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Retrospective Study

Minimally Invasive Full-Endoscopic Posterior Cervical Foraminotomy Assisted by O-Arm-Based Navigation

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Background: Navigated percutaneous endoscopic cervical discectomy (PECD) is a promising minimally invasive surgery for treating cervical spondylotic radiculopathy. PECD has been described as a safe, effective, and minimally invasive method for patients with radiculopathy, but it comes with a steep learning curve. Due to the limited field of vision, anatomic localization is difficult for surgeons until using the O-arm based navigation. In this study, patients with radiculopathy due to foraminal disc herniation or foraminal stenosis in the lower cervical spine underwent the single level full endoscopic posterior cervical foraminotomy procedure assisted by O-arm-based navigation.

Objective: The purpose of this study was to evaluate the clinical, radiological outcome and the factors predicting an excellent outcome of patients who underwent full endoscopic posterior cervical foraminotomy procedure assisted by O-arm-based navigation.

Study Design: A retrospective analysis of consecutively prospectively collected data.

Setting: This study was conducted by a university-affiliated hospital in a major Chinese city.

Methods: Forty-two patients who had single-level foraminal disc herniation or foraminal stenosis were retrospectively reviewed. Radicular arm pain was the most common presenting symptom in patients. All patients underwent full-endoscopic posterior cervical foraminotomy assisted by O-arm-based navigation. Clinical outcomes were assessed by the visual analog scale (VAS) for neck and radicular arm pain, neck disability index (NDI), and the short form-36 health survey questionnaire (SF-36) in the immediate preoperative period, immediately postoperative, and at the final follow-up. The clinical parameters and radiological parameters included cervical curvature (CA), segmental angle (SA), and range of motion (ROM), which were assessed preoperatively and at the last follow-up.

Results: The mean follow-up for the patients was 15 months. There were no perioperative complications. The VAS score for radicular arm pain and neck pain and the NDI score improved significantly in all of the patients. The SF-36 score reflected significant improvement in all 8 domains. Excellent and good outcomes were achieved in 38 out of 42 patients. The cervical curvature range of motion (CA-ROM) statistically and significantly improved at the final follow-up period compared with the preoperative period. The SA was less kyphotic after PECD at the final follow-up. The postoperative CA and CA-ROM improved but did not significantly change. On the univariate analysis, patients with a symptom duration of less than 3 months had a better outcome than patients with a symptom duration of more than 3 months (excellent, 83.33% vs. 50.00%).

Limitations: This was a retrospective study with medium follow-up outcomes (mean 15 months).

Conclusions: The results of this study show that the full endoscopic posterior foraminotomy assisted by O-arm-based navigation is a safe and effective option for cervical radiculopathy, with the advantages of a minimally invasive method. Patients with symptom duration less than 3 months had a better outcome than patients with symptom duration more than 3 months.

Key words: Minimally invasive, cervical foraminotomy, endoscopic, navigation, O-arm, percutaneous endoscopic cervical discectomy

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Percutaneous endoscopic cervical discectomy (PECD) for decompression of cervical nerve roots is a well-established, minimally invasive surgery for cervical radiculopathy. It was first described by Ruetten et al (1) in 2007 with indications of posterolateral soft disc herniations or foraminal stenosis. Traditional posterior foraminotomy is performed without additional stabilization and thus preserves the mobility of the segment (2-4). However, approach-induced neck pain by extensive stripping of the paraspinal musculature or intraoperative bleeding is still a problem (5). Unlike open surgery, the blunt insertion of a dilator and a working tube onto the facet joint make the incision of PECD only less than 1cm, without extensive subperiosteal stripping of the paraspinal musculature (6,7). The approach can decrease postoperative pain, blood loss, muscle spasm, and dysfunction when compared with the traditional open approach (8-10). Moreover, with the high-definition endoscope and under water infusion, a clear field of surgery can be achieved by inhibition of the bleeding. With the minimally invasive approach, morbidity is reduced and recovery and hospital stay are shortened (11-13).

In the past decade, only a few studies have been published as this technique still has some difficulties (14,15). First, anatomic structure identification is hard due to the limited visibility provided by a 5.9 mm diameter endoscope. Moreover, the requirement for a sufficient decompression without removing more facet joint needs an effective technique that preserves the minimally invasive character (6,16). Nevertheless, for patients with lower level diseases or short and thick necks, the x-ray cannot provide a clear position for the working canal.

Under image guidance systems, surgeons can obtain greater accuracy and high efficiency in most of spine surgery (17,18). By the image-guided spinal surgery, surgical instruments can be tracked in 3-dimensional (3D) space, which allows surgeons to navigate the spinal anatomy using preoperative or intraoperative computed tomography (CT) scan data. Through a navigation system, surgeons can get a real-time 3D anatomy of the spine structure and proximity of neurovascular structures in the surgery field. The advent of the intraoperative O-arm and computer-assisted navigation system has constituted a major breakthrough in this field. Previous studies have described successful navigation-assisted decompression and fixation of the spine with a shorter operation time, high screw-placement accuracy, and satisfactory decompression compared with traditional x-ray monitored surgery (19,20).

In this study, we describe the surgical technique of a full endoscopic posterior cervical foraminotomy assisted by an O-arm-based navigation system, as used in the treatment of unilateral radiculopathy due to foraminal disc herniation or foraminal stenosis in the cervical spine, especially for the lower levels.

Methods

Patients' Characteristics

Forty-two patients who had single-level foraminal disc herniation at our institution underwent PECD from May 2015 to December 2016. The study is based on a retrospective analysis of prospectively collected data with a mean follow-up period of 15 months. There were 28 women and 14 men patients whose ages ranged from 27 to 71 years (mean 47 years). The inclusion criteria of this study were: single-level foraminal or lateral soft cervical disc herniation demonstrated on CT and magnetic resonance imaging (MRI), radicular arm pain with or without neck pain being the most common presenting symptom, and a lack of response to extensive conservative treatment. The exclusion criteria were medial localization of the disc herniation, patients with isolated neck pain or foraminal stenosis without disc herniation, cervical myelopathy or spinal instability, and patients who had undergone earlier cervical surgery.

Hospital charts of the patients meeting the study inclusion criteria were further reviewed for information on relevant characteristics (body mass index, symptom duration, physical sign, and potential comorbidities). Clinical outcomes were assessed by the visual analog scale (VAS) for neck and radicular arm pain, neck disability index (NDI), and by the short form-36 health survey questionnaire (SF-36) in the immediate preoperative period, immediately postoperative, and at the final follow-up. A minimum interval of 7 months after surgery was required for patients to be considered in the analyses of clinical outcomes.

The radiological parameters obtained at the preoperative and final follow-up periods were evaluated, including the cervical curvature (CA, C2-7, tangential method), the segmental Cobb's angle at the operative level (SA), and the range of motion (ROM) of the CA and SA, which was measured from the extension and flexion lateral radiographs.

Surgical Technique

The patient is placed in a prone position under general anesthesia. The cervical spine was delordosated and the head was fixed with MAYFIELD® skull clamps (Integra Life Sciences, Plainsboro, NJ). The arms were positioned caudal on the body and immobilized with adhesive tape. Somatosensory evoked potentials and myotomal electromyography (EMG) were monitored.

In all patients, the O-arm and computer-assisted navigation system (O-arm Surgical Imaging System and Stealth-Station) (Medtronic, Minneapolis, MN) were used (Fig. 1A). The reference frame was fixed on an extension of a MAYFIELD® head-rest system after preparation and draping of the surgical field. The O-arm was then used to take images in anteroposterior and lateral views to assure that the surgical lever was in the center of the O-arm gantry. Then, the O-arm was used to take a 3D image with a medium dose of irradiation to reduce the x-ray exposure to the patient. The images acquired were rapidly transferred to the navigation system. Imaging reconstructions of the cervical spine were generated in a few seconds. After that, the navigation was ready and the surgery could continue. The whole procedure includes scan, image transfer, and registration and can take less than 10 minutes.

The operative level and incision site were confirmed using the navigation system (Fig. 1B), with the aid of the sagittal reconstructions aimed at the target facet joint and the axial views pointing over the laminofacet junction. A 0.7 cm incision was then made in the skin and cervical fascia. Blunt insertion of a dilator, which can be monitored by the navigation system, was performed onto the facet joint (Fig. 1C). The working cannel was inserted via the dilator (Fig. 1D). Then, the dilator was removed. In our first 10 cases, to verify the accuracy of navigation, we also re-scanned the surgical field after working cannel insertion. The results showed that all of the working cannels were in place, as shown in the pre-navigation image (Fig. 1E and 1F); the accuracy loss is acceptable for this technique.

Fig. 1. A) Intraoperative CT scan by O-arm. B) Incision identified by navigation monitor; The reference frame was fixed on the MAYFIELD® frame. C) The working cannel was inserted via the navigation probe, which acts as a dilator. D) The proper localization of the working cannel was verified via the navigation system. E) Intraoperative radiograph showing the difficulty in verifying the location of the working cannel. F) Intraoperative CT scan by O-arm after working cannel insertion verified the accuracy of the navigation.

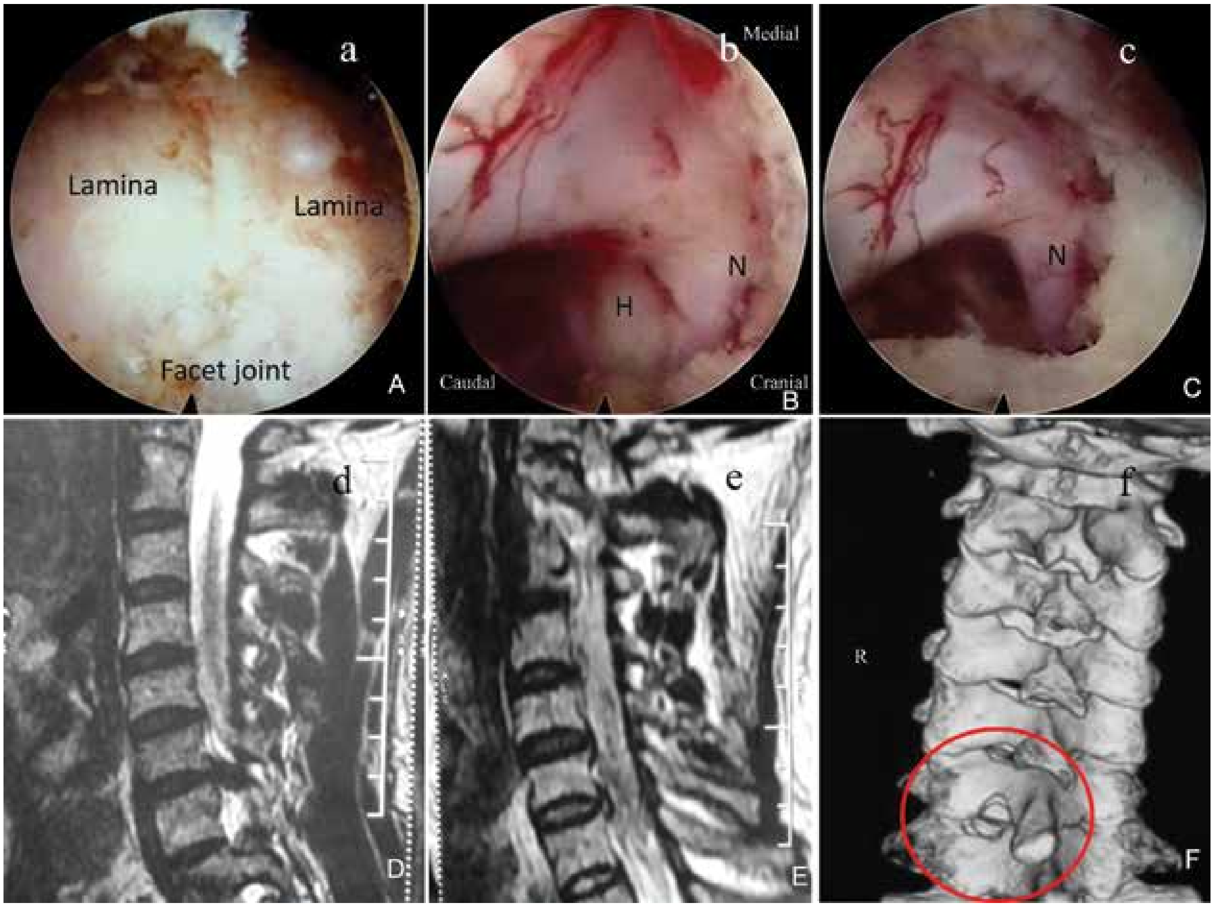

Fig. 2. *A) Removal of soft tissue on the laminar and facet joint. B) The herniation site at right side of C6/7 (H= herniation, N= C-7 nerve root). C) Intraoperative view after resection of the herniation and free C-7 nerve. D) MRI image of herniation before surgery. E) MRI image after surgery. F) Postoperative view of a 3-D reconstruction of the keyhole decompression field, which preserved most of the facet joint.*

After insertion of the 5.9 mm endoscope, further operation was performed under visual control and continuous fluid flow with 0.9% saline solution. After cleaning the soft tissue on the joint by a bipolar radiofrequent coagulation, the margin of the superior laminar, inferior laminar, and medial point of the facet joint were identified (Fig. 2A). A keyhole foraminotomy was performed at the lamina-facet junction using a 3 mm diamond burr and a bone punch (1). The lateral ligamentum flavum was resected without violating the prominent venous plexus around the nerve root. Then, the lateral edge of the spinal cord and branching of the spinal nerves were identified. Bipolar radiofrequent coagulation of the venous plexus was gently performed for preparation of the desired nerve root and herniation (21). The ruptured fragments were removed, and the discectomy was completed using micropituitary forceps of different angles. The completeness of the desired nerve root decompression was identified under particular attention at the end of procedure (Fig. 2B, 2C). Depending on the herniation, the foraminotomy can be extended toward lateral or craniocaudal under navigation. The postoperative MRI and CT scan identified the decompression and keyhole range (Fig. 2D-2F).

Statistical Analysis

The paired t test and relevant nonparametric tests were performed for the preoperative and final follow-up radiological parameters (CA, SA, ROM of CA/SA). One-way ANOVA was used for the clinical outcomes for the 3-evaluated period. Mann-Whitney's U test and the chi-square test were used for the univariate analysis of the clinical factors affecting prognosis. The descriptive assessments and analytical statistics were performed depending on the group characteristics with SPSS Version 21.0 (IBM Corporation, Armonk, NY). A positive significance was defined as probability of less than 0.05 for 2-sided.

Results

In all patients, disc herniation was successfully removed and there was no need to convert to open surgery. The mean operative time was 86 minutes, and there was no measurable blood loss; postoperative drainage was not necessary. The demographic characteristics of 42 patients are summarized in Table 1. There were no perioperative complications. Two cases of temporary postoperative dysesthesia had an effective result of pain relief in the postoperative fifth day after intervertebral foramen block with an analgesic drug and steroid.

Clinical Evaluation

The VAS score for radicular arm pain and neck pain improved significantly in all patients. The mean preoperative VAS score for neck pain was 6.95 ± 0.85, whereas the immediate postoperative score was 2.07 ± 1.26. At the final follow-up, improvement continued, reaching a mean VAS score of 0.33 (0 to 3). The VAS score for radicular pain improved from 7.05 ± 0.85 before surgery to 1.57 ± 1.31 at the immediate postoperative period and reaching 0.14 (0 to 3) at the final follow-up. The NDI score also significantly decreased from 55.64 ± 12.01 (%) before surgery to 22.37 ± 13.36 (%) and then reaching 4% at the final follow-up (Table 2).

The SF-36 score reflected significant improvement in all 8 domains. SF-36 Bodily Pain (BP), Physical Functioning (PF), and Social Function (SF) index scores improved significantly after surgery and continued significantly increasing at the final follow-up. There was a statistically significant increase in 5 other SF-36 index scores at the final follow-up visit compared to the preoperative period (Fig. 3). Based on the MacNab criteria, the surgical outcomes were excellent in 27 (64.3%) patients, good in 11 (26.2%) patients, and fair in 4 (9.5%) patients; there were no poor outcomes reported.

Radiological Parameters

The radiological results are summarized in Table 3. The cervical curvature ROM (CA_ROM) statistically, significantly improved at the final follow-up period compared with the preoperative period. The segmental angle (SA) was less kyphotic after the PECD at the final follow-up. The preoperative SA was kyphotic in 27 out of 42 of the patients and the postoperative SA was kyphotic in 23 out of 42 of the patients after the PECD at the final follow-up period. The postoperative CA and SA-ROM were improved but not significantly changed.

Table 1. *Demographic characteristics of 42 patients.*

Characteristics	No. of Patients	%
Gender		
Male	28	66.7
Female	14	33.3
Average Age (yrs)	47.1 ± 9.1	-
Symptom Duratio		
<3 mos	18	42.9
≥3 mos	24	57.1
Operation Level		
C3-C4	1	2.4
C4-C5	2	4.8
C5-C6	24	57.1
C6-C7	15	35.7
Body Mass Index		
Normal (18.5 ~ 24)	19	45.2
Overweight (24 ~ 28)	18	42.9
Obese (≥ 28)	5	11.9
Physical Sign		
Sensory deficits	8	19.0
Motor deficits	9	21.4
Both	7	16.7
Pain alone	18	42.9
Surgical Time (mins)	86.0 ± 19.6	-
Postoperative Hospitalization Stay (days)	4.6 ± 1.9	-
Hospitalization Cost ($)	5130.6 ± 700.0	-
Potentially Contributing Comorbidities		
Hypertension	4	9.5
Diabetes	2	4.8
Tobacco Use	4	9.5
None	32	76.2

Univariate Analysis of Prognosis and Risk Factors

The potential risk factors of 42 patients and the results of the univariate analysis of the effects of the clinical factors on prognosis are listed in Table 4. On the univariate analysis, patients with symptom duration less than 3 months had a better outcome than patients with symptom duration more than 3 months (excellent, 83.33% vs. 50.00%). No significant differences were found between prognosis and any other factors.

Table 2. *VAS scores for neck pain and radicular arm pain and SF-36 scores survey questionnaire preoperative, postoperative, and at the final follow-up.*

	Preoperative	Postoperative	Final Follow-Up
Neck-VAS	6.95 ± 0.85	2.07 ± 1.26*	0.33 ± 0.79*#
Arm-VAS	7.05 ± 0.85	1.57 ± 1.31*	0.14 ± 0.52*#
NDI	55.64 ± 12.01	22.37 ± 13.36*	4.00 ± 7.11*#
PF	44.02 ± 3.32	75.69 ± 10.54*	85.19 ± 4.96*#
PR	12.98 ± 16.64	15.95 ± 17.99	53.33 ± 21.82*#
BP	26.98 ± 12.70	47.18 ± 12.54*	78.62 ± 5.53*#
GH	53.36 ± 17.64	56.10 ± 16.45	65.55 ± 5.16*#
VT	59.01 ± 11.82	65.05 ± 11.83*	69.02 ± 4.37*
SF	9.08 ± 4.78	59.54 ± 15.07*	71.02 ± 17.13*#
ER	16.14 ± 19.33	17.22 ± 27.21	40.94 ± 30.89*#
MH	58.60 ± 9.24	64.93 ± 12.27*	65.64 ± 4.84*

*Significant difference between postoperative and preoperative or between final follow-up and preoperative.
#Significant difference between postoperative and final follow-up.
NDI = Neck Disability Index; PF = physical functioning; PR = physical role; ER = emotional role; SF= social function; MH = mental health index; VT = vitality; BP = bodily pain index; GH = general health prescriptions

Discussion

Posterior cervical foraminotomy (keyhole) is a well-established surgery technique for treating radicular symptoms caused by lateral disc herniations and/or foraminal stenosis (1,22). Under the aim of sufficient decompression with concurrent minimization of surgery-related trauma, PECDs have already been demonstrated in previous studies, with satisfactory results being achieved in most of the studies (10,23,24). With a one-step dilatation, the working cannel, endoscope, and instruments were directly placed over the surface of the lamina or facet joint and placed through a 0.7 cm skin incision. The reduction of the incision size and the direct placement of the working cannel without any muscle dissection could result in an improvement of the postoperative recovery (3,5,11,12). Therefore, the low approach-related morbidity is one of the advantages of PECD. Com-

Table 3. *Radiological outcomes.*

	Pre	Final	*P*-Value
CA (°)	-3.59 ± 10.22	-4.83 ± 8.61	0.144
CA_ROM (°)	27.77 ± 16.18	31.82 ± 15.18	0.002*
SA (°)	3.29 ± 5.42	1.84 ± 4.76	0.0001*
SA_ROM (°)	6.09 ± 4.61	6.66 ± 4.35	0.123

CA = cervical curvature; ROM= range of motion; SA = segmental angle
*Significant difference between preoperative and final follow-up.

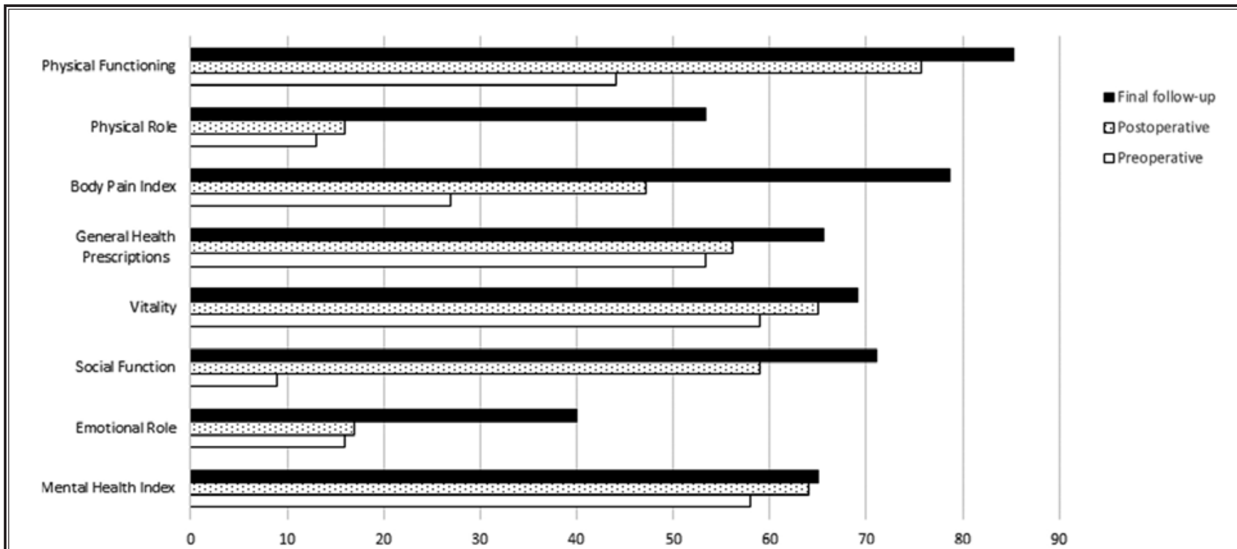

Fig. 3. *SF-36 health survey questionnaire at preoperative, postoperative, and final follow-up periods.*

Table 4. *Results of multivariate analysis of the clinical factors affecting prognosis.*

Factor	No. of Patients	Excellent Outcome		*P*-Value
		No.	%	
Gender				
Male	28	16	57.14	0.153
Female	14	11	78.57	
Age < 40 (yrs)	7	5	71.43	0.512
Age ≥ 40 (yrs)	35	22	61.11	
Comorbidity				
Hypertension	4	3	75.00	0.259
Diabetes	2	0	0.00	
Tobacco	4	3	75.00	
None	32	21	65.63	
Sense or Motor Deficit				
Yes	24	16	66.67	0.754
No	18	11	61.11	
Body Mass Index				
≥ 28	5	2	40.00	0.329
< 8	37	25	67.57	
Symptom Duration				
< 3 mos	18	15	83.33	0.027*
≥ 3 mos	24	12	50.00	
Preoperative Kyphotic SA (°)				
< 1.45	16	10	62.50	0.553
≥ 1.45	26	17	65.38	

pared to traditional open surgery or microendoscopic surgery, the full endoscopic technique can provide great vision and limited bleeding, under a continuous fluid flow or an irrigation system. Moreover, by an endoscopic special radio frequent, bipolar coagulation, the epidural bleeding could also be reduced efficiently (13). Bone resection is necessary in all cases, especially in foraminal stenosis. The range of bone resection by a small diamond burr always depends on the target of decompression.

In our study, the VAS score for radicular arm pain and neck pain and NDI score improved significantly in all patients. Excellent and good outcomes were achieved in 38 out of 42 patients. The SF-36 score reflected significant improvement in all 8 domains. The CA_ROM statistically, significantly improved at the final follow-up period compared with the preoperative period. The SA was less kyphotic after the PECD at the final follow-up. These results are comparable to those of previous studies (1,21). All of the patients who had an adequate follow-up have had no recurrence thus far. Some authors reported that preoperative kyphotic SA (cut-off value 1.45°, sensitivity 80%, specificity 73%) seemed to be associated with a poor outcome, however the sample size of the study was only 22 (28). On the univariate analysis clinical factors affecting prognosis in our study, there was no significant difference between the preoperative kyphotic SA (< 1.45°) group and SA (≥ 1.45°) regarding excellent outcomes. Therefore, mildly kyphotic was not the contraindication of PECD for cervical spondylotic radiculopathy. Patients with symptom duration less than 3 months had a better outcome than patients with symptom duration more than 3 months (excellent, 83.33% vs. 50.00%).

In the past decade, only a few centers have reported this technique, with a limited number of cases (14,15). The major disadvantage of this technique is the steep learning curve; particularly, most spine surgeons are not familiar with endoscopic systems (25). Furthermore, under the endoscope, the verification of local anatomy structures, such as laminar or facet joints, is challenging with the small surgical field, especially for surgeons with limited endoscope experience.

The preoperative planning based on CT scans and MRI is one of the most important keys in the spine surgery. The full endoscopic spine surgery needs more accuracy planning before surgery because of the small incision and limited vision under the endoscope. Therefore, endoscope combined with an efficient navigation system can reduce the difficulty of surgery as well as increase the accuracy and efficiency (17,18). The image-guided systems were first designed to improve the surgical accuracy of pedicle screw insertion. With the advances and improvement of computer-assisted surgery systems, computer-guided surgery has been applied to all the spine parts, with the advantages of reduced x-ray exposure and increased pedicle screw placement accuracy. Recently, an intraoperative CT scan device, the O-arm, has been used in most of the spine field. Combined with a navigation system, the O-arm can provide intraoperative 3-D imaging for most spine surgeries. In this study, we described the surgical technique of the PECD assisted by O-arm-based navigation.

Radiation exposure is always a significant concern in spine surgery, especially for minimally invasive spine surgery, which depends more on fluoroscopy (26). However, using a computer-guided system, there is minimal to no radiation exposure to the surgeons (20). With an O-arm, a 13-second or 26-second scanning can accomplish the only part of radiation. Usually only a few intraoperative radiographs are needed to check instrumentation placement, with minimal to no radiation exposure. Also, with O-arm-based navigation the surgery time can be reduced according to the adjustment of instrumentation placement, which is not always needed.

Another advantage of the O-arm-based navigation approach is the visible trajectory for working cannel insertion to the correct surgical level, with the appropriate incision site. This technique can help surgeons place the instruments on patients with short and thick necks or lower-level diseases, which is hard to be verified by x-ray image (26). In our cases, the reference frame was fixed on the MAYFIELD® system instead of the bone part, such as the skull or spinous process. We also studied whether the accuracy of navigation was lost when the reference frame was not fixed to the bone. In our first 10 cases, we re-scanned the surgical field after working cannel insertion to verify the accuracy of our system. The results showed that all the working cannels were in place, as shown in the pre-navigation image; the accuracy loss is acceptable for this technique.

Due to the limited field of vision, anatomic localization is difficult for surgeons until using the O-arm-based navigation. The O-arm-based navigation can provide a quick and great quality reference for decompression. In previous surgery, the V-point (including inferior margin of the cephalic lamina, the medial junction of the inferior and superior facet joints, and the superior margin of the caudal lamina) has been used for the beginning of bone drilling (18,27). The bone removal area was assessed around the V-point. However, under the O-arm-based navigation, the probe can be used to plan the range of the bone removal. In our study, we found that the V-point is not a constant site for the drilling due to the anatomical difference of patients. For this purpose, the bone resection area should be designed by the navigation system, especially for cervical foraminal stenosis. For the herniation decompression, the identification of the lateral edge of the dura and branch of the nerve root is the key anatomic localization.

Conclusions

PECD assisted by O-arm navigation is an accurate, safe, effective, and minimally invasive surgery for the treatment of cervical radioculpy. Navigation can provide a real-time reference for adjustment of the decompression field and reserve the segmental stability. Patients with symptom duration less than 3 months had a better outcome than patients with symptom duration more than 3 months.

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Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research

committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from all patients included in the study.

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