formed by the posterior edge of the upper vertebral body, the upper edge of the lower vertebral body, the inner edge of the upper and lower articular processes and the lower edge of the pedicle.

Each index was measured by three technologists using the same method, and the average results of three measurements were taken.

### *Statistical Analysis*

All data were collected by an independent observer and presented as mean ± standard deviation. The data were analyzed by SPSS 22.0 statistical software (SPSS, Inc., Chicago, IL, USA). The paired *t*-test was used to assess the difference between the preoperative, 1 month after surgery, and final follow-up for JOA, NDI, VAS, $C_2$-$C_7$ angel, disc height, foraminal height, superior diagonal distance, inferior

**TABLE 3 Radiographic outcomes**

| | $C_2$-$C_7$ angel (°) | disc height (mm) | foraminal height (mm) | superior diagonal distance (mm) | inferior diagonal distance (mm) | foraminal area ($mm^2$) |
|---|---|---|---|---|---|---|
| preop | 12.8 ± 0.44 | 4.4 ± 0.26 | 8.4 ± 0.21 | 5.3 ± 0.13 | 6.2 ± 0.17 | 35.6 ± 1.55 |
| postop | 17.9 ± 0.46* | 7.1 ± 0.22* | 9.2 ± 0.18* | 5.4 ± 0.12 | 6.3 ± 0.15 | 69.4 ± 2.64* |

*There is significant different between preoperative and postoperative outcome ($P < 0.05$).

diagonal distance, and foraminal area. $P < 0.05$ was considered statistically significant.

## Results

### *General Results*

A total of 19 subjects were included in this study, including $C_4$-$C_5$ (six cases), $C_5$-$C_6$ (10 cases) and $C_6$-$C_7$ (three cases). In all patients, the compression was successfully removed.

The mean age was 49.2 ± 5.08 years (range, 40–59 years); The mean operation time was 100 ± 11.10 min (range, 80-120 min); The mean surgical blood loss was 19.4 ± 7.05 mL (range, 10–30 mL); The mean hospital stay was 7.1 ± 0.99 days (range, 5–9 days) and the mean follow-up time was12.1 ± 2.25 months (range, 8–16 months). The data are showed in Table 1.

### *Clinical Evaluation*

*JOA*

The JOA score showed significantly improvement and the mean preoperative JOA score was 11.9 ± 1.31, then improved to 15.7 ± 0.73 ($t = -13.45$, $P < 0.001$) with improvement of 22.3% and 16.2 ± 0.74 ($t = -14.39$, $P < 0.001$) with improvement of 25.3% at 1 month after operation and at last follow-up, respectively (Table 2).

*NDI*

Compared to preoperative results, the NDI score was decreased from preoperative 27.3 ± 3.36 to 5.1 ± 1.79 and 4.5 ± 1.21 with a decrement rate of 46.6% at 1 month after operation and at last follow-up, respectively (Table 2).

*VAS*

The VAS score showed statistically decreased and the average preoperative VAS score was 6.7 ± 0.93, then decreased to 2.4 ± 0.69 ($t = 15.05$, $P < 0.001$) with a decrement rate of 43% and 1.9 ± 0.78 ($t = 16.40$, $P < 0.001$) with a decrement rate of 48% at 1 month after operation and at last follow-up, respectively (Table 2).

### *Radiographic Outcomes*

As compared with the condition before surgery, there was a significant improvement in the $C_2$-$C_7$ angel (12.8 ± 0.44 *vs.*

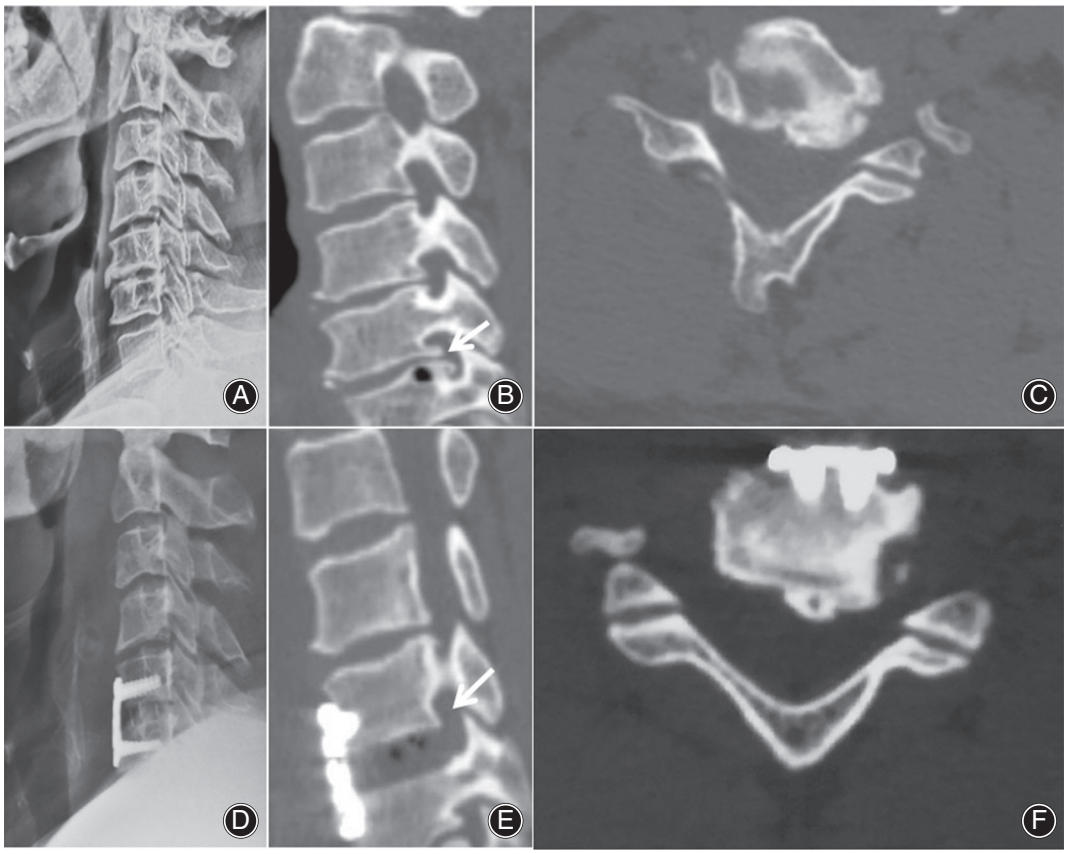


**Fig 2** A case of a 47 year-old man. He had been diagnosed as $C_5$-$C_6$ CSR secondary to bony foraminal stenosis. He had underwent an ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope. The preoperative images were shown in Fig. 2 A, B, and C. D, E, and F were the image taken at 1 month after surgery, indicating foraminal stenosis nearly sufficient decompression.

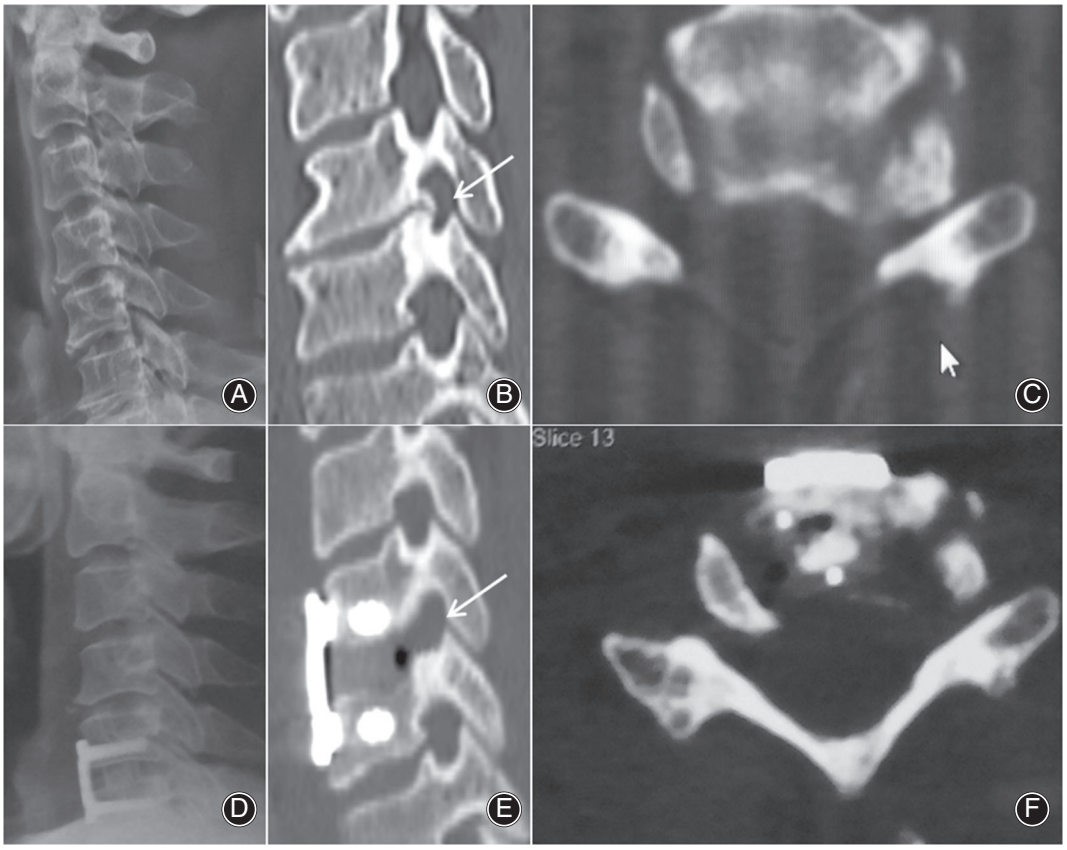


**Fig 3** A case of a 54 year-old man. He had been diagnosed as $C_5$-$C_6$ CSR secondary to bony foraminal stenosis. He had undergone an ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope. The preoperative images were shown in Fig. 3 A, B, and C. D, E, and F were the image taken at 1 month after surgery, indicating foraminal stenosis nearly sufficient decompression.

17.9 ± 0.46, $P < 0.05$), disc height (4.4 ± 0.26 *vs.* 7.1 ± 0.22, $P < 0.05$), foraminal height (8.4 ± 0.21 *vs.* 9.2 ± 0.18, $P < 0.05$), and foraminal area (35.6 ± 1.55 *vs.* 69.4 ± 2.64, $P < 0.05$) (Table 3). Three typical cases in this study are shown in Figs 2–4.

### *Complication*

During the follow-up, none of the patients developed postoperative vascular injury, nerve injury, loosening and rupture of the internal fixation, displacement of interbody fusion cage, and pseudarthrosis.

## Discussion

### *Clinical Outcomes*

The pathological location of CSR was classified as intervertebral foramen and posterolateral[10,11]. ACDF combined with ACF can directly and effectively remove nerve root compression, reconstruct the stability of diseased segments, and improve the physiological curvature of cervical vertebra. But for significant bony foraminal stenosis, the operation space is deep and narrow, which is prone to poor visual field, resulting in incomplete decompression[7]. In this study, we used the High-Definition 3-Dimensional Exoscope assisted by ACDF combined with ACF to treat CSR secondary to bony foraminal stenosis. The operation had the advantages of clear vision, less injury, less bleeding and complete decompression. All patients completed the operation successfully. JOA score, NDI score, VAS score, and the radiographic outcomes were significantly improved compared with preoperatively.

### *Characteristics of CSR*

The treatment for CSR is currently controversial. Because the causes of CSR are complicated, which may involve nerve root compression by the herniation side of intervertebral disc, Luschka joint and facet joint hyperplasia, abnormal position of facet joint and intervertebral disc space stenosis can cause intervertebral foramen stenosis[12–14]. Thus, there is no consensus on whether intervertebral foramen incision and decompression should be performed in CSR patients with secondary bone foramen stenosis. Some researches[15] reported that after reliable interbody joint fusion, satisfactory surgical results can be obtained by intervertebral disc space

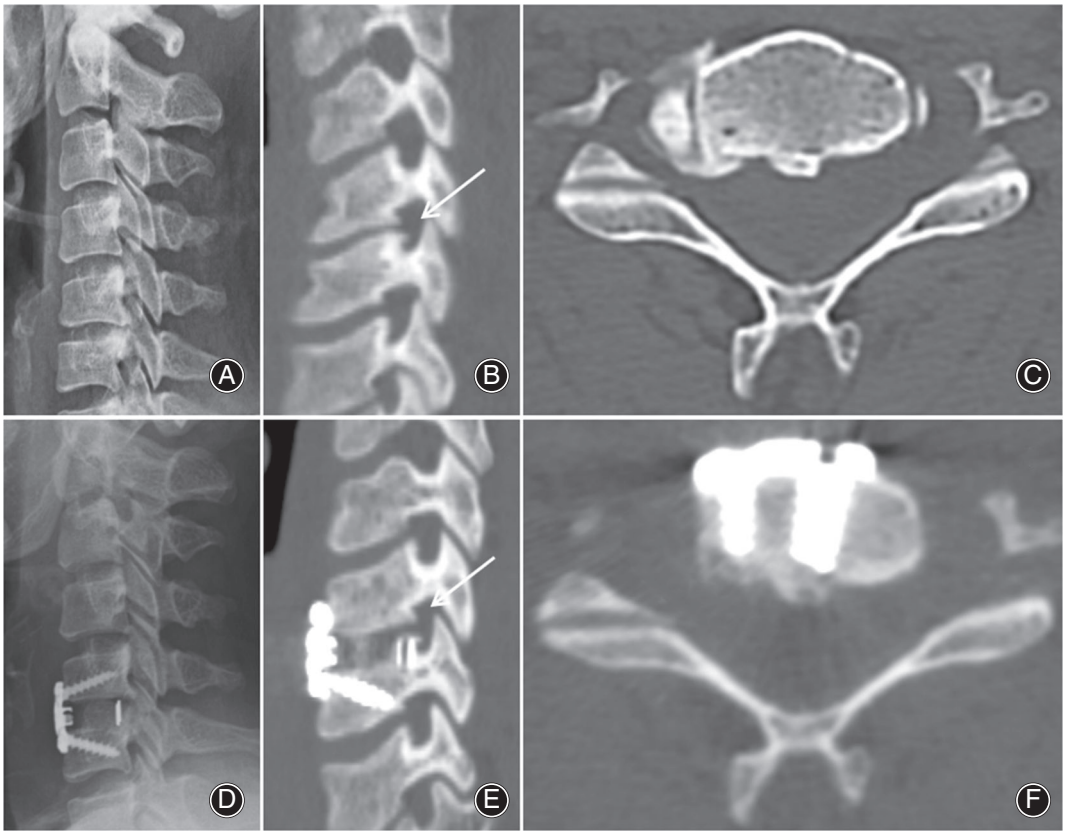


**Fig 4** A case of a 46 year-old man. He had been diagnosed as $C_5$-$C_6$ CSR secondary to bony foraminal stenosis. He had underwent an ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope. The preoperative images were shown in A-C. D-F were the image taken at 1 month after surgery, indicating foraminal stenosis nearly sufficient decompression.

stretch, indirect decompression and natural absorption of osteophytes. Some studies[16] also found that foraminotomy can directly and effectively remove the pathology. However, either ACF or posterior cervical foraminotomy (PCF) had drawbacks. PCF can cause postoperative neck pain and exercise paralysis caused by cervical kyphosis or instability secondary to facet resection and excessive muscle peeling[17,18]. Tong *et al.*[19] concluded that ventral bony decompression was better than simple dorsal decompression in CSR caused by cervical foraminal and/or lateral spinal stenosis. Therefore, anterior decompression might be preferable if there were significant bony compression pathology causing foraminal stenosis. However, ACF can accelerate the degeneration of index level and adjacent segment, decrease the height of intervertebral space and restrict the movement of cervical vertebrae[20]. The possible reason is that the posterior lateral angle of intervertebral disc space will inevitably be invaded during decompression, resulting in intervertebral disc material overflow, intervertebral disc space narrowing and degeneration process. So ACF should be combined with interbody fusion, especially if there is instability before operation. Furthermore, ACDF does not increase the failure rate of adjacent segments requiring secondary surgical intervention[21]. Therefore, in our study, we used ACDF combined with ACF in the treatment of CSR caused by secondary to bony foraminal stenosis. The final follow-up showed that there was no significant decrease in intervertebral space height and adjacent segment degeneration, and symptom of all patients was significantly improved.

***Advantages of Surgical Operation by Using High-Definition 3-Dimensional Exoscope***

Although for the CSR secondary to bony foraminal stenosis, the decompression range is larger and more difficult, ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope has many advantages. Firstly, High-Definition 3-Dimensional Exoscope is a new visualization tool used in a variety of surgical fields. Excellent visibility can be obtained through integration of exoscope, special 3D glasses and high definition (HD or 4K) 3D screen, and it can be used as an alternative for microscopes and endoscopes in spinal surgery[22]. In clinical practice, it has remarkable advantages: High-Definition 3-Dimensional Exoscope provide good lighting and a magnified view of the field of vision compared to the naked eye or head-mounted microscopes.

ACDF surgery has a narrow operating space and a deep operative field, so the conventional lighting line is difficult to provide ideal lighting effect. At the same time, the lighting effect is greatly reduced due to the head shielding of the surgeon or assistant. As a result, many physicians use headlamps or suction heads with their own light sources to improve lighting, but only to improve the surgeon's field of vision, which is still not ideal for assistants and others. On the contrary, the illuminating light of the High-Definition 3-Dimensional Exoscope enters directly above the surgical field without any occlusion. Secondly, the good lighting and magnified scope of vision of the High-Definition 3-Dimensional Exoscope can provide bright, clear and amplified three-dimensional images. During the operation, the posterior longitudinal ligament and dural sac can be clearly identified to reduce the risk of dural sac and nerve injury. At the same time, small bleeding points can be found and timely hemostatic can keep clear the operation field[23]. Thirdly, under the bright, clear, amplified and high-resolution operative field, the decompression of osteophytes secondary to bony foraminal stenosis becomes very safe, and ultrasonic osteophytes can be safely and fully used to remove pathology. Finally, in addition to providing safe and effective decompression, intraoperative High-Definition 3-Dimensional Exoscope is also beneficial to the surgeon. After proper adjustment, the surgeon and assistant can operate at the same level, avoiding long-term damage to the surgeon by lowering their head, which is reduces the risk of injury to the neck and lumbar vertebrae[24]. Moreover, the High-Definition 3-Dimensional Exoscope has the function of video and image preservation, which is convenient for data preservation, teaching demonstration and academic communication.

### *Limitation*

Although ideal clinical results were achieved, there were limitations in our study. It is necessary to evaluate the long term postoperative efficacy and feasibility of the ACDF combined with ACF assisted by High Definition 3-Dimensional Exoscope. Regrettably, this study is a retrospective study, with a small number of samples, and we lacked a control group. Our results, however, show that ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope exhibits ideal clinical outcomes in the short term. Thus, we conclude that the High-Definition 3-Dimensional Exoscope has excellent visualization, depth perception, clarity. It can be widely used as a substitute for microscope and endoscope in spinal surgery and achieve satisfactory surgical results.

### *Conclusions*

ACDF combined with ACF assisted by High-Definition 3-Dimensional Exoscope is effective and safe for the treatment of CSR caused by secondary to bony foraminal stenosis.

## Acknowledgments

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## Ethics Approval and Informed Consent

This study was approved by the ethics committee of Xi'an Honghui Hospital, and written informed consent was obtained from the patient to publish the details of his case.

## References

**1.** Bono CM, Ghiselli G, Gilbert TJ, *et al*. An evidence-based clinical guideline for the diagnosis and treatment of cervical radiculopathy from degenerative disorders. Spine J, 2011, 11: 64–72.
**2.** Balasubramanian C, Price R, Brydon H. Anterior cervical microforaminotomy for cervical radiculopathy–results and review. Minim Invasive Neurosurg, 2008, 51: 258–262.
**3.** Golfinos JG, Dickman CA, Zabramski JM, Sonntag VK, Spetzler RF. Repair of vertebral artery injury during anterior cervical decompression. Spine (Phila pa 1976), 1994, 19: 2552–2556.
**4.** Nesterenko SO, Riley LH 3rd, Skolasky RL. Anterior cervical discectomy and fusion versus cervical disc arthroplasty: current state and trends in treatment for cervical disc pathology. Spine (Phila pa 1976), 2012, 37: 1470–1474.
**5.** Guo Q, Wang L, Zhang B, *et al*. Standalone anterior cervical discectomy and fusion versus combination with foraminotomy for the treatment of cervical spondylotic radiculopathy secondary to bony foraminal stenosis. World Neurosurg, 2016, 95: 134–142.
**6.** Nasser R, Yadla S, Maltenfort MG, *et al*. Complications in spine surgery. J Neurosurg Spine, 2010, 13: 144–157.
**7.** Bhalla A, Rolfe KW. Inadequate surgical decompression in patients with cervical myelopathy: a retrospective review. Global Spine J, 2016, 6: 542–547.
**8.** Kwan K, Schneider JR, Du V, *et al*. Lessons learned using a high-definition 3-dimensional exoscope for spinal surgery. Oper Neurosurg (Hagerstown), 2019, 16: 619–625.
**9.** Harrison DE, Harrison DD, Cailliet R, Troyanovich SJ, Janik TJ, Holland B. Cobb method or Harrison posterior tangent method: which to choose for lateral cervical radiographic analysis. Spine (Phila pa 1976), 2000, 25: 2072–2078.
**10.** Huntoon MA. Anatomy of the cervical intervertebral foramina: vulnerable arteries and ischemic neurologic injuries after transforaminal epidural injections. Pain, 2005, 117: 104–111.
**11.** Windsor RE, Storm S, Sugar R, Nagula D. Cervical transforaminal injection: review of the literature, complications, and a suggested technique. Pain Physician, 2003, 6: 457–465.
**12.** Yoganandan N, Knowles SA, Maiman DJ, Pintar FA. Anatomic study of the morphology of human cervical facet joint. Spine (Phila pa 1976), 2003, 28: 2317–2323.
**13.** Lu J, Ebraheim NA, Huntoon M, Haman SP. Cervical intervertebral disc space narrowing and size of intervertebral foramina. Clin Orthop Relat Res, 2000, 370: 259–264.
**14.** Yue WM, Brodner W, Highland TR. Long-term results after anterior cervical discectomy and fusion with allograft and plating: a 5- to 11-year radiologic and clinical follow-up study. Spine (Phila pa 1976), 2005, 30: 2138–2144.
**15.** Bayley JC, Yoo JU, Kruger DM, Schlegel J. The role of distraction in improving the space available for the cord in cervical spondylosis. Spine (Phila pa 1976), 1995, 20: 771–775.
**16.** Sonntag VK, Han PP, Vishteh AG. Anterior cervical discectomy. Neurosurgery, 2001, 49: 909–912.
**17.** Chen BH, Natarajan RN, An HS, Andersson GB. Comparison of biomechanical response to surgical procedures used for cervical radiculopathy: posterior keyhole foraminotomy versus anterior foraminotomy and discectomy versus anterior discectomy with fusion. J Spinal Disord, 2001, 14: 17–20.
**18.** Choi KC, Ahn Y, Kang BU, Ahn ST, Lee SH. Motor palsy after posterior cervical foraminotomy: anatomical consideration. World Neurosurg, 2013, 79: 405.e1-4.

**19.** Tong Y, Huang Z, Hu C, *et al*. A comparison study of posterior cervical percutaneous endoscopic ventral bony decompression and simple dorsal decompression treatment in cervical spondylotic radiculopathy caused by cervical foraminal and/or lateral spinal stenosis: a clinical retrospective study. BMC Musculoskelet Disord, 2020, 21: 290.
**20.** Park YK, Moon HJ, Kwon TH, Kim JH. Long-term outcomes following anterior foraminotomy for one- or two-level cervical radiculopathy. Eur Spine J, 2013, 22: 1489–1496.
**21.** Skovrlj B, Gologorsky Y, Haque R, Fessler RG, Qureshi SA. Complications, outcomes, and need for fusion after minimally invasive posterior cervical foraminotomy and microdiscectomy. Spine J, 2014, 14: 2405–2411.
**22.** Sack J, Steinberg JA, Rennert RC, *et al*. Initial experience using a high-definition 3-dimensional exoscope system for microneurosurgery. Oper Neurosurg (Hagerstown), 2018, 14: 395–401.
**23.** Tani T, Ushida T, Ishida K, Iai H, Noguchi T, Yamamoto H. Relative safety of anterior microsurgical decompression versus laminoplasty for cervical myelopathy with a massive ossified posterior longitudinal ligament. Spine (Phila pa 1976), 2002, 27: 2491–2498.
**24.** Hafez A, Elsharkawy A, Schwartz C, *et al*. Comparison of conventional microscopic and Exoscopic experimental bypass anastomosis: a technical analysis. World Neurosurg, 2020, 135: e293–e299.