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Comparison of clinical efficacy of posterior percutaneous endoscopic cervical discectomy versus unilateral biportal endoscopy key-hole techniques for cervical spondylotic radiculopathy: a retrospective study with 2 years

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Abstract

Purpose To compare the clinical efficacy of posterior percutaneous endoscopic cervical discectomy (PECD) with unilateral biportal endoscopy (UBE) key-hole techniques for treating cervical spondylotic radiculopathy (CSR).

Methods A retrospective study was performed for patients with CSR treated by PECD ($n = 40$) and UBE ($n = 30$). Patients background, operative data, and radiographic measurements were obtained. The visual analog scale (VAS) and neck disability index (NDI) were recorded preoperatively and 3 months and 2 years postoperatively, and modified Macnab criteria was recorded at 2 years postoperatively.

Results The background data of the two treatment groups were similar. There was no significant difference in hospitalization or fluoroscopy times ($P > 0.05$), whereas, the UBE group had shorter operative time and longer incision length than those of the PECD group ($p < 0.001$). There was a statistically significant difference in the postoperative cervical sagittal vertical axis compared to preoperative measurement (PECD: $p = 0.009$; UBE: $p = 0.010$). The VAS and NDI significantly improved in each time period in both groups ($p < 0.001$). The excellent/good rates were 87.5% in the PECD group and 90.0% in the UBE group. One case of postoperative nerve root irritation symptoms occurred in the PECD group and one case of mild spinal cord injury occurred in the UBE group.

Conclusion UBE, as well as PECD, was recommended as an option for CSR because of easy operation, minimal invasiveness, high safety profiles, and satisfactory clinical efficacy.

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Keywords Cervical spondylotic radiculopathy, Posterior percutaneous endoscopic cervical discectomy, Unilateral biportal endoscopy technique, Key-hole technique, Efficacy

Introduction

Due to factors such as the popularization of electronic devices, changes in lifestyle, and an aging population, cervical spondylosis has become increasingly common in clinical practice, with cervical spondylotic radiculopathy (CSR) being the most common form, accounting for 60–70% of cases [1]. CSR is mainly caused by degenerative changes in the cervical spine, including disc herniation or protrusion and bone hyperplasia of facet or uncovertebral joints, which stimulate and compress spinal nerve roots, leading to corresponding symptoms and signs [2]. While most patients can achieve good results with strict conservative treatment, some patients may require surgical intervention due to severe nerve compression symptoms or a failure to respond to conservative treatment [3]. Anterior cervical discectomy and fusion (ACDF) is the standard surgical procedure for treating CSR and has proven effectiveness [4], however, it may lead to complications such as accelerated adjacent segment degeneration, dysphagia, hematoma, and recurrent laryngeal nerve palsy [5, 6].

With the development of the concept of minimally invasive spine and the increasing patients' demand for rapid recovery, minimally invasive techniques have gained increasing attention in spinal treatment due to their minimal invasiveness and accelerated recovery. The posterior cervical spine key-hole technique has gradually emerged and become an effective treatment for CSR because it reduces surgical trauma, achieves accurate decompression, and avoids the complications associated with ACDF [7]. Percutaneous endoscopic cervical discectomy (PECD) is a novel minimally invasive technique that achieves favorable decompression results similar to open surgery, characterized by minor trauma, accelerated recovery, and accurate clinical efficacy, and numerous studies have demonstrated its clinical advantages [8, 9]. With the continuous development of minimally invasive techniques, the application of spinal endoscopy is gaining popularity among orthopedic surgeons for the treatment of CSR. Unilateral biportal endoscopy (UBE) was first proposed in 1996 [10]. In contrast to uniaxial spinal endoscopic system, UBE surgery has separate observation and working channels. This facilitetes a wider selection of instruments, flexible surgical operation, high efficiency, and a gentle learning curve, leading to its widespread adoption within the field of spinal surgery and achieved satisfactory clinical outcomes [11–13]. This study aimed to compare the clinical efficacy and radiological outcomes of PECD with UBE key-hole techniques for the treatment of CSR to investigate UBE safety and efficacy.

Materials and methods

Patient characteristics

This retrospective analysis was conducted on patients with CSR who were treated by applying PECD and UBE key-hole techniques in our department from March, 2019 to July, 2022. The study was performed following the principles of the Declaration of Helsinki and approval was obtained our hospital ethics committee approved and informed consent. All participants signed a written informed consent form. The inclusion criteria were as follows: (i) patients with typical radicular symptoms and positive findings by the Spurling's or brachial plexus traction tests; (ii) radiological evidence showed that the unilateral nerve root was compressed at a single level, consistent with the symptoms and signs observed; (iii) failure of strict non-surgical treatment for a period of 12 weeks or progressive worsening of symptoms, significantly impacting the patient's daily life and work; and (iv) patients with complete clinical data who had completed the follow-up period. The exclusion criteria were as follows: (i) cervical myelopathy; (ii) central disc herniation or calcification of the posterior longitudinal ligament; (iii) radiographic evidence of cervical instability [14] before surgery; (iv) congenital or acquired bony structural deformity of the cervical spine or a history of cervical trauma, tumor, or previous posterior cervical surgery; (v) concomitant cervical extraspinal conditions, such as thoracic outlet syndrome, shoulder impingement syndrome, carpal tunnel syndrome, cubital tunnel syndrome, or frozen shoulder, which could affect surgical evaluation; and (vi) severe underlying diseases, abnormal coagulation function, or inability to cooperate with the surgery. According to the inclusion and exclusion criteria, a total of 70 patients with CSR were enrolled in this study. Patients were divided into two groups: the PECD group ($n = 40$) and the UBE group ($n = 30$) depending on the different surgical techniques they received. There were no statistically significant difference in demographic or clinical characteristics between the two groups (Table 1). Preoperative and postoperative radiographic assessments, including lateral and dynamic X-rays, computed tomography (CT) and magnetic resonance imaging (MRI) examinations of the cervical spine were completed in both groups before and after surgery. All procedures were performed by the same surgeon who had experience in more than 300 cases of PELD surgery and 300 cases of UBE surgery.

Table 1 Patient characteristics

Characteristic	PECD group($n=40$)	UBE group($n=30$)	*p*-value
Age, years	52.5 ± 8.9	49.9 ± 7.8	0.217
Body mass index, kg/l^2	24.0 ± 1.6	23.9 ± 1.4	0.662
Sex, Male/Female	17:23	14:16	0.728
Operative level			0.628
C3/4	1	0	
C4/5	2	1	
C5/6	26	17	
C6/7	10	12	
C7/T1	1	0	
Comorbidities			
Hypertension	8	7	0.737
Coronary disease	1	1	1.000
Diabetes	3	2	1.000
Osteoporosis	13	8	0.598

Values are presented as mean ± SD or number

PECD posterior percutaneous endoscopic cervical discectomy, UBE unilateral biportal endoscopy

$p < 0.05$, statistical significance

Surgical techniques

PECD group

Taking the right side as an example, following successful anesthesia the patient was placed in a prone position with the head fixed in a neutral position using a head holder. The responsible intervertebral space was located by C-arm fluoroscopy (Fig. 1A), and a puncture point was made approximately 2 cm lateral to the right side of the midline on the posterior neck. Routine disinfection and draping were performed, and an incision with a diameter of approximately 0.8 cm was made at the puncture point. The working cannula was gradually dilated, and advanced under fluoroscopic guidance, to a position near the medial aspect of the facet joint and the lateral aspect of the interlaminar space at the responsible intervertebral space (Fig. 1B). Under endoscopic visualization, the interlaminar space encompassing the pathological area and the outer half of the superior and inferior laminae, as well as the inner part of the facet joint, were exposed. A bipolar radiofrequency electrode was used to clear the soft tissues from the laminae and facet joint surfaces to locate the "V" point. A drill and micro-rongeur were used to resect the inferior-outer portion of the superior laminae and the superior-outer portion of the inferior laminae. The ligamentum flavum was then removed, and at least approximately 4 mm of bone was excised from the cephalad and medial portion of the superior articular process using a micro Kerrison rongeur. The nerve root was exposed and explored, and the power drill was used to remove hypertrophic bone (Fig. 1C). The ventral aspect of the nerve root was explored. The nucleus pulposus was removed if it was free or significantly herniated, otherwise, the disc was not resected. The nerve root canal was enlarged, and the nerve root decompression area was explored to the pedicles of both the proximal and distal vertebrae and laterally until the nerve hook easily passes through the ventral aspect of the superior articular process, ensuring adequate decompression around the nerve root, the restoration of nerve root fluctuation and significant improvement in mobility (Fig. 1D). Following thorough hemostasis, the endoscope and working cannula were removed, the incision was sutured, and a sterile dressing was applied.

UBE group

Taking the right side as an example, following successful anesthesia, the patient was placed in a prone position with the head fixed in a neutral position using a head holder. Routine disinfection and draping were performed. C-arm fluoroscopy was applied to locate the responsible segment and intervertebral space on the right side (Fig. 2A). With the intervertebral disc space as the central point, and a location 1.5 cm lateral to it

Fig. 1 There was PECD surgical procedure. (**A**) Responsible intervertebral space was located under the guidance of fluoroscopy machine. (**B**) Working channel was Established. (**C**) "V" point was found under endoscopy, and soft tissue and bone were removed to expose the nerve root. (**D**) The nerve root canal was enlarged under microscopy

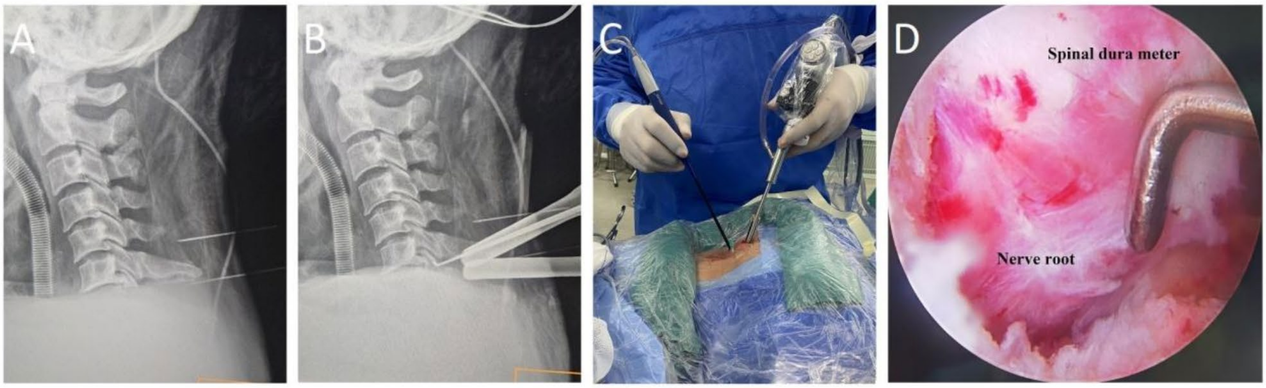

Fig. 2 There was UBE surgical procedure. (**A**) Responsible intervertebral space was located under the guidance of fluoroscopy machine. (**B**) Working channel was Established. (**C**) "V" point was found under endoscopy, and soft tissue and bone were removed to expose the nerve root. (**D**) The nerve root canal was enlarged under microscopy

(or the midpoint of the lateral mass facet joint in obese patients), two approximately 1 cm vertical incisions were made, one 1 cm cephalad and the other 1 cm caudad, respectively. Under fluoroscopic guidance (to avoid the catastrophic sequelae associated with cervical dilator instruments entering the vertebral canal), the initial dilator sleeve was safely advanced to the lamina. The soft tissues were gradually dilated using the working cannula, with the cranial end serving as the observation channel and the caudal end as the operating channel. The two channels were observed to intersect at the level of the transition between the superior and inferior laminae and the articular processes (Fig. 2B). Under endoscopic visualization, the interlaminar space between the laminae and the outer half of the superior and inferior laminae, as well as the inner part of the facet joint, were exposed. RF ablation was performed to remove the soft tissues on the laminae and facet joint surfaces to locate the "V" point (Fig. 2C). The inferior-outer portion of the superior laminae and the superior-outer portion of the inferior laminae, together with at least approximately 4 mm cephalad and medial portion of the superior articular process and the ligamentum flavum, were removed using a power drill and miniature bone nibbler. The nerve root was exposed and explored, and the power drill was used to remove hypertrophic bone. The nucleus pulposus was removed if it was free or significantly herniated, otherwise, the disc was reserved. The neural foramen was enlarged, and the nerve root decompression area should be explored to the pedicles of both the proximal and distal vertebrae and laterally until the nerve hook easily passes through the ventral aspect of the superior articular process, ensuring adequate decompression around the nerve root, the restoration of nerve root fluctuation and significant improvement in mobility (Fig. 2D). Following thorough hemostasis, the endoscope and working cannula were removed, the incision was sutured, and a sterile dressing was applied.

Clinical and radiological assessment

Demographic and clinical characteristics included age, sex, body mass index, number of operation segments, and medical comorbidities.

Operative data included the hospitalization time, operative duration, fluoroscopy exposures times, and incision length.

Radiographic measurements included the following sagittal parameters in lateral cervical X-rays (Fig. 3): (i) the segmental Cobb's angle (SCA), namely, the angle between the parallel line of the inferior endplate of the upper vertebral body and the parallel line of the superior endplate of the lower vertebral body in the surgical segment; (ii) the C2–C7 cervical sagittal vertical axis (cSVA), namely, the horizontal distance between the vertical line of the midpoint of the C2 vertebra and the posterior upper corner of the C7 superior endplate; (iii) cervical curvature (C2–C7), namely, the angle between the tangent of the posterior margin of the C2 and C7 vertebral bodies on lateral radiographs by the Harrison tangential method; (iv) the T1 slope (T1S), namely, the angle between the parallel line on the upper edge of the T1 endplate and the horizontal straight line; and (v) surgical segment disc height (DH), namely, average of the anterior and posterior DH. The anterior facet length (FL) and postoperative facet length (po-FL) were measured by CT to assess the extent of facet preservation resection (FPR) (Fig. 4), FPR = po-FL/FL×100%.

The visual analog scale (VAS) pain score was used preoperatively and at 3 months and 2 years postoperatively for neck and arm pain assessment; the neck disability index (NDI) was used preoperatively and at 3 months and 2 years postoperatively to evaluate the patients' functional state; and the modified MacNab criteria [15]

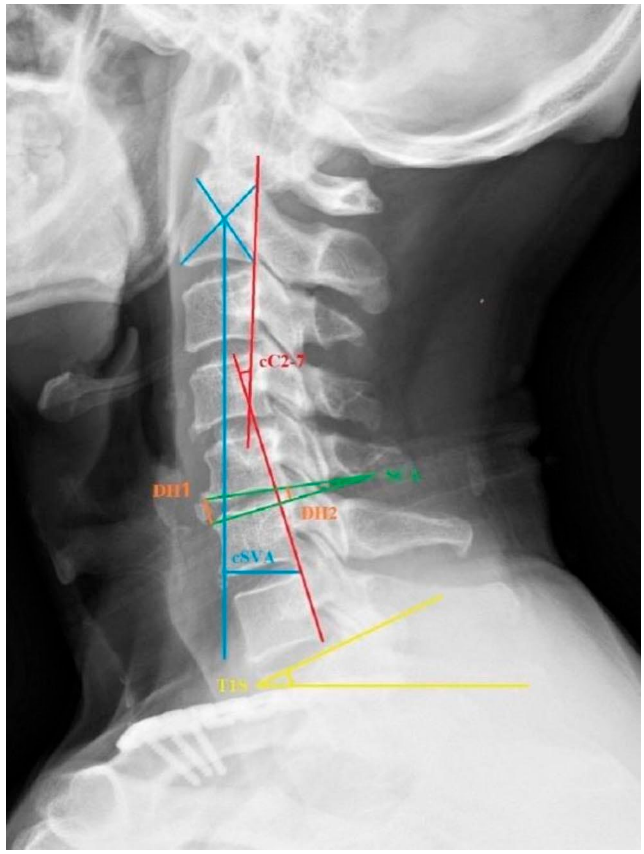

Fig. 3 Lateral X-ray measurements of cervical spine were illustrated. SCA, the angle between the parallel line of the inferior endplate of the upper vertebral body and the parallel line of the superior endplate of the lower vertebral body in the surgical segment; cSVA, the horizontal distance between the vertical line of the midpoint of the C2 vertebra and the posterior upper corner of the C7 superior endplate; cC2–7, the angle between the tangent of the posterior margin of C2 and C7 vertebral bodies on lateral radiographs; T1S, the angle between the parallel line on the upper edge of the T1 endplate and the horizontal straight line; DH1, anterior intervertebral disc height of the surgical segment; DH2,posterior intervertebral disc height of the surgical segment

was applied to characterize surgial outcomes at 2 years postoperatively.

Statistical analysis

Statistical analyses were performed with Statistical Package for the Social Science (SPSS) software (version 24.0; IBM, Inc.). The Shapiro−Wilk test was used to test the normality of the distribution, and continuous values are expressed as the mean ± standard deviation or median (interquartile range). The comparison between groups was made by the independent sample *t* test or rank-sum test. The classified variables were expressed as numbers, and comparisons between groups were performed by the chi-square test followed by Bonferroni correction. One-way analysis of variance (ANOVA) and repeated measures ANOVA followed by the least significant difference test was used to compare multiple groups of variables. A p value of <0.05 was considered to be statistically significant.

Results

Demographic results and clinical efficacy

There was no significant difference in hospitalization ($p = 0.487$) or fluoroscopy times ($p = 0.329$). In contrast, the UBE group had significantly shorter operative time compared to the PECD group (65.6 ± 17.6 vs. 85.1 ± 24.2 min, $p < 0.001$), but the former had longer incision length than the latter (2.4 ± 0.4 cm vs. 1.3 ± 0.4 cm, $p < 0.001$) (Table 2). There was no significant change in the postoperative SCA, cervical curvature, T1S, or DH compared to the preoperative values within both groups ($p > 0.05$). Both groups showed a significant reduction in the postoperative cSVA compared to preoperative measurements (PECD: $p = 0.009$; UBE: $p = 0.010$) (Table 3). The FPR did not have a statistically significant difference between the two groups ($p = 0.158$) (Table 2).

The follow-up results of the two groups showed a significant improvement in the postoperative neck and arm pain VAS scores and NDI compared to preoperative values ($p < 0.001$). The improvement in these indicators continued to be significant over time, and the differences

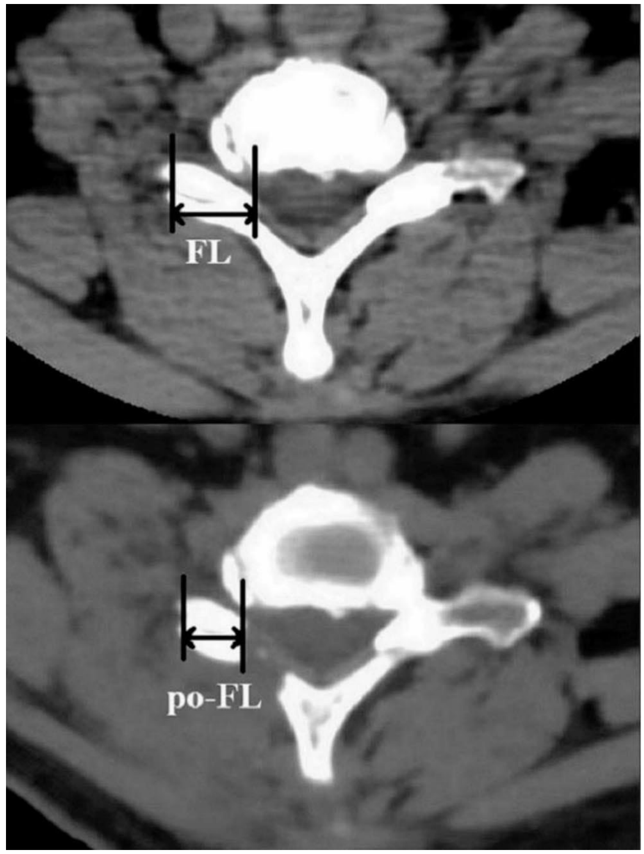

Fig. 4 Facet length measurement of cervical spine was illustrated in CT. FL, anterior facet length; po-FL, postoperative facet length

Table 2 Surgical outcome data

Variable	PECD group($n=40$)	UBE group($n=30$)	p-value
Hospitalization time, days	7.5 ± 1.8	7.4 ± 1.8	0.847
Operative duration, min	85.1 ± 24.2	65.6 ± 17.6	<0.001
Number of fluoroscopy exposures (range)	3(2–3)	3(2–3)	0.329
Incision length, mm	1.3 ± 0.4	2.4 ± 0.4	<0.001
Facet preservation rate, %	65.4 ± 15.7	70.2 ± 11.3	0.158

Values are expressed as the median (P25-P75), mean ± SD or number as stated

$p < 0.05$, statistical significance

were statistically significant in pairwise comparisons ($p < 0.001$). In contrast, there was no statistically significant difference in these indicators between the two groups ($p > 0.05$) (Fig. 5). The clinical efficacy at 2 years postoperatively, as evaluated by the modified MacNab criteria, showed that in the UBE group, 27 out of 30 patients were graded as having a good or excellent result according to the modified MacNab criteria, with an excellent/good rate of 90.0%. In the PECD group, 35 out of 40 patients were graded as having a good or excellent result, with an excellent/good rate of 87.5%. However, no statistically significant difference was identified between the two groups ($p = 0.08$) (Table 4).

Table 3 The comparison of the imaging relevant data of two groups

	PECD group ($n=40$)			UBE group ($n=30$)		
Variable	Preoperative	Postoperative 2 years	p-value	Preoperative	Postoperative 2 years	p-value
SCA, °	3.4 ± 3.1	3.8 ± 2.5	0.136	0.8 ± 3.7	1.4 ± 3.3	0.580
cSVA, mm	24.1 ± 9.3	20.3 ± 8.0	0.009	27.0 ± 9.5	22.4 ± 8.4	0.010
Cervical curvature, °	11.7 ± 10.4	12.6 ± 8.1	0.433	8.0 ± 10.8	9.4 ± 9.1	0.750
T1S, °	25.0 ± 6.8	23.7 ± 6.9	0.273	22.6 ± 6.8	24.2 ± 6.3	0.331
DH, mm	4.1 ± 0.5	3.9 ± 0.5	0.061	4.2 ± 0.6	4.0 ± 0.3	0.101

Values is expressed as mean ± SD

SCA segmental Cobb's angle; cSVA cervical sagittal vertical axis; T1S the T1 slope; DH disc height

$p < 0.05$, statistical significance

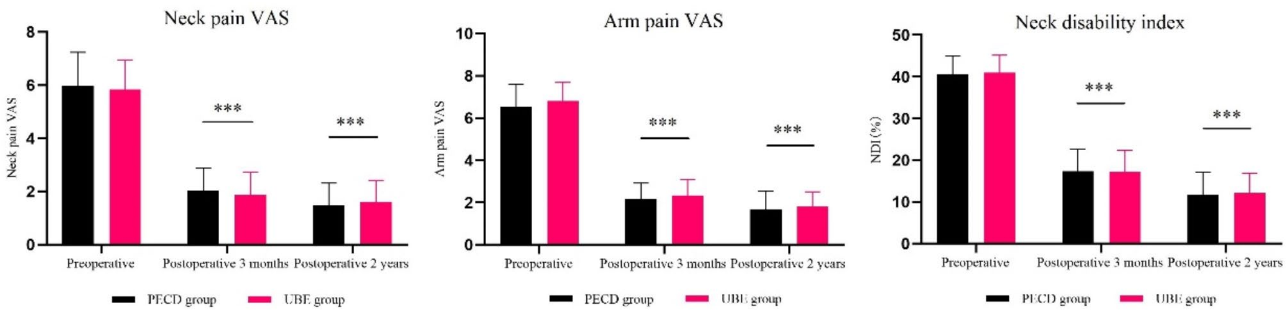

Fig. 5 The visual analogue scale (VAS) and Neck Disability Index (NDI) were showed at each point in time. *** Statistically significant change compared to preoperative period in each group, $p<0.001$. PECD percutaneous endoscopic cervical discectomy, UBE unilateral biportal endoscopy

Table 4 Modified MacNab outcome assessment of patient satisfaction with the surgical procedure at 2 years postoperatively

index		PECD group ($n=40$)	UBE group ($n=30$)
	Excellent	24	16
MacNab	Good	11	11
Criteria	Fair	5	3
	Poor	0	0
	Excellent/good rate(%)	87.5	90.0
p-value		0.723	

$p<0.05$, statistical significance

Surgical complications

All incisions healed in stage I. One case of postoperative nerve root irritation symptoms occurred in the PECD group, with no obvious abnormalities found on re-MRI, and the symptoms resolved after 3 weeks of nutritional nerve drugs administration. One case of mild spinal cord injury occurred in the UBE group and recovered after 3 months of nutritional neurological drugs and rehabilitation exercises. No patients in either group experienced recurrence or required reoperation during the follow-up (Figs. 6 and 7).

Discussion

With the rapid advancement of electronic information products and changes in lifestyles, the cervical spine is subjected to more stress than ever before, contributing to an increasing incidence of CSR and a trend towards younger populations. CSR is a common type of cervical spine disease characterized by the degeneration of intervertebral disc, facet joints, and ligaments, leading to nerve root compression or irritation and subsequent secondary inflammatory damage [1, 16]. Although 75–90% of CSR patients can obtain pain relief after conservative treatment, surgical intervention is necessary for those who do not respond to standard nonoperative treatments [17, 18]. ACDF, first described by Smith and Robinson in 1958, has achieved a good therapeutic effect [19]. By providing immediate cervical stability, direct and effective nerve decompression, and restoration of cervical lordosis, ACDF has been widely recognized as the gold standard treatment for CSR [20]. However, spinal fusion

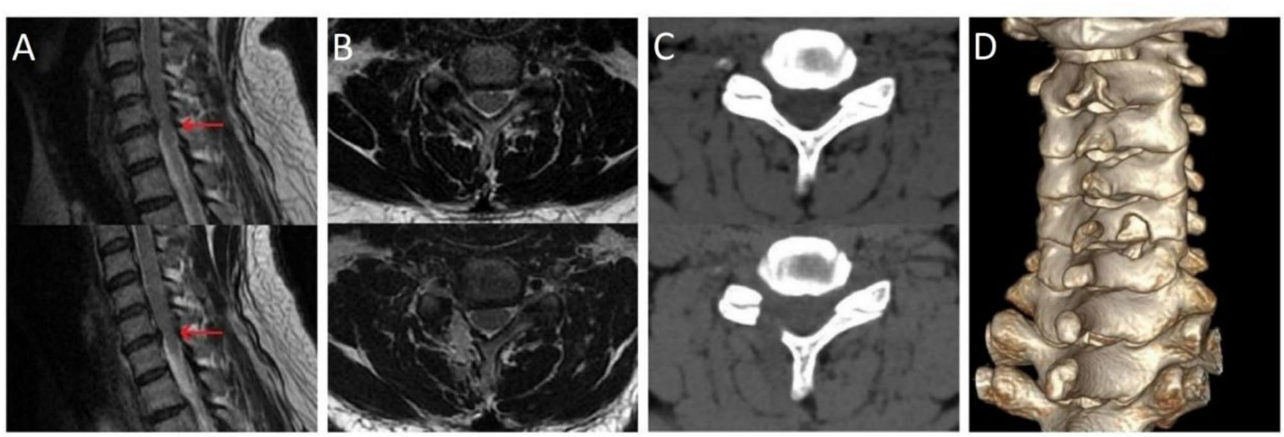

Fig. 6 A 52-year-old male who was diagnosed with CSR had been experiencing neck pain accompanied by radiating pain in the right upper limb for 2 years, and underwent PECD key-hole decompression treatment. (**A**, **B**) Preoperative MRI showed compression of the right C5–6 intervertebral disc on the cervical nerve root, and postoperative MRI showed relief of right nerve root compression and the nerve root canal was smooth. (**C**) Axial CT indicated a facet preservation rate of 85.6%. (**D**) Postoperative three-dimensional CT showed limited bone resection

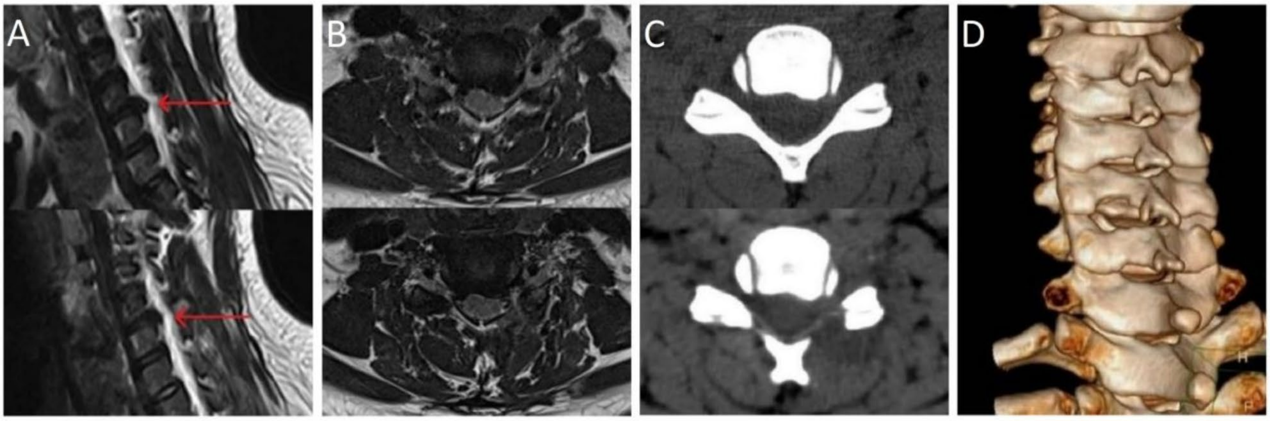

Fig. 7 A 37-year-old male who was diagnosed with CSR had been experiencing neck pain accompanied by radiating pain in the left upper limb for 1 year, and underwent UBE key-hole decompression treatment. (**A**, **B**) Preoperative MRI showed compression of the left C5–6 intervertebral disc on the cervical nerve root, and postoperative MRI showed relief of right nerve root compression and the nerve root canal was smooth. (**C**) Axial CT indicated a facet preservation rate of 77.7%. (**D**) Postoperative three-dimensional CT showed limited bone resection

alters the biomechanical characteristics of the spinal operated and adjacent segments, increasing the risk of adjacent segment disease [21]. Many other complications, including dyspahgia, recurrent laryngeal nerve injury, hematoma, esophageal perforation, cage migration, and pseudoarthrosis, must be taken into consideration [22, 23]. In 1993, Zeidman and Ducker first reported the use of a posterior key-hole technique for CSR treatment, suggesting that this technique was highly effective for decompression of lateral or foraminal nerve root compression [7]. Key-hole techniques are favored due to their minimal invasiveness, avoidance of fusion, and more rapid recovery [24].

Minimally invasive endoscopic techniques have gained popularity in recent years due to their minimal invasiveness and precision. In 2007, Ruetten et al. first reported PECD for CSR treatment, which showed excellent clinical outcomes with a satisfaction rate > 90% [25]. Due to minimal disruption of cervical muscle tissue, preservation of motion segments, and more rapid postoperative recovery, PECD has gradually become more widely adopted [26]. As an essential part of minimally invasive spine surgery, endoscopic techniques have continuously evolved and are regarded as a practical surgical approach in the field of spinal surgery, both domestically and internationally [27]. UBE has been attracting attention since its introduction due to its flexibility, minimal invasiveness, and safety, with effective clinical outcomes [28, 29]. Park et al. reported the first application of the UBE technique in CSR treatment in 2017, showing significant improvements in VAS scores and NDI postoperatively, and considered it to be a good alternative surgical technique for the treatment of soft cervical disc herniation and foraminal stenosis, which was the first report of UBE in the treatment of cervical spine diseases [12]. Song et al. reported the treatment of seven cases of radiculopathy caused by cervical foraminal bone spur applying the UBE technique in 2020, which achieved sufficient decompression of the foraminal area by removing < 50% of the facet joint bone, without affecting cervical stability, increased the postoperative foraminal area significantly, and achieved satisfactory clinical outcomes, making it an effective method for treating this form of radiculopathy [13].

In this study, both groups underwent key-hole technique with limited paraspinal muscle dissection, which resulted in minimal tissue damage and shorter hospital stays. Without any specific complications, patients in both groups were able to ambulate on the first postoperative day, thereby reducing the occurrence of postoperative bed rest-related complications such as atelectasis and deep vein thrombosis. In general anesthesia surgeries, extended operation time, and increased blood loss are associated with delayed recovery [30], which in turn increases the surgical risks. In the present study, the UBE group had a shorter operation time compared to the PECD group. Despite the UBE group having larger incisions compared to the PECD group due to the bilateral approach, UBE provides more flexibility in terms of coaxial restrictions and dual-channel manipulation, allowing for a shorter operation time and reduced surgical risks. Excessive radiation exposure can cause varying degrees of damage to both patients and surgeons, and medical personnel have a limited allowance for radiation exposure annually without the presence of radiation shielding [31]. Studies have shown that repeated exposure to radiation increased the risk of cataract development [32]. In the present study, both PECD and UBE utilized the interlaminar approach, which simplified and expedited the localization process, significantly reducing radiation exposure for both patients and medical personnel, thereby further reducing radiation-related injuries. Compression, inflammatory factor stimulation, and ischemia are the three main pathological mechanisms for radiculopathy in cervical spondylosis. Both PECD and UBE effectively remove compressive elements, relieving nerve root compression. Additionally, the surgeries were performed under water medium, which flushes out local inflammatory factors, alleviating postoperative pain. Furthermore, reestablishing the blood supply aids in long-term pain relief. The VAS and NDI scores postoperatively showed significant improvement at different time points, with excellent/good rates attaining 89.8% and 91.3%, respectively, which were comparable to previous research findings [12, 13, 26].

The sagittal alignment of the cervical spine is an important indicator for evaluating the effectiveness of surgical treatment. Deviations in the cervical sagittal plane can lead to sagittal imbalance of the cervical spine and even the entire spinal axis, resulting in neck and shoulder pain, decreased cervical range of motion, and affecting surgical outcomes [33, 34]. In the present study, there was no significant changes in segmental Cobb angles or cervical curvature in both groups, but there was a slight increase in C2–7 SVA after the surgery. This may be due to the reduction of intervertebral disc pressure, alleviation of nerve stimulation, and pain relief. Some cervical spondylosis patients have significant thoracic kyphosis, and in order to maintain a level visual horizon, the compensatory mechanism of the cervical spine leads to an increase in Cobb angles and changes in the cSVA. Under these circumstances, the T1S can better reflect the sagittal balance of the cervical spine and the entire spine [35]. In the present study, there was no statistically significant change in the T1S in either group, indicating that PECD and UBE had no significant effect on the sagittal balance of either the cervical or entire spine. In minimally invasive surgery, preserving the posterior elements of the spine can minimize the risk of postoperative instability and/or accelerated facet joint and intervertebral disc degeneration [36]. DH loss is one of the most common radiographic manifestations of lumbar disc degeneration and can also cause spinal canal narrowing [37]. Both groups underwent a key-hole technique which only decompressed the nerve roots and selectively removed free nucleus pulposus tissue while preserving the original intervertebral disc. There was no statistically significant difference in DH between preoperative and postoperative measurements, indicating that PECD and UBE had no significant impact on disc degeneration or spinal canal diameter. The changes in cervical lordosis and DH were not significant at the final follow-up, which was consistent with previous reports in the literature [38]. In key-hole surgery, partial resection of the lateral facet joints is necessary to obtain operating and decompression space, but excessive resection can lead to cervical instability. To avoid instability, it is recommended that resection of lateral facet joints should be $<50\%$ [39]. In the present study, none of the included patients exhibited cervical instability. The mean FPR was $>50\%$ in both groups, indicating that both PECD and UBE minimized damage to the facet joints and effectively reduced the risk of iatrogenic cervical instability.

Postoperative complications are an important indicator for evaluating the safety of surgery and are a major concern for clinicians. Complications associated with endoscopic surgery include dural injury, postoperative sensory disturbances, wound infection, and hematoma, among others [26, 38]. In the PECD group, one patient experienced postoperative root irritation symptoms during the surgery, but no significant abnormalities were found on subsequent MRI. The symptoms resolved after 3 weeks of treatment with neurotrophic medicine. We supposed that it may have been associated with the electrocautery stimulation of the nerve root during the surgery or was stretched due to adhesions around the nerve root during the decompression. While general anesthesia generally provides a more comfortable surgical experience for patients, the risk of nerve root irritation or injury is relatively increased due to the inability to receive timely feedback from the patient during the surgery. In the UBE group, one patient had mild numbness of the limbs and movement disorder below the surgical plane after surgery, and MRI reexamination showed no hematoma formation or abnormal signal changes in the spinal cord after surgery. The symptoms gradually disappeared after administration of microcirculation-improving drugs, methylcobalamin drug treatment and functional rehabilitation exercises. We considered that this phenomenon was a mild spinal cord injury caused by nerve hook pulling the spinal cord to remove nucleus pulposus tissue in a narrow cervical spinal canal. The spinal cord's tolerance for traction is much lower than that of the cauda equina, thus excessive traction and stimulation of the spinal cord should be avoided as far as possible. During the surgical procedure, it is imperative to achieve meticulous hemostasis to ensure an unobstructed surgical field. Techniques including controlled hypotension (90/60 mmHg) and standard patient positioning (with the cervical spine aligned parallel to the floor) can mitigate intraoperative hemorrhage. We recommend performing bony decompression prior to soft tissue decompression as excessive bleeding may compromise bony decompression. This sequential approach can substantially enhance surgical efficiency and reduce the duration required for hemostasis, thereby circumventing the hazardous application of probes and rongeurs to forcefully expose nerve roots (which can precipitate intractable hemorrhage). Upon completion of decompression, a small curette may be utilized to address any residual bony tissue dorsally, thereby facilitating improved visualization of the nerve roots. In the present study, in both groups, intraoperative decompression revealed clear neural root canal patency and good mobility of the nerve roots and dural pulsations. The patients experienced significant improvement in symptoms after surgery, without any cases of recurrence or reoperation at the final follow-up, which could be related to factors such as the study sample size or follow-up duration,, highlighting the need for future investigations involving larger cohorts and prolonged observation.

Precise determination of the decompression range under endoscopic visualization, combined with a thorough evaluation of decompression adequacy, is crucial for optimal surgical outcomes [40]. Due to the imbricated configuration of the cervical facet zygapophysial joints, cervical UBE procedures require resection of approximately 4 to 5 mm of the cephalad and medial portion of the inferior vertebra's superior articular process, after moderate resection of the superior vertebra's inferior articular process and a portion of the inferior vertebral lamina. This maneuver facilitates sufficient decompression (in view of the fact that the overwhelming majority of radicular cervical spondylosis is attributable to neural foraminal stenosis), and exploration extending to the pedicles of adjacent vertebrae. Concurrently, the surgeon should observe the nerve root for pulsation. The presence of a flattened nerve root indicates potential compression by a protruding or free disc, most commonly found in the axilla of the nerve root (at the C5/6/7 disc spaces) and less commonly directly ventral to the nerve root (at the C3/4/5 disc spaces). A ball-tipped probe, fine nerve dissector, and micro pituitary rongeur are utilized for delicate removal of the nucleus pulposus, with great care to prevent any iatrogenic damage to the spinal cord. Kim et al. suggested using the "V" point at the junction of the upper and lower endplates adjacent to the facet joints as an anatomical landmark for endoscopic operation [38]. However, the "V" point is a dynamic landmark that moves internally and externally with cervical flexion and extension, and the distance between the "V" point and the outer edge of the dura and the vertebral artery varies across different segments. Therefore, the surgeon needs to adjust the window size accordingly based on the different target location and responsible segment. Both PECD and UBE can effectively achieve precise key-hole decompression, while compared with PECD, UBE has the advantages such as a wider field of view, elimination of coaxial limitation, flexible dual-channel operation, shorter operation time, lower instrument and equipment requirements, and a smoother learning curve. Additionally, strict selection criteria for surgical indications is crucial. PECD is mainly suitable for CSR caused by lateral cervical disc herniation and foraminal stenosis, while it is not suitable for cases with a narrow disc space, bone stenosis, or a rigid intervertebral disc [41]. UBE is primarily applicable to CSR caused by foraminal stenosis, with or without osteophytes, whereas it is not suitable for cases with central canal stenosis, instability, or a collapsed intervertebral disc [13]. Therefore, for patients with CSR who require surgery, a personalized treatment plan should be provided by considering the patient's clinical symptoms, radiographic findings, and the surgeon's experience.

Conclusion

PECD and UBE, as surgical methods for treating CSR, have the advantages of minimal trauma and rapid postoperative recovery. Both of them effectively protected the sagittal balance and stability of the cervical spine and achieved satisfactory clinical efficacy. Despite the possibility of endoscopy-related complications, to a certain extent, PECD and UBE make up for the shortcomings associated with anterior open decompression or posterior fenestration techniques. Compared with PECD, however, UBE has a wider field of view, more flexible dual-channel operation, lower instrument and equipment requirements, and a smoother learning curve. For patients without cervical instability or ligament ossification symptoms, UBE can be used as a transitional treatment method before fusion and fixation surgery, effectively supplementing the deficiencies of conventional surgeries.

Abbreviations

CSR	Cervical spondylotic radiculopathy
ACDF	Anterior cervical discectomy and fusion
PECD	Percutaneous endoscopic cervical discectomy
UBE	Unilateral biportal endoscope
CT	Computed tomography
MRI	Magnetic resonance imaging
SCA	Segmental Cobb's angle
cSVA	Cervical sagittal vertical axis
DH	Disc height
FL	Facet length
FPR	Facet preservation resection
VAS	Visual analog scale
NDI	Neck disability index

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Author contributions

YZ, PH and GD were involved in study concept and design, acquisition of data. YZ and WZ helped in statistical analysis. YZ and JD contributed to drafting of the manuscript. YW and PH were involved in study supervision. All authors helped in interpretation of data; critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the ethics committee of Binzhou Medical University Hospital, China (2023, LW-159), with all patients signing the written informed consent. All methods were performed in accordance with the relevant guidelines and regulations approved by the ethics committee of Binzhou Medical University Hospital.

Consent for participation
Informed consent was obtained from all participants for using their imaging data and questionnaire scores.

Consent for publication
Written informed consent to publish the clinical details and images of the patient was obtained.

Competing interests
The authors declare no competing interests.

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