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Effect of intervertebral foramen area and width on postoperative pain relief in patients with cervical spondylotic radiculopathy

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Abstract

Objective This study aims to investigate the relationship between preoperative cervical intervertebral foramen width and area and the persistence of postoperative pain in patients diagnosed with cervical spondylotic radiculopathy (CSR).

Methods Patients were divided into two groups, based on their pain relief at the 6-month postoperative follow-up: the pain relief group and the persistent pain group. We compared various parameters, including age, sex, body mass index (BMI), duration of symptoms, preoperative Japanese Orthopedic Association (JOA) score, Neck Disability Index (NDI) score, postoperative ratio of disc space distraction, preoperative width of the intervertebral foramen (WIVF), and area of the intervertebral foramen (AIVF) between the two groups. Binomial logistic regression analysis was conducted to identify the factors affecting pain relief.

Results Significant differences were observed in preoperative WIVF, AIVF, duration of symptoms, preoperative NDI scores, and the ratio of disc space distraction between the two groups (all $P < 0.05$). Regression models indicated that symptom duration, preoperative NDI score and ratio of disc space distraction were negatively associated with pain relief, whereas preoperative WIVF and AIVF were positively associated with pain relief.

Conclusion Preoperative WIVF and AIVF may be linked to persistent postoperative pain in patients with CSR.

Keywords Cervical spondylotic radiculopathy, Intervertebral foramen, Area, Width, Pain

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Introduction

Cervical spondylotic radiculopathy (CSR) is the most prevalent form of cervical spondylosis [1, 2], with its common clinical manifestations including neck and shoulder pain accompanied by radiating pain and numbness in the upper limbs [3, 4]. CSR primarily arises from intervertebral foramen narrowing and nerve root compression, which can result from disc herniation and hypertrophy of the uncovertebral joints. Notably, the majority of cases are attributed to uncovertebral joint hypertrophy [5, 6], while only 20-25% of cases are linked to disc herniation [7, 8]. The objective of surgical intervention is to enlarge the intervertebral foramen and alleviate nerve compression. While most patients experience significant symptom relief following surgery, a subset of patients may not achieve substantial alleviation of neck and shoulder pain. Given that neck and shoulder pain can profoundly impact patients' daily lives and work, pain relief is as critical as neurological improvement when assessing the efficacy of surgical outcomes [9–12].

The Neck Disability Index (NDI) is widely utilized as a disability score for patients with CSR [13, 14] and effectively assess the impact of neck pain on patients' daily lives [9, 15–18]. While factors associated with improved NDI after following spine surgery have been identified [19–21], including patient gender, body mass index (BMI), and the specific surgical segment [22]. Recent studies have also highlighted the correlation between the morphology of preoperative disc herniation and postoperative pain relief [23].However, there is a paucity of research examining the relationship between the size of the intervertebral foramen in the cervical spine and improvements in postoperative NDI. In 2015, Suk et al. [24]. investigated the correlation between clinical outcomes and intervertebral foramen size in patients with cervical intervertebral foramen stenosis undergoing anterior cervical discectomy and fusion (ACDF). Their findings indicated that postoperative pain improvement was negatively correlated with postoperative intervertebral foramen size, suggesting greater pain relief was associated with an increase in intervertebral foramen size. Nonetheless this study did not clarify whether preoperative intervertebral foramen size was linked to persistent postoperative pain. Sun et al. [25] (2021) reported that the preoperative width of the intervertebral foramen (WIVF) significantly influenced improvements in postoperative NDI scores. Specifically, a preoperative WIVF of ≤4.35 mm was associated with an increased likelihood of persistent postoperative pain. This study was the first to investigate the relationship between preoperative WIVF and clinical outcomes. The cervical intervertebral foramen has an oblique sagittal 45° [26], and the minimum area of the intervertebral foramen measured along the alignment direction of the cervical intervertebral foramen, is referred to as the minimum oblique sagittal cross-sectional area. This area is considered the area of the intervertebral foramen (AIVF). However, there is a scarcity of studies examining the relationship between preoperative AIVF and NDI scores. Therefore, the purpose of this study was to evaluate the effect of preoperative AIVF in conjunction with other factors on postoperative NDI.

Table 1 The Baseline Data of the enrolled patients

Items (201 patients)	Mean ± SD
Age	54.44 ± 12.38
Male / Female	63/138
BMI	24.20 ± 2.50
Smoking / Nonsmoking	59/142
Symptom duration (months)	7.74 ± 2.69
C2-C7 Cobb angle (°)	8.52 ± 3.79
Preoperative WIVF (mm)	5.26 ± 1.16
Postoperative WIVF (mm)	7.11 ± 1.06
Preoperative AIVF (mm^2)	23.97 ± 7.81
Postoperative AIVF(mm^2)	64.67 ± 7.19
Preoperative JOA scores	10.77 ± 1.36
Postoperative JOA scores	14.83 ± 0.85
Ratio of disc space distraction	1.30 ± 0.07
Preoperative NDI	32.10 ± 4.06
The NDI scores at the 6-month follow-up	11.71 ± 3.00

SD: Standard Deviation, BMI: Body Mass Index, WIVF: Width of Intervertebral Foramen, AIVF: Area of Intervertebral Foramen, JOA: Japanese Orthopedic Association, NDI: Neck Disability Index

Materials and methods

Patient data

The study received approval from the ethics committee of our hospital. All patient data were obtained from the hospital's medical record system and were treated as anonymous and confidential. Verbal informed consent was obtained from the participants.

This retrospective analysis examines patients with CSR who underwent ACDF at our institution from January 2018 to August 2021. The study primarily included patients with intervertebral foramen stenosis resulting from osteophytes of the hook vertebral joint or vertebral body. The exclusion criteria were as follows: (1) cervical intervertebral foramen stenosis due to disc or ligament herniation, (2) a history of cervical spine surgery, (3) presence of tumors or malignancies, (4) traumatic causes, (5) congenital or other skeletal dysplasia, and (6) less than six months of follow-up or missing follow-up data. A total of 201 patients (mean age: 54 years, range: 23–81) with single-segment (C6/7) radicular cervical spondylosis were selected, and detailed preoperative information for these patients is presented in Table 1. This study was approved by the local ethics committee (BYL20190712).

Surgery method

All patients underwent ACDF, which was performed by the same group of surgeons in a supine position following successful anesthesia. Routine sterilization procedures were implemented, and sterile towels were applied. The anterior vertebral space was exposed, and once confirmed by the C-arm machine, specialized intervertebral distractors were inserted on both sides of the intervertebral disc space, and the distraction force was gradually increased to separate the upper and lower vertebral bodies and open the intervertebral space, the cervical intervertebral disc was scraped using a scraping spoon under microscopic assistance, while the upper and lower soft endplates were treated. The nerve root canal was probed with a nerve root hook to ensure patency, after which the posterior longitudinal ligament was incised, allowing for the probing and removal of the residual protruding nucleus pulposus. Following flushing and mold testing, an appropriately sized intervertebral zero-cut fusion device was implanted into the intervertebral space, secured with screws and locked in place. The incision was thoroughly flushed with physiological saline, and a final check for active bleeding was conducted. Drainage tubes were placed, and the incision was closed layer by layer.

Clinical parameters and analysis

We considered several factors that may influence postoperative pain relief in patients, including age, gender, BMI, smoking history, duration of symptoms, preoperative C2-C7 Cobb angle, preoperative NDI, JOA score, postoperative JOA score, and preoperative WIVF and HIVF and postoperative ratio of disc space distraction. Postoperative WIVF and HIVF were also measured to confirm the resolution of intervertebral foramen stenosis.

Measurement of the AIVF and WIVF

The measurement data consist of conventional CT images of the cervical spine in a neutral position, spanning from the cervical 4 to the thoracic 1 vertebrae (Fig. 1 ABC). Reconstruction of the cervical intervertebral foramen and measurement of the minimum oblique sagittal cross-sectional area of the cervical intervertebral foramen were performed using Mimic software (version 20.0, Materialise, Belgium). The measurement scheme is as follows: (1) A 3D digital simulation was conducted to reconstruct the cervical spine and intervertebral foramen model of the target segment (Figs. 1D and 2). (2) The plane of the largest intervertebral space of the target segment was identified in the coronal position, and a centerline was established. An oblique line at a 45° angle to the centerline was drawn across the intervertebral foramen, representing the centerline of the intervertebral foramen of the target segment. (3) The cervical intervertebral foramen model and centerline were transferred to 3-matic software, where a series of continuous planes, spaced 0.1 mm apart, were created perpendicular to the cervical intervertebral foramen centerline. These planes intersected the cervical intervertebral foramen to produce a continuous section (Fig. 3). (4) The software was utilized to fill the sections and calculate the area of each section, with the area of the smallest section being designated as

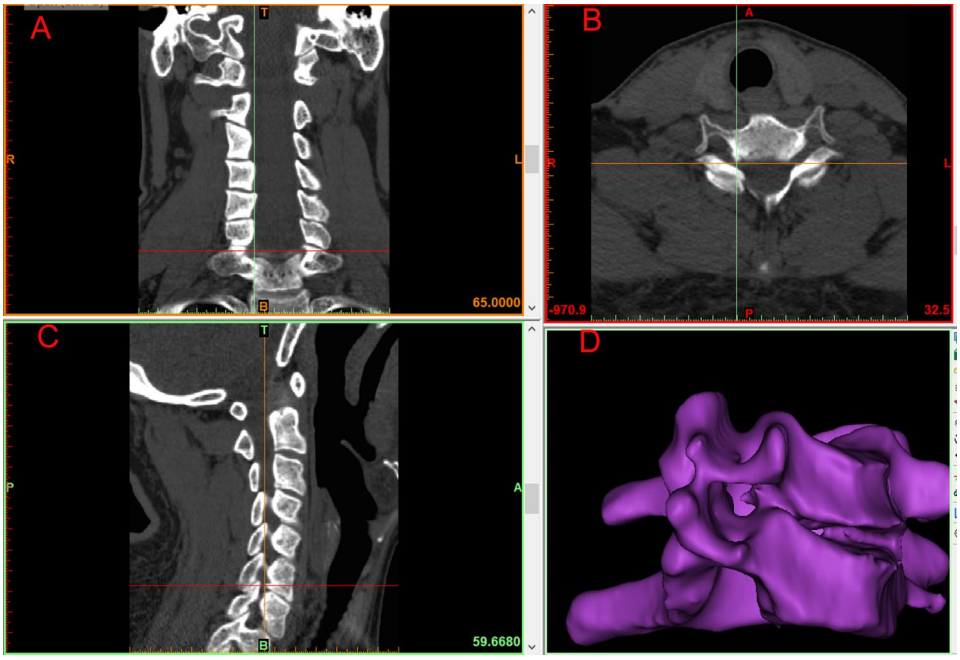

Fig. 1 **ABC**: preoperative conventional CT images of the patient; **D**: 3D reconstructed cervical spine model

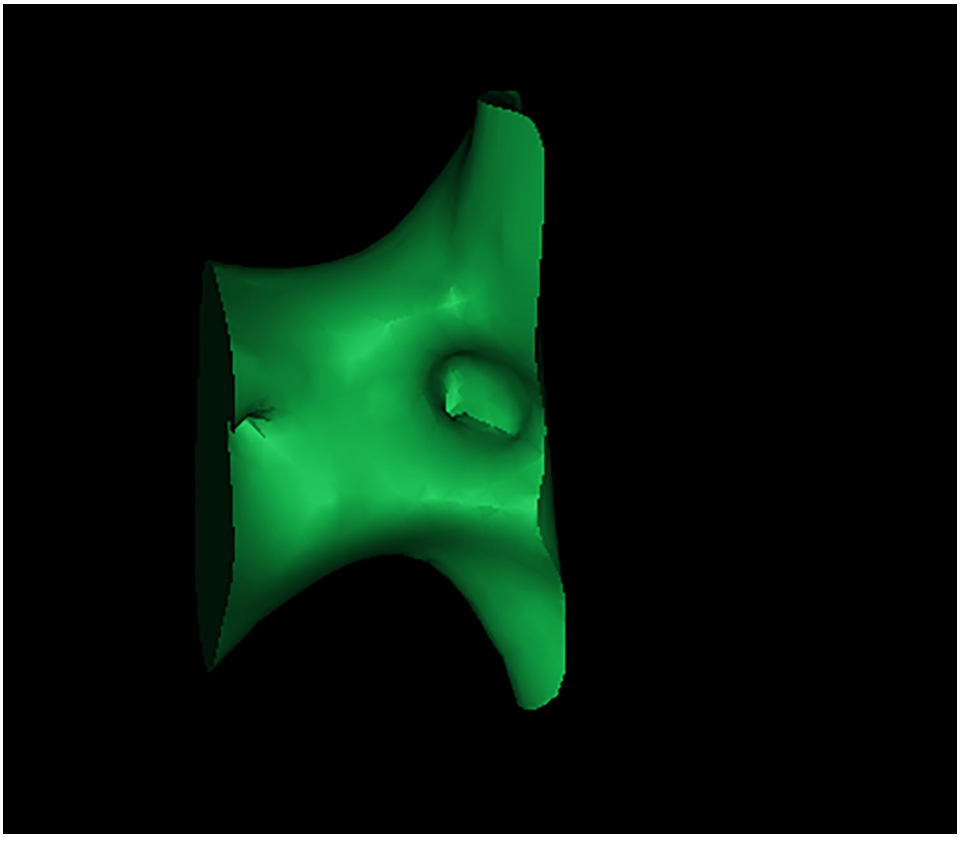

Fig. 2 Three-dimensional reconstruction of the cervical intervertebral foramen model

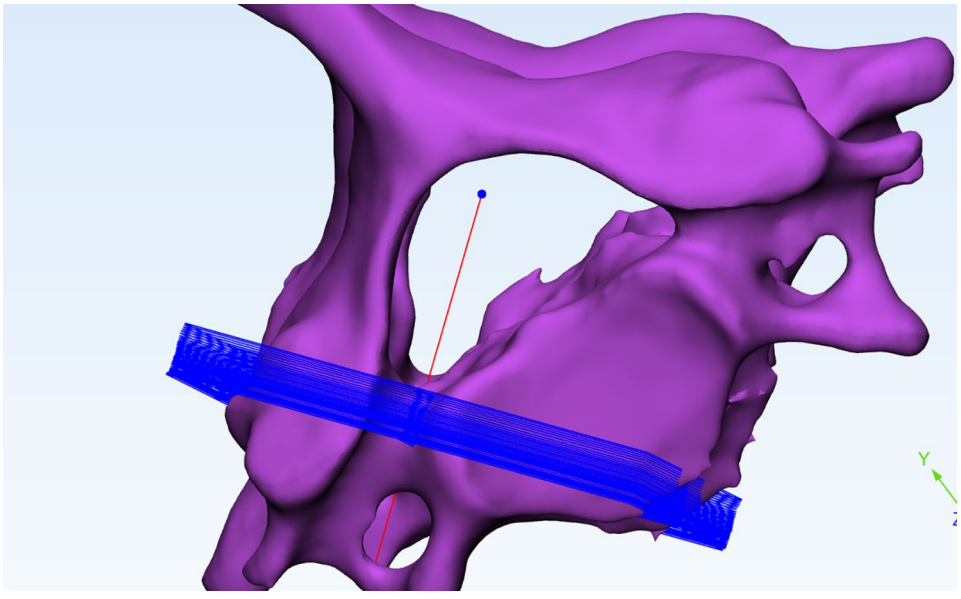

Fig. 3 A series of planes at intervals of 0.1 mm perpendicular to the centerline of the intervertebral foramen, and the planes are tangential to the intervertebral foramen, producing a cut surface

the AIVF. The width was measured on this smallest section, which was identified as the WIVF (Fig. 4).

Ratio of disc space distraction

The ratio of disc space distraction is calculated as the postoperative intervertebral space height divided by the preoperative intervertebral space height, with measurements obtained from X-rays for both preoperative and postoperative intervertebral space heights.

We utilized the NDI to evaluate postoperative pain relief, categorizing patients into two groups based on their NDI scores at the 6-month postoperative follow-up. Patients with an NDI score of less than 15 were classified as the pain relief group, while those with an NDI score of 15 or greater were categorized as the persistent pain group [27–30].

Statistical methods

Analyses were conducted using SPSS 25.0 statistical software (PASW Statistics, IBM). Independent t-tests or chi-square tests were employed to identify significant differences between the two groups. Factors affecting postoperative NDI scores were subsequently assessed using binomial logistic regression analysis. A p-value of less than 0.05 was considered statistically significant.

Results

This study included a total of 201 patients, with baseline characteristics presented in Table 1. Among these, 172 patients in the pain relief group reported NDI scores below 15; while 29 patients with NDI scores of 15 or higher were categorized into the persistent pain group.

At the 6-month follow-up, 14.4% of patients continued to report chronic pain. There were no significant differences in age, gender, BMI, smoking status, preoperative C2-C7 Cobb angle, preoperative JOA score, and postoperative WIVF versus AIVF between the two groups. However, the preoperative WIVF and AIVF were significantly lower in the persistent pain group compared to the pain relief group ($P<0.01$). Additionally, significant differences were observed in the duration of symptoms, preoperative NDI scores, and disc space spreading ratio between the 2 groups (all $P<0.01$, Table 2). These variables were included in a binomial logistic regression model, which indicated that symptom duration, preoperative NDI score and disc space spreading rate were

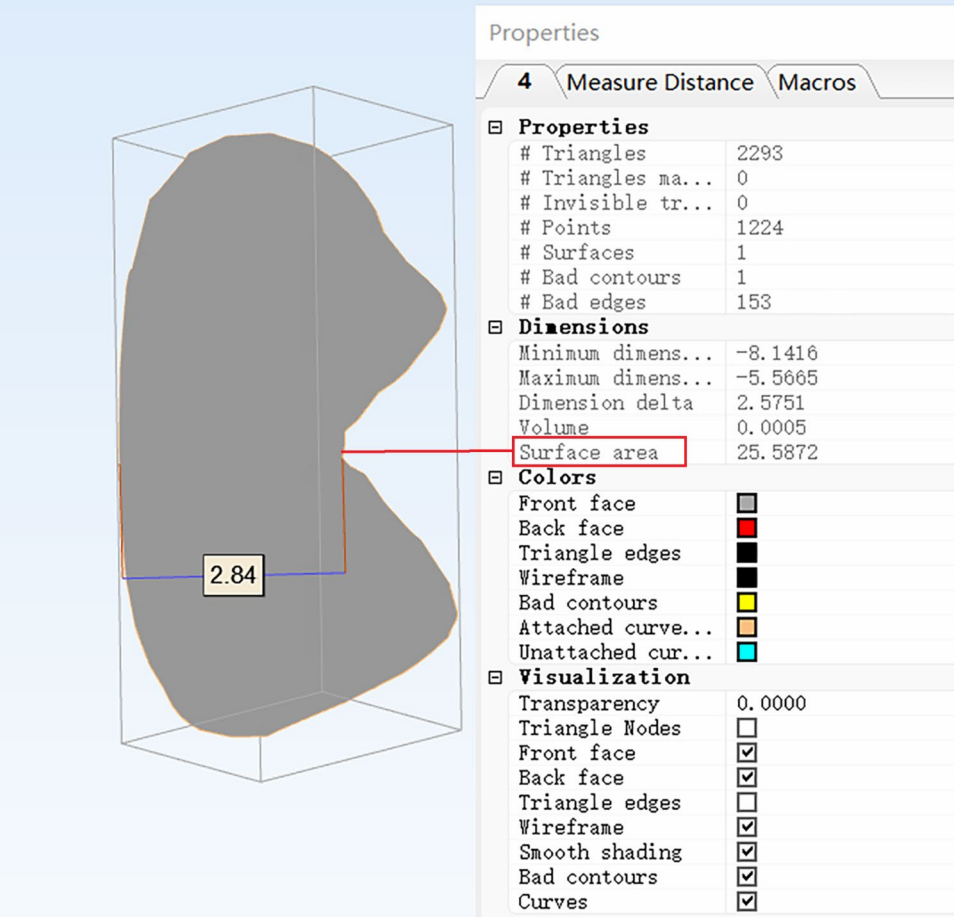

Fig. 4 Area and width of intervertebral foramen calculated in the software

Table 2 Characteristics of each group

	Pain relief group (NDI < 15)	Persistent pain group (NDI ≥ 15)	*P* value
Age	54.05 ± 12.24	56.86 ± 13.21	0.27
Male / Female	53/120	10/18	0.59
BMI	24.18 ± 2.52	24.34 ± 2.45	0.74
Smoking / Nonsmoking	52/121	7/21	0.59
Symptom duration (months)	6.94 ± 1.70	12.64 ± 2.50	<0.01
C2-C7 Cobb angle (°)	8.47 ± 3.40	9.79 ± 2.14	0.03
Preoperative WIVF (mm)	5.68 ± 1.32	2.69 ± 0.79	<0.01
Postoperative WIVF (mm)	7.12 ± 1.13	7.06 ± 0.53	0.86
Preoperative AIVF (mm^2)	25.78 ± 6.62	12.76 ± 4.51	<0.01
Postoperative AIVF(mm^2)	64.70 ± 7.60	64.48 ± 3.91	0.37
Preoperative JOA scores	10.83 ± 1.37	10.36 ± 1.22	0.85
Postoperative JOA scores	15.05 ± 0.63	13.43 ± 0.69	<0.01
Ratio of disc space distraction	1.29 ± 0.05	1.41 ± 0.07	<0.01
Preoperative NDI	31.35 ± 3.64	36.78 ± 3.35	<0.01

*$P < 0.05$ was considered statistically significant. NDI: Neck Disability Index, BMI: Body Mass Index, WIVF: Width of Intervertebral Foramen, AIVF: Area of Intervertebral Foramen, JOA: Japanese Orthopedic Association, SD: Standard Deviation

Table 3 Factors Associated with Pain Relief at 6-Month follow up

	OR	95%CI	*P*
Symptom duration (months)	1.91	1.35–2.71	<0.01
Preoperative WIVF (mm)	0.81	0.64–0.89	<0.01
Preoperative AIVF (mm^2)	0.70	0.58–0.85	<0.01
Postoperative JOA scores	-	-	0.31
Ratio of disc space distraction	3.59	2.18–5.83	<0.01
Preoperative NDI	1.90	1.34–2.70	<0.01

*$P < 0.05$ was considered statistically significant. WIVF: Width of Intervertebral Foramen, AIVF: Area of Intervertebral Foramen, OR: Odds Ratio, CI: Confidence Interval. JOA: Japanese Orthopedic Association, NDI: Neck Disability Index

negatively associated with pain relief, while preoperative WIVF and AIVF were positively associated with pain relief (Table 3).

Discussion

The majority (85.6%) of patients with CSR had relief from neck and shoulder pain at the 6-month postoperative follow-up; however, 14.4% continued to report persistent pain. Significant differences were observed in the duration of symptoms, preoperative NDI score, preoperative WIVF, AIVF and postoperative JOA between the two groups. Binomial logistic regression analysis indicated that the duration of symptoms, preoperative NDI score, ratio of disc space distraction, preoperative WIVF, and AIVF may be associated with persistent postoperative pain.

The primary finding of this study was a significant positive correlation between preoperative intervertebral foramen size and postoperative pain relief. Specifically, as the intervertebral foramen narrows beyond a certain threshold, the likelihood of patients experiencing persistent postoperative pain increases, probably because when the width and area of the intervertebral foramen are reduced, the nerve root may become compressed, and the degree of nerve root compression affects the severity and recoverability of the injury [31]. Our previous study [32] indicated that patients with an intervertebral foramen area of less than 25.95 mm [2] exhibited lower preoperative NDI scores compared to those with an intervertebral foramen area greater than 25.95 mm [2]. Previous studies [32] have assessed the relationship between changes in intervertebral foramen size before and after surgery and postoperative symptom improvement, but there are fewer investigations focusing on the association between preoperative intervertebral foramen size and persistent pain in postoperative patients. In 2021, Sun et al. [25] found that patients with WIVF less than 4.35 mm may experience persistent postoperative pain, marking the first study to demonstrate an association between preoperative WIVF and persistent pain in postoperative patients. In contrast to the findings of Sun et al., we introduced a novel parameter for evaluating intervertebral foramen stenosis: the AIVF. Our study revealed that both the AIVF and WIVF were negatively correlated with persistent postoperative pain. This represents the first investigation to assess the correlation between AIVF and postoperative pain relief.

In addition, this study also found a negative correlation between the duration of preoperative symptoms and postoperative pain relief. However, controversy remains regarding the relationship between these two factors. Consistent with the findings of the present study, Daniel et al. [33] demonstrated that symptoms persisting beyond 2 years were predictive of poorer patient prognosis, while patients with a symptom duration of less than 6 months experienced greater improvement in both postoperative neck and arm pain compared to those with a symptom duration exceeding 6 months. Similarly, Sun et al. [25] also identified a negative correlation between the duration of preoperative symptoms and postoperative pain relief. Conversely, other studies have not established longer symptom duration as a prognostic factor for persistent pain over time; for instance, Peolsson [34] concluded that symptom duration was less significant for clinical outcomes. Additionally, research by Lied et al. [35] indicated that symptom duration was not a prognostic indicator for postoperative pain relief. Sigita et al. [31] reported a significant reduction in arm pain scores among patients who underwent surgery within 6 months, in contrast to those who delayed surgery for more than 6 months, although no significant difference was observed in postoperative neck pain scores. Potential reasons for these discrepancies may include substantial variations in patient selection criteria, sample size, and duration of

symptoms. This relationship warrants further validation through large prospective studies.

A negative correlation was observed between the ratio of disc space distraction and the presence of persistent pain in patients following surgery. Conversely, a positive correlation was identified between the size of the vertebral space and both the WIVF and AIVF [36]. However, excessive prolongation of the intervertebral space may, on one hand, reduce the size of the intervertebral foramen in the adjacent segment, potentially leading to degeneration of the adjacent segment of the vertebral body [37, 38]. On the other hand, it may increase the loading on the small joints, resulting in neck pain [39, 40].

Our study has several limitations. First, it employed a retrospective design, which may not have adequately controlled for the influence of various confounding factors on postoperative NDI scores. Second, being a single-center study may restrict the generalizability of our findings; thus, a multicenter prospective study is necessary to replicate and validate our results. Third, the follow-up period was limited to only 6 months, which may be insufficient to fully capture the long-term benefits of the procedure. Fourth, we focused on patients with single-segment neurogenic cervical spondylosis resulting from bony neurogenic stenosis, which may further limit the applicability of our findings. Additionally, the outcomes of the procedure may evolve over time following the initial postoperative improvement. Finally, due to the insufficient number of positive samples, the model may be biased, and thus the results need to be interpreted more cautiously. As this is a preliminary study, more comprehensive research is required to address these limitations in future investigations.

Conclusion

Preoperative WIVF and AIVF are predictive factors associated with pain relief. Furthermore, the duration of symptoms and the ratio of disc space distraction may adversely affect postoperative pain relief.

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Author contributions
Shuang Liu: Formal analysis, Data curation, Writing- Original draft preparation, Writing- Reviewing and Editing.Peng Pu: Resources, Supervision, Writing- Reviewing and Editing.Qing Xiang and Jie Chen: Validation.Guangye Wang and Xiangling Pu: Conceptualization, Methodology, Writing- Reviewing and Editing, Project administration.all authors have read and approved the manuscript.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest
The authors declare that they have no conflicts of interest and financial disclosures.

Ethics approval
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by our ethics committee. The full name of the research institute associated with the Ethics Committee of Shenzhen Bao'an District People's Hospital is the Clinical Trial Research Center of Shenzhen Bao'an District People's Hospital.

Consent to participate
Informed consent was obtained from all individual participants included in the study.

Consent to publication
Not Applicable.

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