CLINICAL ARTICLE

Morphology of Herniated Disc as a Predictor for Outcomes of Posterior Percutaneous Full-endoscopic Cervical Discectomy in Treating Cervical Spondylotic Radiculopathy

Yi Liu, MD[1†], Guo-ke Tang, MD[1†], Wei-heng Wang, MD[1†], Chang-gui Shi, MD[1], Shuang Wang, MD[1], Lei Yu, MD[1], Jiang-ming Yu, MD[1,2], Xiao-jian Ye, MD[1,2]

[1]*Department of Orthopaedics, Changzheng Hospital, Second Military Medical University and* [2]*Department of Orthopaedics, Tongren Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China*

Objective: To quantitively characterize the morphology of cervical disc herniation (CDH) causing cervical spondylotic radiculopathy (CSR) and investigate whether the morphological features of CDH are associated with clinical outcomes in CSR patients treated by posterior percutaneous full-endoscopic cervical discectomy (PPECD).

Methods: This is a single-center retrospective study. Eighty-seven PPECD-treated patients meeting the inclusion criteria were included between May 2017 and May 2019. Based on preoperative T2-weighted magnetic resonance imaging (MRI), we designed and measured six morphological parameters of CDH for all patients to reflect its relative position to cervical spinal cord and protruding degree: DC-SC distance from the center of disc (DC) and the center of spinal cord (SC); DC-DP distance from the center of cervical disc (DC) to the peak of herniation (DP); internal diameter of the disc; axial length of CDH; central angle of CDH formed by central axes of CDH and spinal cord; the modified index of CDH. We recorded general information, neck disability index (NDI) scores, visual analog scale (VAS) scores of neck and arm of all patients preoperatively and postoperatively at 1-year follow-up. The association of preoperative general variables and morphological parameters with clinical outcomes were explored by utilizing logistic regression and receiver operating characteristic curve (ROC) analysis.

Results: The preoperative neck-VAS, arm-VAS, and NDI were significantly decreased after PPECD and remained at a low value at follow-up. In regards to the morphological parameters of CDH, the mean value of DC-SC distance, DC-DP distance, internal diameter of the disc, axial length of CDH, central angle of CDH, and modified index of CDH were 1.61 ± 0.30 cm, 1.66 ± 0.32cm, 1.04 ± 0.21 cm, 0.63 ± 0.19cm, $39.38° \pm 11.94°$, and 0.39 ± 0.24, respectively. For patients grouped by difference in the recovery rate of NDI and arm-VAS (excellent improved group, EI; and limited improved group, LI), there were no differences in the age, gender, surgical segments, and morphological parameters, except for the central angle of CDH. According to binary logistic regression analysis, only the preoperative central angle of CDH was significantly associated with postoperative NDI recovery (odds ratio: 0.873; 95% confidence interval: 0.819–0.931, $P = 0.002$). ROC analysis showed the optimal cut-off value of the central angle of CDH for predicting the postoperative improvement of functional outcomes is 33.788°.

Conclusion: Preoperative morphology of CDH is related to the outcomes of CSR patients after PPECD. Patients with a large central angle of CDH (>33.788°) have more likelihood of ameliorating neurological symptoms of CSR. There is the potential to select the central angle of CDH as a predictor for outcomes of PPECD in treating CSR.

Address for correspondence Xiao-jian Ye, MD and Jiang-ming Yu, MD, Department of Orthopaedics, Changzheng Hospital, Second Military Medical University, 415 Fengyang Road, Shanghai, China 200003 Tel +86 21 8188 5624; Fax +86 21 6372 0099; Email: xjyespine@smmu.edu.cn and yjm_st@163.com

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[†]Yi Liu, Guo-ke Tang, Wei-heng Wang contributed equally to this work.

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Introduction

Cervical spondylotic radiculopathy (CSR) is a typical degenerative spinal disorder with symptoms of numbness and radicular pain in the neck, shoulder, and upper extremities. In some serious cases, it can also cause motor dysfunction of arms and hands, which can seriously impair the quality of life and working ability of patients[1]. As the anatomical and pathological basis of CSR, cervical disc herniation (CDH) is the predominant reason for the compression and irritation of cervical nerve roots[2]. Full decompression of the cervical spinal cord and nerve root, without altering cervical anatomical alignment and balance, is the core philosophy of surgical treatment for cervical spondylopathy.

Adhering to this philosophy, various cervical surgical procedures, which are classified into anterior and posterior approaches, have been developed in past decades. Among them, anterior cervical discectomy and fusion (ACDF) is widely regarded as the gold standard procedure in surgically treating cervical spondylopathy[3]. Through this anterior approach, the herniated or prolapsed discs and other osteophytes can be directly resected, and the decreased intervertebral height can be restored to some extent, so as to decompress the nerve root and alleviate symptoms of CSR. Despite obtaining satisfied clinical outcomes and good fusion rates, there are still several inevitable disadvantages of ACDF, such as fusion-caused cervical immobility, graft-related complications, approach-related complications, and adjacent segment degeneration[4]. These problems are inspiring spinal surgeons and scholars to re-explore other feasible approaches to avoid these problems. As the most common alternative to ACDF, posterior cervical foraminotomy (PCF) is another effective surgical procedure for CSR[3,5]. Through this posterior approach, the nerve roots are indirectly decompressed by enlarging their canals, meanwhile the segment mobility is preserved without additional internal fixation. Although PCF perfectly avoids those adverse consequences related to anterior approach, it inevitably detaches the paraspinal muscles from the cervical laminae and spinous process, resulting in postoperative neck and back pain and muscles fibrositis[6]. In general, both approaches are imperfect and inevitably accompanied by several intractable complications[7].

On the basis of the advancement of microchannel and endoscopic techniques and minimally invasive concepts, percutaneous full-endoscopic cervical decompression (PPECD) has been increasingly applied in treating cervical degenerative disorder in the past decade, with the aim of minimizing the disadvantages of traditional open surgical techniques[8]. Based on similar concepts to posterior cervical foraminotomy, decompression of nerve root by PPECD is carried out through endoscopic-assisted excision of the soft herniated disc and half ostectomy of facet joint with a smaller diameter, for maximally reducing intraoperative damage to paraspinal muscular tissue and cervical stability[8,9]. In the past decade, a series of clinical trials and retrospective studies have demonstrated outcomes of PPECD are equivalent to those of standard anterior or posterior open procedures in treating CDH-caused CSR. In the treatment for CSR caused by lateral CDH, several studies have investigated the effectiveness of PPECD[10–12]. In 2008, Ruetten *et al.* carried out a prospective study and found that patients with CSR acquired satisfied pain relief of neck, shoulder, and arm after receiving the surgical treatment of PPECD, which was comparable to ACDF[10]. After that, Kim *et al.* performed a comparative study between minimally PCF and PPECD and concluded in 2015 that PPECD had similar therapeutic efficacy to minimally invasive PCF in treating patients with foraminal soft disc herniation[11]. Although the decompression results of PPFECD were similar to conventional ACDF with minimized operation-related traumatization in some CSR cases, evidence provided by existing comparative clinical trials are not sufficient to reach a consensus on the specific indication for PPECD in treating different types of CDH with characteristic morphology[13]. In our clinical practice, we noticed that CSR patients with paramedian herniated discs especially those close to the cervical spinal cord usually acquire unsatisfactory outcomes after being treating by PPECD. Since the operational space is limited under the endoscope, compression from paramedian herniated disc adjacent to spinal cord cannot be fully removed by PPECD in some instances, because the working path may be obstructed by dura mater and nerve roots[14]. Hence, we hypothesize the varied morphological features of paramedian CDH interior to the operational area of PPECD might be correlated to postoperative pain relief and functional improvement. It is critical to figure out the significance of morphological measurements on CDH to the prediction of clinical outcomes after PPECD.

For the sake of verifying this hypothesis, the current retrospective study was carried out with the objectives of: (i) quantitively analyzing the morphological features of CDH in CSR patients with more specific and accurate methods; (ii) investigating the correlation between these features and post-PPECD clinical outcomes, including arm pain relief and functional restoration; (iii) exploring the potential value of morphological characteristics of CDH in predicting the prognosis of CSR patients treated by PPECD.

Materials and Methods

Inclusion and Exclusion Criteria

The present study was approved by the Second Military Medical University Chancellor's Human Research Committee and performed in accordance with protocol 2015–0018. All patients signed consent after being informed with the details of the treatment and study.

The inclusion criteria were: (i) patients (≥18 years) who were diagnosed with single-level CSR caused by soft disc herniation who failed to obtain satisfied symptomatic relief from conservative treatment for over 3 months; (ii) underwent PPECD between May 2017 and May 2019; (iii) at least 1-year follow-up for enabling a comparison between preoperative and postoperative outcomes; (iv) radiographical and clinical outcomes were completely recorded; (v) data were collected retrospectively.

The exclusion criteria were: (i) central cervical disc herniation with myelopathic symptoms; (ii) cervical instabilities or deformities; (iii) ossification of the posterior longitudinal ligament; (iv) infection or tumor in the cervical spine; (v) cervical spinal or foraminal stenosis; (vi) history of cervical surgery; (vii) calcification of herniated disc; (viii) symptoms and physical examinations were not consistent with radiographic examination.

Surgical Procedure

Preparation and Approach

Under general anesthesia, the patient was placed in a prone position and their head was fixed by Gardner-Wells tongs skeletal fixation system. With the assistance of intraoperative orthogonal fluoroscopic imaging, a guide needle was inserted into the intersection of the upper and lower lamina, then an 8-mm incision was spotted and made above the pathologic segment. After splitting muscles with a dilator and serially inserting working channel to facet joint, the V-point was recognized and the bone around it was drilled from the medial margin to the interlaminar space.

Endoscopic Cervical Discectomy

The procedures were performed entirely under the CESSYS TM system (Joimax GmbH, Germany) with continuous irrigation. After resecting the ligament flavum and exposing the margin of dura and nerve root, the herniated disc or its fragments were visualized and removed. In the meanwhile, the cleaning of soft tissue and hemostasis was performed with bipolar radiofrequency ablation. After confirming nerve roots were fully depressed, all endoscopic instruments were disassembled and the incision was sutured.

MRI Measurements

The conventional classification of CDH depending on location and shape of the protrusion is not detailed enough to accurately reflect its morphological association with the spinal cord and degree of protrusion, which is limited in clinical application, especially for the prognosis of PPECD[15]. For this reason, we designed two auxiliary lines and six parameters for CDH morphological features in the present study, which are defined as followed (illustrated in Fig. 1).

DC-SC Line

This line connects the center of cervical disc (DC) with the center of cervical cord (SC), which indicates the sagittal plane of cervical spine. Considering the cervical spinal cord may drift away, the DC-SC line serves as the baseline for

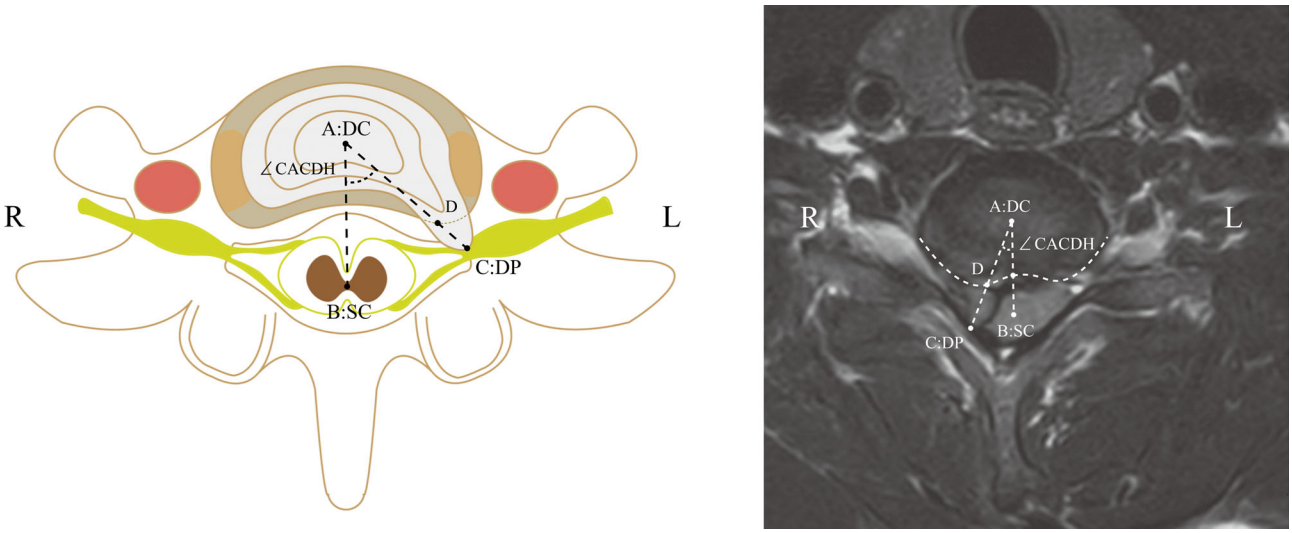

Fig. 1 Schematic diagram morphological measurements of CDH. Points: A, the center of cervical disc; B, the center of spinal cord; C, the peak of herniated disc; D, the intersection of DC-DP line and the border of cervical disc. Lines segments and angle: AB, DC-SC distance; AC, DC-DP distance; AD, internal diameter of disc; CD, axial length of CDH = AC-AD; modified index of CDH = CD/AB; ∠CDHCA, central angle of CDH (CDHCA).

normalizing the positional relationship between cervical disc and cervical spinal cord.

DC-SC Distance
This measurement is presented as the length from the center of cervical disc to the center of cervical cord. Considering the individual variance of patients, this measurement is used to normalize following evaluation.

DC-DP Line
This line connects the center of the cervical disc (DC) with the peak of the herniated disc (DP), which indicates the sagittal plane of herniated disc. Because of the irregular shape of disc herniation, DC-DP Line is used to indicate the relative position of disc herniation to the spinal cord and cervical disc.

DC-DP Distance
This measurement is presented as the length from the center of cervical disc to peak of herniated disc. Because the irregular morphology of disc herniation causes hardship in precisely evaluating the protruding degree of disc, this measurement is defined as an important observed value for following calculation of CDH degree.

Internal Diameter of Disc
For measuring the size of cervical disc on the plane of the cross section, the length from the center of cervical disc to the intersection of DC-DP line and the border of cervical disc is defined as the internal diameter of the disc. This parameter serves as the benchmark for calculating the degree of herniation.

Axial Length of CDH
For evaluating the degree of CDH, we defined the axial length of CDH to reflect the size of protruded part of disc on cross-sectional plane. This value is calculated by subtracting the internal diameter of disc from DC-DP distance, which indicates the absolute degree of CDH.

Central Angle of CDH
This angle is composited by DC-SC line and DC-DP line, which symbols the relative position of herniated disc to the mid-line of cervical spine. This parameter is used for quantitively comparing and analyzing the variance of CDH location among different patients.

Modified Index of CDH
Fagerlund *et al*. initially introduced Disc Herniation Index (DHI) to evaluate the degree of lumbar disc herniation[16]. In the present study, we modified this index to make it more suitable for cervical measurements. The modified index is defined by the ratio between the axial length of CDH and DC-SC distance. Through calculating this relative ratio, the variance of CDH size among different patients is eliminated and the degree of CDH is normalized.

The Centricity PACS 4.0 system (GE Healthcare) was applied in this study. Each herniated disc responsible for CSR was scanned with a slice thickness of 3 mm in a 3.0T MRI system. The slice of T2-weighted MRI was the scan in which the cervical disc revealed the greatest herniation. All of the measurements were performed on axial imaging of preoperative T2-weighted MRI by three independent spine surgeons who were blinded to the clinical information of patients. The final values obtained by different observers were averaged out for analysis.

Assessments of Clinical Outcomes

Visual Analog Scale
The Visual Analog Scale (VAS) is designed to conduct pain scale surveys for evaluating varying degrees of pain or discomfort. Through this scale, patients can provide an integral score with the range 0–10 which corresponds to the intensity of pain they subjectively experienced. In the present study, The VAS was used to assess the pre- and post-PPECD pain on arm and neck.

Neck Disability Index
The Neck Disability Index (NDI) is a questionnaire which is comprised of 10 items to assess disability associated with neck pain[17]. By means of NDI, the patients' subjective symptomatic experiences (pain intensity, headache, concentration, sleeping) and ability of daily living (lifting, work, driving, recreation, personal care, reading) are reflected. In the present study, NDI was used to assess pre- and post-PPECD motor functional states of patients.

The clinical outcomes were evaluated at 1 day, 3 months, and 12 months after PPECD. The follow-up evaluation was performed by two doctors, neither of whom were familiar with this study. The recovery rate of NDI and VAS was calculated as follows: (postoperative NDI–preoperative NDI) / preoperative NDI × 100%; (postoperative VAS–preoperative VAS) / preoperative VAS × 100%. According to this calculation, all patients were subdivided into two groups: excellent improved group (EI group) with more than 50% recovery of both NDI and arm-VAS, and limited improved group (LI group) with less than 50% recovery of both NDI and arm-VAS.

Statistic Analysis
SPSS software (version 25, IBM, Armonk, NY, USA) was used for statistical analysis on acquired data. The continuous variables (angle and distances) were presented as the mean ± SD. The quartiles were used to present categorical variables (age, VAS scores, and NDI scores). The comparative analysis was performed using the Mann–Whitney *U* test, Chi-square test, or Fisher's exact test. The predictors for postoperative excellent or limited improvement of clinical outcomes were identified *via* binary logistic regression with a forward stepwise selection. The receiver operating characteristic (ROC) curve was plotted and evaluated with the pROC

package for R software (version 3.6.2). The cut-off value for morphological parameters was determined by calculating the Youden index. The *P*-value of <0.05 was selected as the threshold of statistical significance.

Results

Baseline Characteristics and Intraoperative Findings

From May 2017 to May 2019, 122 patients who underwent PPECD for CSR were reviewed. According to the inclusion criteria, 87 (71.3%, 38 males; 49 females) of 122 CSR patients with a mean age of 52.1 years (range, 31–85 years) were finally finished at 1-year follow-up and included in the analysis, 12 of them were excluded as they were lost to follow-up. The surgical segments were C_{4-5} in three included patients, C_{5-6} in 46 patients, C_{6-7} in 36 patients, and C_7-T_1 in two patients. The average follow-up duration was 14 months (range, 12–16 months). The mean operative time of PPECD was 74.3 ± 11.3 min. The intra- and postoperative blood loss of PPECD was 30.1 ± 8.7 mL. The average hospital stay was 4.7 ± 1.6 days.

Complications

There were no patients who experienced severe complications, such as bleeding, injury to the nerve root or cervical spinal cord, infection, spondylodiscitis, or thrombosis. A patient complained of transient thumb hypesthesia after surgery, which disappeared within a week without any intervention. None of the patients suffered from deterioration of existing symptoms or recurrences at the same segment at 1-year follow-up.

Clinical Outcomes

For all patients, the preoperative and postoperative changes of neck-VAS, arm- VAS, and NDI scores were presented (Table 1 and Fig. 2).

VAS Score

The VAS score of neck pain and arm pain decreased significantly from 7 (5,8) and 7 (6,8) to 3 (2,4) and 2 (1,3) after surgery and remained stable at 3-months and 1-year follow-ups.

NDI Score

The NDI score decreased significantly from 26 (21,33) to 11 (9,14) after surgery and remained at 10 (8,13) at 3-months follow-up. Although at last follow-up, NDI scores showed an insignificant bounce to 11 (9,13), it was still significantly less than its preoperative scores.

Recovery Rate

The recovery rate of neck-VAS, arm-VAS, and NDI was 46.44% ± 48.92%, 58.53% ± 31.42%, 54.13% ± 25.73% after surgery, 45.88% ± 45.63%, 60.54% ± 34.92%, 58.41% ± 28.30% at 3-months follow-up, 44.80% ± 47.96%, 56.59% ± 40.13%, 56.35% ± 25.95% at 1-year follow-up, respectively.

Overall, the intervention of PPECD obtained favorable clinical outcomes of pain relief and functional improvement in this study. But the recovery effect of PPECD for neurofunction is varied in different patients.

Morphological Measurements of CDH by MRI Measurements

For better characterizing the morphology of cervical herniated disc, we defined four morphological parameters on preoperative T2-weighted MRI and measured all included patients. Preoperatively, the mean DC-SC distance was 1.61 ± 0.30 cm; the mean DC-DP distance was 1.66 ± 0.32 cm; the mean internal diameter of disc was 1.04 ± 0.21 cm; the mean axial length of CDH was 0.63 ± 0.19 cm; the central angle of CDH (CDHCA) was 39.38° ± 11.94°; based on above measurements, the modified index of CDH for all patients was 0.39 ± 0.24.

Clinical and Radiographic Comparison between LI Group and EI Group

Since NDI restoration and pain relief of included patients are varied along with the morphological difference of CDH, we investigated whether preoperative morphological parameters of CDH is associated with postoperative functional outcomes. Through performing comparative analyses on the LI group and EI group concerning age, gender, morphological parameters of CDH (Table 2), it was found that the gender ($P = 0.121$), operational segments ($P = 0.986$), DC-SC distance ($P = 0.952$), internal diameter of disc ($P = 0.067$),

TABLE 1 Clinical outcomes of included patients

Outcomes	Pre-op	Post-op 1d	Post-op 3 months	Post-op 1 year
N-VAS score	7 (5,8)	3 (2,4)*	3 (2.5,4)*	3 (3,4)*
A-VAS score	7 (6,8)	2 (1,3)*	2 (1,3)*	2 (2,3)*
NDI score	26 (21,33)	11 (9,14)*	10 (8,13)*	11 (9,13)*
Recovery rate of N-VAS (%)	N/A	46.44 ± 48.92	45.88 ± 45.63	44.80 ± 47.96
Recovery rate of A-VAS (%)	N/A	58.53 ± 31.42	60.54 ± 34.92	56.59 ± 40.13
Recovery rate of NDI (%)	N/A	54.13 ± 25.73	58.41 ± 28.30	56.35 ± 25.95

NDI, Beck Disability Index; VAS, Visual Analog Scale.; All scores were represented as median and inter quartile range. All recovery rates were represented as mean ± SD.; * Significant differences compared with pre-op outcomes ($P < 0.05$).

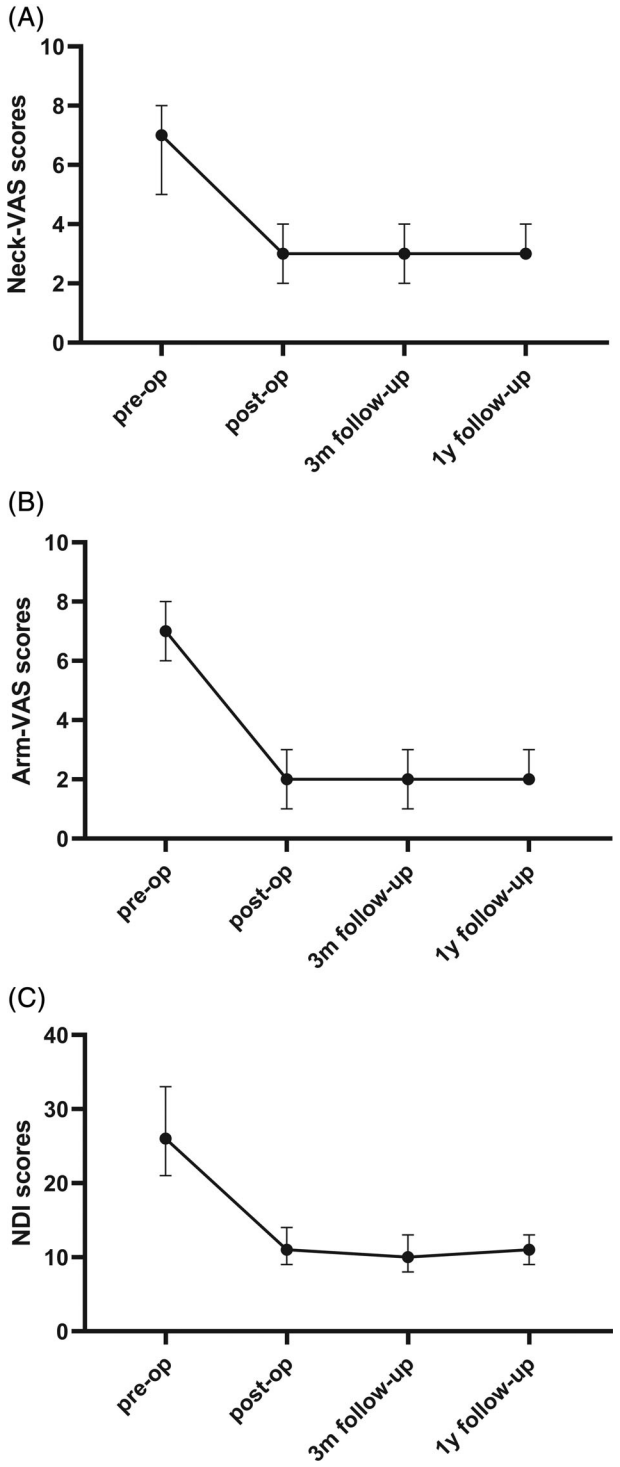

Fig. 2 The changes of neck-VAS (A), arm-VAS (B), and NDI (C) at different time-points of follow-up.

DC-DP distance ($P = 0.132$), axial length of CDH ($P = 0.734$), and modified index of CDH ($P = 0.628$) showed no significant differences, while the age ($P = 0.015$) and CDHCA ($P = 0.003$) were significantly different, indicating that, besides age, the protruding direction and degree of the degenerated cervical disc were correlated with limited improvement of clinical outcome after PPECD.

Correlation between Preoperative Morphological Parameters of CDH and Postoperative Outcomes

To probe into the risk predictors for postoperative limited neurological improvement of PPECD-treated CSR patients from the perspective of CDH morphology and other patients' traits, we performed a binary logistic regression analysis. Considering potential collinearity of DC-SC distance, DC-DP distance, and axial length of CDH, we only selected the modified index of CDH, CDHCA, and general features of patients (age, gender, operative segments) as correlated factors to build the logistic regressive model. As indicated in Table 3, only the CDHCA was a crucial preoperative predictor for the limited NDI improvement (odds ratio: 0.873; 95% confidence interval: 0.819–0.931, $P = 0.002$). Moreover, the ROC analysis revealed an AUC of 0.809 (95% confidence interval: 0.712–0.906, $P < 0.001$) for CDHCA regarding limited neurofunctional improvement (Fig. 3). Based on the calculation of Youden index, a cutoff value of 33.788° for CDHCA with a sensitivity of 63.9% and a specificity of 96.1%, was screened out as a threshold for the differentiation of excellent and limited NDI improvement. Therefore, we propose the 33.788° of CDHCA as an optimal predictor for limited neurofunctional improvement after PPECD.

Discussion

Since Ruetten *et al.* originally reported significant pain relief effects of PPECD on 83 CSR patients[18], the therapeutic value and features of this MIS procedure have been analyzing in depth through a series of retrospective or comparative studies. In Ruetten's follow-up randomized control trial in which PPECD was compared with conventional ACDF in treating CSR[10], there was no significant discrepancy in post-operational outcomes and incidence of revision and complications between these two procedures, while the advantages of PPECD in minimizing traumatization, preserving mobility, and promoting rehabilitation is prominent. Even though ACDF seems to obtain better lordosis maintenance than PPECD in terms of cervical sagittal balance[19], it is not sufficient for excluding PPECD as an effective alternative treatment of CSR. In our prior retrospective study, a cohort of patients with symptomatic cervical disc herniation or foraminal stenosis underwent single segment PPECD and received satisfactory clinical results without serious complications[20]. In the present study, we retrospectively analyze dynamic changes on post-operational neck-VAS scores, arm-VAS scores, and NDI index at time points of follow-up (1 day, 3 months, 1 year), then found that within a year after PPECD, a sharp descending trend followed by leveling off is evident in pain scoring and disability index. This further indicated that as an alternative of ACDF, PPECD is safe and effective in treating CSR.

TABLE 2 Comparison of general parameters and preoperative morphological parameters of CDH in groups with different NDI improvement and relief of arm pain

Characteristics	EI group	LI group	*P*-value
Patients	51	36	
Age (years)	**50 (42.5,58)**	**54.5 (49,63)**	**0.015**
Gender			0.121
Male	27	11	
Female	24	25	
Operative segments			0.986
C_4-C_5	2	1	
C_5-C_6	27	19	
C_6-C_7	21	15	
C_7-T_1	1	1	
CDHCA (°)	**44.75 ± 9.44**	**31.79 ± 11.21**	**0.003***
DC-SC distance (cm)	1.61 ± 0.31	1.60 ± 0.28	0.952
Internal diameter of the disc (cm)	1.07 ± 0.22	0.98 ± 0.19	0.067
DC-DP distance (cm)	1.71 ± 0.32	1.60 ± 0.31	0.132
Axial length of CDH (cm)	0.63 ± 0.19	0.61 ± 0.20	0.734
Modified index of CDH (cm)	0.39 ± 0.09	0.38 ± 0.08	0.628

CDH, cervical disc herniation; CDHCA, the central angle of CDH; DC-DP distance, the length between the center of cervical disc and the peak point of herniated disc; DC-SC distance, the length between the center of cervical disc and the center of cervical cord; EI group, excellent improved group; LI group, limited improved group.; The number of patients, gender, and operative segments were presented by counting. The age of two groups were represented as median and interquartile range. All CDH measurements were represented as mean ± SD. Bold labeled values with asterisk mean significant differences comparing with pre-op outcomes ($P < 0.05$).

TABLE 3 Logistic regression analysis of clinical traits and CDH morphology for improvement of functional outcomes

Characteristics	*P*-value	*OR*	95% *CI*
Age	0.181	N/A	N/A
Gender	0.903	N/A	N/A
Operative segments	0.976	N/A	N/A
CDHCA	**0.002***	**0.873**	**0.819–0.931**
Modified index of CDH	0.168	N/A	N/A

CDH, cervical disc herniation; CDHCA, the central angle of CDH; *CI*, confidence interval; *OR*, odds ratio.; Bold labeled values with asterisk mean significant differences comparing with pre-op outcomes ($P < 0.05$).

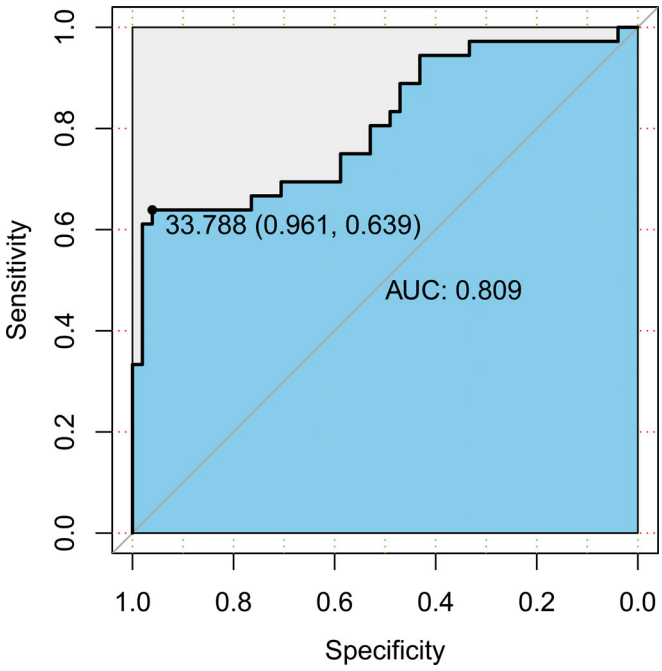

Fig. 3 The ROC curve of central angle of CDH between EI group and LI group. Its specificity and sensitivity are presented in parentheses.

Dilemma of PPECD Selection for CSR

The crux of PPECD in clinical treatment is to strictly choose indications for different CSR patients, which is still controversial in the current application of MIS cervical surgeries. According to the relative location relationship between ruptured annulus fibrosus and vertebral body, cervical disc herniation is anatomically classified into three types: median herniation, paramedian herniation, and lateral herniation[21]. Compared with lateral herniation, which is evidently suitable for being resected by PPECD, paramedian herniation is difficult to be distinguished with median herniation under the condition that the herniated disc is close to the midsagittal plane without causing myelopathic symptoms. Moreover, due to the limitation of endoscopic visual field feasible for discectomy, extended ostectomy of the facet is inevitable for providing sufficient angular space to access paramedian herniated disc ventral to the cervical cord. But this procedure is infeasible due to the following two reasons: (i) to ensure cervical stability not being impaired, the recommended area of facet resection should be no more than 50%[22]; (ii) because

of the fixed working channel, visual scope under cervical endoscope is strictly limited. So, it is challenging for full discectomy of CDH adjacent to spinal cord through endoscopic working channel conventionally positioned at V-point. In present study, we found that pain relief and functional improvement of patients with paramedian CDH is varied, implying the classical classification of CDH described above is too indistinct to serve as a reliable indicator for PPECD prognosis and outcomes.

Morphology of CDH and Post-PPECD Outcomes

For making an indication of PPECD more specific, it is valuable to explore novel methods for accurate measuring morphological parameters of CDH. Wen *et al*. proposed a significant method in which the distances between the dural sac and peak or medial border of herniated disc on T2-weighted MRI were measured to spot the resectable range of CDH[23]. This method was significant and assisted the specific selection of PPECD indication. However, in some cases, the presentation of dural sac on MRI is not recognizable because of the coverage of the herniated disc. Inspired by Wen's idea, we designed a novel measuring system to quantify morphological features of CDH. In this system, the angular relationship between the major axis of herniated part and the cervical central axis is defined by CDHCA for reflecting CDH location. It is noteworthy that the DC-SC line linking the center of the cervical disc to the center of the spinal cord was chosen for composite CDHCA rather than cervical median line. In some cases, cervical spinal cord may float away from the center of spinal canal under the pressure of herniated disc. Hence, setting the DC-SC line as the baseline of CDHCA is preferable to reflect CDH location. Based on the area ratio between herniated part of disc and spinal canal, Fagerlund *et al*. introduced the disc herniation index (DHI) which is meaningful in sizing lumbar herniated disc[15]. However, for CDH, this index might become meaningless when a cervical disc herniates laterally out of the area of the spinal canal. Given this condition part and modifying index of CDH to quantify the protrusive degree of cervical disc. For solving this problem, we proposed a modified index to define the relative degree of CDH, which is equal to the ratio between the axial length of CDH and DC-SC distance.

Through logistic regression and ROC curve analysis, CDHCA was found to be significantly correlated to clinical outcomes after PPECD, and 33.785° of CDHCA, as the best cutoff with favorable sensitivity and specificity for prognostic prediction, was figured out. A conclusion can be drawn from this result, that a smaller CDHCA on T2-weighted MRI before surgery is a single independent risk factor for PPECD. When the CDHCA is >33.785°, performing PPECD is more likely to achieve satisfactory outcomes of pain relief and life improvement. According to our intraoperative experience of PPECD, herniated discs with less than 33.785° of CDHCA were commonly located at infra-axillary or anterior region of the nerve root. This anatomical relationship between the herniated disc and nerve root requires an extended excision of ligamentum flavum, which consequently leads to more bleeding and influences endoscopic visuality[24]. In addition, there exists an underlying physiological relationship between the variation of CDHCA and motion of cervical cord. Cervical spinal cord keeps moving subtly in three directions (cranial/caudal, anterior/posterior, and right/left), which is possibly regulated by cardiac activity and peripheral pulse[25]. According to a recent study, the myopathic symptoms are positively associated with the passive motion of cervical spinal cord under anterior compression[26]. So, it can be speculated that cervical disc herniation with smaller CDHCA possibly leads to greater displacement and tension of spinal cord and nerve root, which consequently increases the risk of injury on them during PPECD procedures. To a certain extent, these theories can be used to explain the clinical significance and predictive potential of CDHCA cut-off we introduced for post-PPECD outcomes. Recently, a novel trenching technique shows a promising prospect in treating median CDH[27], which extends the indications of PCED for CS. The morphological parameters we introduced may serve as an effective indicator for better selection between conventional or trenching PPECD procedures.

Unexpectedly, the modified index of CDH was not significantly correlated to post-PPECD pain relief and functional improvement. This result is similar to those in CSR cases where the degree of CDH is not parallel to the severity of radicular symptoms[28]. In the latest research carried out by Yawara *et al*., radicular pain and endoscopic surgical outcomes were associated with the morphological change of nerve root sheath under special SHINKEI-Quant imaging technique[29]. Hence, it is necessary to explore more specific morphological parameters that precisely reflect compression degree on nerve root *via* advanced imaging beyond single T2-weighted MRI.

Limitations

The aim of the present study was to explore the two-dimensional morphological relationship between the cervical herniated disc and spinal cord and figure out its impact on clinical outcomes of PPECD. However, considering the three-dimensional structure of CDH, only performing measurements on cross-sectional plane might not be precise enough to reflect its holistic morphology. In some cases, the herniated fragment may drift superior or inferior to the matched cervical disc. Under this condition, the peak of CDH, the center of herniated disc, and spinal cord may not be at the same horizontal plane, which produces deviations in measuring the realistic angular relationship between CDH and spinal cord. Hence, the morphological features of CDH revealed on sagittal or coronal view should be taken into account in further studies. In addition, V-point, the anchor for the working channel of PPECD, and its positional relationship with CDH were omitted in the present study due to the limitation of measurements on MRI. The line connecting V-point with the center of disc is angulated with the horizontal plane of herniated disc, which varies in degree with different cervical segments or different cervical curvature[30]. So, it is reasonable to hypothesize that the angular

relationship between V-point, the center of spinal cord, and the peak of CDH might confine the working space of PPECD and affect whether herniated disc fragment is fully dissected under the endoscope. This assumption will be further investigated in our future study.

Besides, there were several other limitations in our study. Firstly, this was a single-center retrospective study, which was inevitably prone to bias, especially concerning the inclusion of patients. Considering people have different therapeutic experiences and pain tolerances, the influence of baseline heterogeneity of baseline may influence preoperational pain assessment and functional evaluation. Secondly, the follow-up period of this study was not sufficient to investigate the association of CDH morphological parameters with long-term pain relief and relapse. In addition, it is confusing that the ages of patients were not associated with pain relief and neurofunctional restoration as shown in logistic regression, while it is significantly different between two groups with different prognoses (as shown in Table 2). This might be attributed to the difficulty of accurate stratification of patients' age or potential selective bias originating from age, which significantly disturb the logistic regression model. Therefore, it is necessary to carry out prospective cohort studies on the correlation between the long-term outcomes of PPECD and morphological features of CDH to further demonstrate the significance of CDH parameters in the selection of PPECD indication.

Conclusion

In summary, the morphology and location of CDH probably affected the feasibility of nerve root decompression through PPECD. We analyzed morphological parameters of CDH and clinical outcomes of PPECD and found that CDHCA, representing the horizontal direction of herniated disc, was significantly correlated with improvement of the NDI index. The post-PPECD NDI index and relief of upper limb pain is limitedly improved when CDHCA is smaller than a cut-off value of 33.788°. Therefore, CDHCA can serve as a predictor of postoperative outcomes and an indicator for selection of PPECD.

Authorship Declaration

We declare that all authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors.

References

1. Baba H, Maezawa Y, Uchida K, *et al*. Cervical myeloradiculopathy with entrapment neuropathy: a study based on the double-crush concept. Spinal Cord, 1998, 36: 399–404.
2. Corey DL, Comeau D. Cervical radiculopathy. Med Clin North Am, 2014, 98: 791–799 xii.
3. Deora H, Kim SH, Behari S, *et al*. Anterior surgical techniques for cervical spondylotic myelopathy: WFNS spine committee recommendations. Neurospine, 2019, 16: 408–420.
4. Tzaan WC. Anterior percutaneous endoscopic cervical discectomy for cervical intervertebral disc herniation: outcome, complications, and technique. J Spinal Disord Tech, 2011, 24: 421–431.
5. Adamson TE. The impact of minimally invasive cervical spine surgery. Invited submission from the joint section meeting on disorders of the spine and peripheral nerves, March 2004. J Neurosurg Spine, 2004, 1: 43–46.
6. Mendenhall S, Parker S, Sivasubramaniam P, Mcgirt M, Devin C. Anterior versus posterior approach for cervical myelopathy: comparative effectiveness and cost-utility analysis. J Neurosurg, 2015, 123: A481.
7. Chu CW, Kung SS, Tsai TH, Huang TY, Hwang SL. Anterior discectomies and interbody cage fusion without plate fixation for 5-level cervical degenerative disc disease: a 5-year follow-up. Kaohsiung J Med Sci, 2011, 27: 524–527.
8. Quillo-Olvera J, Lin GX, Kim JS. Percutaneous endoscopic cervical discectomy: a technical review. Ann Transl Med, 2018, 6: 100.
9. Oertel JM, Philipps M, Burkhardt BW. Endoscopic posterior cervical foraminotomy as a treatment for osseous foraminal stenosis. World Neurosurg, 2016, 91: 50–57.
10. Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic cervical posterior foraminotomy for the operation of lateral disc herniations using 5.9-mm endoscopes: a prospective, randomized, controlled study. Spine (Phila Pa 1976), 2008, 33: 940–948.
11. Kim CH, Kim KT, Chung CK, *et al*. Minimally invasive cervical foraminotomy and diskectomy for laterally located soft disk herniation. Eur Spine J, 2015, 24: 3005–3012.
12. Ahn Y, Keum HJ, Shin SH. Percutaneous endoscopic cervical discectomy versus anterior cervical discectomy and fusion: a comparative cohort study with a five-year follow-up. J Clin Med, 2020, 9: 371.
13. Ahn Y. Endoscopic spine discectomy: indications and outcomes. Int Orthop, 2019, 43: 909–916.
14. Ahn Y. Percutaneous endoscopic cervical discectomy using working channel endoscopes. Expert Rev Med Devices, 2016, 13: 601–610.
15. Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze GK. Lumbar disc nomenclature: version 2.0: recommendations of the combined task forces of the North American Spine Society, the American Society of Spine Radiology, and the American Society of Neuroradiology. Spine (Phila Pa 1976), 2014, 39: E1448–E1465.
16. Fagerlund MK, Thelander U, Friberg S. Size of lumbar disc hernias measured using computed tomography and related to sciatic symptoms. Acta Radiol, 1990, 31: 555–558.
17. Sterling M, Rebbeck T. The neck disability index (NDI). Aust J Physiother, 2005, 51: 271.
18. Ruetten S, Komp M, Merk H, Godolias G. A new full-endoscopic technique for cervical posterior foraminotomy in the treatment of lateral disc herniations using 6.9-mm endoscopes: prospective 2-year results of 87 patients. Minim Invasive Neurosurg, 2007, 50: 219–226.
19. Ji-Jun H, Hui-Hui S, Zeng-Wu S, Liang Z, Qing L, Heng-Zhu Z. Posterior full-endoscopic cervical discectomy in cervical radiculopathy: a prospective cohort study. Clin Neurol Neurosurg, 2020, 195: 105948.
20. Zheng C, Huang X, Yu J, Ye X. Posterior percutaneous endoscopic cervical diskectomy: a single-center experience of 252 cases. World Neurosurg, 2018, 120: e63–e67.
21. Kokubun S, Tanaka Y. Types of cervical disc herniation and relation to myelopathy and radiculopathy. J Back Musculoskelet Rehabil, 1995, 5: 145–154.
22. Nakamura S, Taguchi M. Area of ostectomy in posterior percutaneous endoscopic cervical foraminotomy: images and mid-term outcomes. Asian Spine J, 2017, 11: 968–974.
23. Wen H, Wang X, Liao W, *et al*. Effective range of percutaneous posterior full-endoscopic paramedian cervical disc herniation discectomy and indications for patient selection. Biomed Res Int, 2017, 2017: 3610385.
24. Yao S, Ouyang B, Lu T, Chen Q, Luo C. Treatment of cervical spondylotic radiculopathy with posterior percutaneous endoscopic cervical discectomy: short-term outcomes of 24 cases. Medicine (Baltimore), 2020, 99: e20216.
25. Figley CR, Stroman PW. Investigation of human cervical and upper thoracic spinal cord motion: implications for imaging spinal cord structure and function. Magn Reson Med, 2007, 58: 185–189.
26. Vavasour IM, Meyers SM, MacMillan EL, *et al*. Increased spinal cord movements in cervical spondylotic myelopathy. Spine J, 2014, 14: 2344–2354.
27. Yu KX, Chu L, Chen L, Shi L, Deng ZL. A novel posterior trench approach involving percutaneous endoscopic cervical discectomy for central cervical intervertebral disc herniation. Clin Spine Surg, 2019, 32: 10–17.
28. Kuijper B, Tans JT, van der Kallen BF, *et al*. Root compression on MRI compared with clinical findings in patients with recent onset cervical radiculopathy. J Neurol Neurosurg Psychiatry, 2011, 82: 561–563.
29. Eguchi Y, Enomoto K, Sato T, *et al*. Simultaneous MR neurography and apparent T2 mapping of cervical nerve roots before microendoscopic surgery to treat patient with radiculopathy due to cervical disc herniation: preliminary results. J Clin Neurosci, 2020, 74: 213–219.
30. Waxenbaum JA, Reddy V, Williams C, Futterman B. Anatomy, Back, Lumbar Vertebrae. Treasure Island: StatPearls Publishing, 2021.