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Lower C2 slope and milder uncovertebral joint degeneration are risk factors for pseudarthrosis after single-level anterior cervical corpectomy and fusion (ACCF): retrospective study of 102 patients with minimum 2-year follow-up

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Abstract

Background Achieving bony fusion after anterior cervical corpectomy and fusion is crucial for restoring spinal stability; however, the risk factors associated with fusion failure, or pseudarthrosis, remain unclear. This study aims to identify risk factors for pseudarthrosis following anterior cervical corpectomy and fusion and evaluate the impact of C2 slope and uncovertebral joint degeneration on this condition.

Methods Patients who underwent single-level anterior cervical corpectomy and fusion between May 2015 and April 2022 and had a minimum of 2 years of computed tomography follow-up were retrospectively enrolled. Preoperative demographic, surgical, clinical, and radiographic data were collected. Patients were divided into fusion and pseudarthrosis groups based on fusion status evaluated at the final follow-up computed tomography. After identifying statistically significant variables through intergroup comparisons, multivariate logistic regression analysis was conducted to determine the risk factors for pseudarthrosis.

Results A total of 102 patients were included in the study, with an average follow-up duration of 3.78 ± 1.70 years. At final follow-up, 37 patients (36.3%) developed pseudarthrosis, while 65 patients (63.7%) achieved fusion. No significant differences were observed in demographic and clinical parameters between the groups. The pseudarthrosis group exhibited significantly greater preoperative C2-7 Cobb angles ($p = 0.029$), segment range of motion ($p < 0.001$), lower C2 slope ($p < 0.001$), and less severe uncovertebral joint degeneration grades ($p = 0.001$). Multivariate logistic regression analysis revealed that, after adjustment, greater segment range of motion ($p = 0.003$), lower C2 slope ($p = 0.006$), and milder uncovertebral joint degeneration grades ($p = 0.023$) were significant risk factors for pseudarthrosis following single-level anterior cervical corpectomy and fusion. The area under the curve of the regression model was 0.867.

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Conclusions Lower preoperative C2 slope, greater segment range of motion, and milder uncovertebral joint degeneration grades may be risk factors for pseudarthrosis following anterior cervical corpectomy and fusion. These characteristics should be further considered in surgical planning to identify high-risk patients.

Keywords Anterior cervical corpectomy and fusion, Pseudarthrosis, Risk factor, C2 slope, Uncovertebral joint

Background

Anterior cervical corpectomy and fusion (ACCF) is one of the most frequently performed procedures for treating cervical spondylosis (CS) [1–3], particularly in cases involving localized spinal canal stenosis or ossification of the posterior longitudinal ligament (OPLL) extending beyond the vertebral body (VB) [4]. Achieving bony fusion is a primary objective of ACCF; however, pseudarthrosis—defined as the failure to achieve fusion—can compromise the stability of the anterior column and result in neck pain. This complication poses significant challenges in surgical planning, patient education, and the postoperative rehabilitation process for ACCF [5, 6]. Nevertheless, the mechanisms and risk factors associated with pseudarthrosis following ACCF remain controversial.

Numerous studies have examined the risk factors associated with pseudarthrosis following anterior cervical discectomy and fusion (ACDF). These factors include preoperative cervical alignment parameters, such as greater segment slope, T1 slope and segment range of motion (ROM) [7, 8], as well as internal fixation-related factors, such as a lower screw-to-vertebral body length ratio [9, 10], the use of angiotensin-converting enzyme inhibitors (ACEIs) [11], and poor bone quality [12]. In contrast, only a limited number of studies have investigated pseudarthrosis following ACCF, which may have a higher incidence, with a one-year rate of 39.7%, compared to the ACDF rate of 24.2% to 30.6% [5].

Cervical alignment parameters may influence the direction of force transmission and the mechanical environment of the reconstructed anterior column, potentially affecting the osseointegration process and fusion outcomes. Additionally, medications and the quality of patient bone may reflect individual tendencies in osteogenesis. Consequently, this study collected a range of cervical alignment parameters and clinical factors to investigate their impact on pseudarthrosis following ACCF. Notably, the C2 slope (C2S) was included in this study, as it has recently been identified as a significant sagittal alignment parameter [13–17]. Furthermore, the degree of uncovertebral joint (UVJ) degeneration was also assessed, as it has been previously recognized as a critical site for early bony fusion and osteogenic potential [18–23].

This study aimed to explore potential risk factors for pseudarthrosis following ACCF using a cohort of single-level ACCF patients with a minimum follow-up of two years. Our hypothesis is that preoperative cervical alignment parameters, such as C2S and the degree of UVJ degeneration, may influence the risk of pseudarthrosis. This understanding could facilitate the identification of high-risk patients and the development of targeted rehabilitation strategies.

Methods

Study design and participants

This retrospective cohort study was approved by the ethics review board of Peking University Third Hospital (M2024132). Patients who underwent single-level ACCF using titanium implants at our hospital between May 2015 and April 2022 were included. The inclusion criteria were as follows: (1) a diagnosis of CS; (2) age between 18 and 75 years; (3) availability of preoperative neutral lateral and flexion–extension radiographs, as well as computed tomography (CT) images; and (4) a minimum follow-up of two years for CT [4]. Patients were excluded if they met any of the following criteria: (1) a history of cervical spine surgery; (2) a history of cervical spine tumors, fractures, or infections; or (3) concomitant ACDF or posterior procedures.

Surgical procedure

The exposure and localization of the index VB were conducted following standard surgical procedures. A distractor was positioned at the superior and inferior ends of the affected vertebra to facilitate the removal of the intervertebral discs above and below. A bone punch was employed to excise the majority of the target VB down to the posterior cortical bone. A high-speed burr or lamina bone punch was then carefully utilized to remove a thin layer of cortical bone, and the medial one-third of the UVJs adjacent to the affected vertebra were decompressed. In cases of OPLL, the ossified ligament was excised. The upper and lower endplates of the intervertebral space were meticulously reshaped to ensure they were flat and parallel while preserving the bony endplates. The intervertebral space was distracted, and its height was measured to select an appropriately sized implant. The implant, packed with cancellous bone harvested during decompression, was then inserted into the intervertebral space. After the distractor was removed, fluoroscopy was used to confirm proper implant positioning. A suitable titanium plate was selected and fixed, with fluoroscopic verification of secure placement. Finally, a negative-pressure drain was placed, and the wound was closed in layers.

Radiographic measurement

Radiographic data were stored in the Picture Archiving and Communication System (PACS, General Electric Company, Boston, MA) and were accessible for analysis as needed. Preoperative radiographic parameters were independently measured by two spine surgeons, while fusion status was subsequently evaluated by another surgeon who was blinded to the radiographic data. The methods for measurement are outlined below.

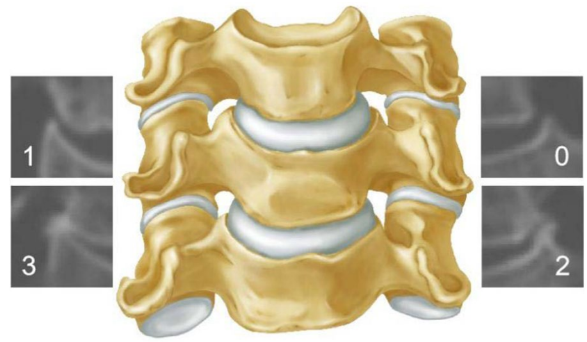

Fig. 1 Illustration of UVJ degeneration grades. UVJ degeneration grades was assessed by observing the four UVJs adjacent to the target surgical segment and summing their individual grades (0–3; representative images shown in the figure)

Evaluation of UVJ degeneration grades

Based on the grading scale proposed by Stoychev et al., we established criteria for grading UVJ degeneration as follows [19]:

Grade 0: No joint space narrowing, osteophytes, subchondral sclerosis, or hypertrophy.

Grade 1: Possible small to moderate joint space narrowing and/or small osteophytes and/or subchondral sclerosis.

Grade 2: Moderate to severe joint space narrowing and at least one of the following: small to moderate osteophytes, subchondral sclerosis, or small hypertrophy.

Grade 3: Severe or moderate joint space narrowing with large or moderate osteophytes, along with one of the following: subchondral sclerosis or small to large hypertrophy. Adjacent UVJ fusion is also classified as Grade 3.

The final grade of UVJ degeneration was determined by summing the degeneration grades of the bilateral upper and lower adjacent UVJs (Fig. 1).

Measurement of X-Ray related parameters on neutral lateral view

The C2-7 sagittal vertical axis (SVA) was defined as the vertical distance from the posterior superior corner of C7 to a plumb line passing through the centroid of C2. Segment SVA was defined as the vertical distance from the posterior superior corner of the lower adjacent VB to the plumb line passing through the centroid of the upper VB. The C2-7 Cobb angle was measured by drawing perpendicular lines to the inferior endplates of C2 and C7, with the angle formed by these lines recorded. Similarly, the segment Cobb angle was defined as the angle between the perpendicular lines to the superior endplate of the upper adjacent VB and the inferior endplate of the lower adjacent VB. The C7 slope was defined as the angle formed between the extended line of the C7 superior endplate and a horizontal reference line. The segment slope was defined as the angle formed between the extended line of the inferior endplate of the lower adjacent VB and the horizontal reference line. C2S was defined as the angle between the extended line of the C2 inferior endplate and the horizontal reference line, while C2 tilt (C2T) was defined as the angle formed between the extension line of the C2 posterior cortex and a plumb reference line. Notably, in the illustrative case (Fig. 2A, left view), the extension line of the C2 posterior cortex exhibited a counterclockwise rotation relative to the plumb line, which was defined as positive.

Measurement of CT values

CT values were obtained from the middle regions of the upper and lower VBs of the target surgical segment. Elliptical regions of interest (ROIs) were defined, and the average CT values for each region were recorded. The mean CT value for the upper and lower adjacent VBs was then calculated as the final outcome (Fig. 2B).

Measurement of segment ROM on dynamic view

The Cobb angles formed by the inferior endplate of the upper adjacent VB and the superior endplate of the lower adjacent VB were measured in both extension and flexion views. The difference between the extension and flexion Cobb angles was recorded as the segment ROM (Fig. 2C-D).

Evaluation of fusion status

This study utilized CT imaging taken a minimum of two years postoperatively to evaluate fusion status. Complete fusion was defined as the formation of extra graft bridging bone (ExGBB) on sagittal or coronal reconstructions [4, 5, 24], with no radiolucent line at the graft-endplate interface (Fig. 3).

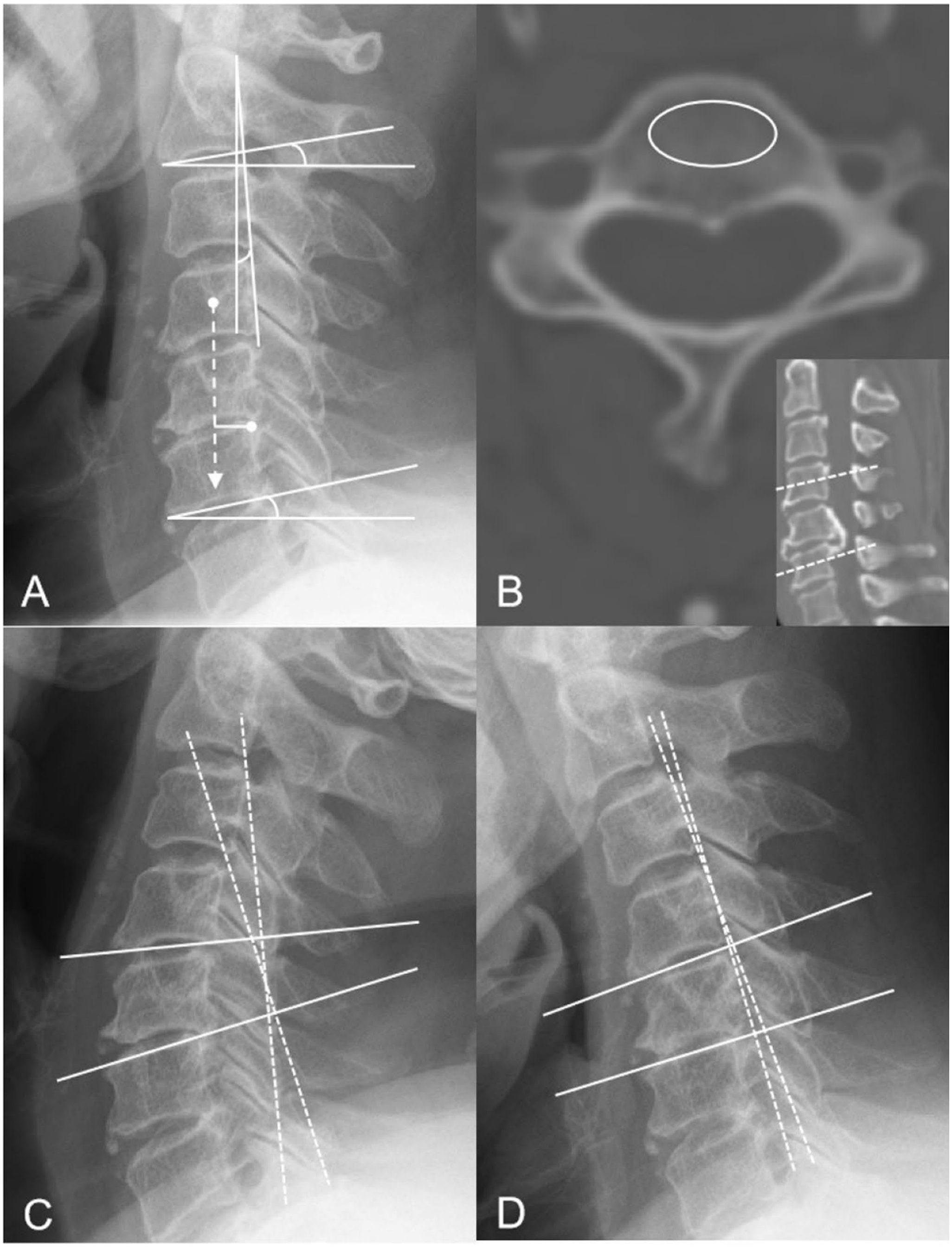

Fig. 2 Illustration of radiographic measurement. Case of a 59-year old male expected to receive C5 corpectomy. **A** Illustration of C2S, C2T, segment SVA and segment slope measurement. **B** Evaluation of CT value of adjacent VBs. An elliptical ROI was shown. **C**-**D** Illustration of segment ROM measurement

Statistical analysis

Continuous variables were presented as mean ± standard deviation, with the Shapiro–Wilk test employed to assess normality. For normally distributed variables, group comparisons were conducted using the Student's t-test, while the Mann–Whitney U test was utilized for variables with non-normal distribution. Categorical variables were compared using the Chi-square test. Variables demonstrating significant differences in univariate analysis were included in a multivariate logistic regression model to control for confounding bias. The receiver operating characteristic (ROC) curve for the multivariate

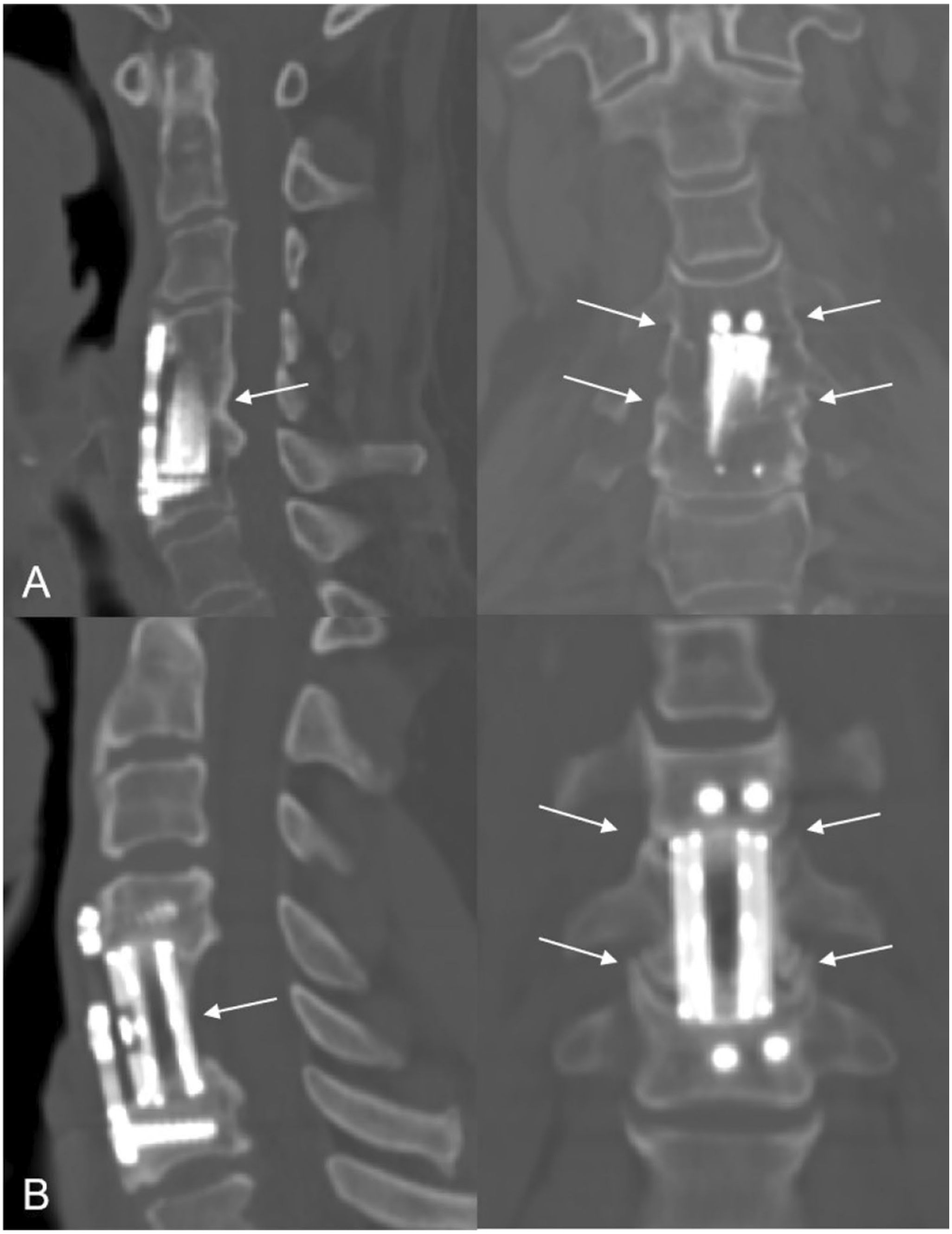

Fig. 3 Illustration of fusion evaluation. Representative cases include a 56-year-old female **A** and a 47-year-old male **B**, both of whom are expected to undergo C5 corpectomy. Continuous ExGBB was observed at both sagittal and coronal reconstruction, which indicated bony fusion in the first case, while no complete ExGBB was observed at sagittal and coronal reconstruction in the second case

logistic regression model was plotted, and the area under the curve (AUC) was calculated. A *p*-value of < 0.05 was considered statistically significant. Statistical analyses and ROC curve generation were performed using SPSS (version 25.0; SPSS Inc., Chicago, IL) and GraphPad Prism (version 8.0.1; GraphPad Software, Boston, MA).

Results

Patient characteristics

A total of 102 patients were included in the analysis. Of these, 37 patients (36.3%) developed pseudarthrosis, while 65 patients (63.7%) achieved fusion at the final follow-up. The cohort comprised 55 females and 47 males, with a mean age of 52.97 ± 9.99 years. The average follow-up duration was 3.78 ± 1.70 years. No significant differences were observed between the two groups regarding body mass index (BMI), comorbidities (hypertension, diabetes), incidence of OPLL and surgical segments. Preoperative clinical outcomes, including the Visual Analogue Scale for neck pain (VAS-neck), the modified Japanese Orthopaedic Association (mJOA) score, and the Neck Disability Index (NDI), did not show any statistical differences between the two groups (Table 1).

Comparison of radiographic parameters between fusion and pseudarthrosis groups

Comparisons between the groups revealed that the pseudarthrosis group exhibited a greater preoperative C2-7 Cobb angle ($p = 0.029$) and segment ROM ($p < 0.001$). Additionally, this group demonstrated smaller C2T ($p = 0.001$) and C2S ($p < 0.001$), as well as less severe UVJ degeneration ($p = 0.001$) (representative cases are shown in Figs. 4–5). No significant differences were observed between the groups regarding other preoperative radiographic parameters (Table 2).

Risk factors for pseudarthrosis after ACCF

Linear regression analysis demonstrated a significant positive correlation between C2T and C2S ($p < 0.001$). Consequently, C2S was selected as the variable for logistic regression analysis. The imaging indicators that exhibited significant differences in the group comparisons were included in the multivariate logistic regression model, which indicated that greater segment ROM ($p = 0.003$), smaller C2S ($p = 0.006$), and less severe UVJ degeneration ($p = 0.023$) were significant risk factors for pseudarthrosis after ACCF. However, the C2-7 Cobb angle did not emerge as a significant factor ($p = 0.229$) (Table 3). The AUC for the multivariate logistic regression model was 0.867 (Fig. 6).

Discussion

Risk factors for pseudarthrosis following ACCF remain relatively underexplored. Achieving bony fusion is a multifactorial process that necessitates a comprehensive assessment of various risk factors to enhance predictive accuracy. To the best of our knowledge, this is the first study to report the influence of C2S and preoperative UVJ degeneration on the development of pseudarthrosis after ACCF. Furthermore, we confirmed the significant role of segment ROM in predicting pseudarthrosis. The model developed in this study achieved an AUC of 0.867, demonstrating favorable diagnostic performance. The results of our study will not only aid in surgical planning and patient education but also enhance our understanding of fusion mechanisms and contribute to the development of predictive models for ACCF fusion outcomes.

In this study, we utilized the widely accepted CT-based criterion focusing on the observation of ExGBB to enhance the reliability of fusion assessment [4, 5]. Due to the lack of an established timeframe for the stabilization of bone ingrowth following ACCF, we included only patients with a minimum of two years of imaging follow-up [4, 25], in line with previous research. Our analysis encompassed demographic, clinical, surgical, and, most notably, radiographic parameters. Among the radiographic parameters, we specifically focused on cervical

Table 1 Patient characteristics

	Fusion group (n = 65)	Pseudarthrosis group (n = 37)	*P*-value
Age	53.20 ± 10.31	52.57 ± 9.52	0.760
Gender (Male: Female)	29:36	18:19	0.694
BMI	24.67 ± 3.46	25.41 ± 3.22	0.299
OPLL (with: without)	45:23	20:17	0.222
Hypertension (with: without)	19:46	8:29	0.402
Diabetes (with: without)	7:58	6:31	0.428
Operative segment			0.649
C4	9	5	
C5	32	15	
C6	24	17	
Follow-up duration (year)	3.92 ± 1.71	3.54 ± 1.68	0.250
Preoperative VAS-neck	2.75 ± 2.58	2.65 ± 2.62	0.840
Preoperative mJOA	14.11 ± 2.35	13.39 ± 2.03	0.061
Preoperative NDI	8.82 ± 9.14	11.35 ± 10.30	0.249

BMI body mass index, *OPLL* ossification of the posterior longitudinal ligament, *VAS* Visual Analogue Scale, *mJOA* modified Japanese Orthopaedic Association, *NDI* Neck Disability Index

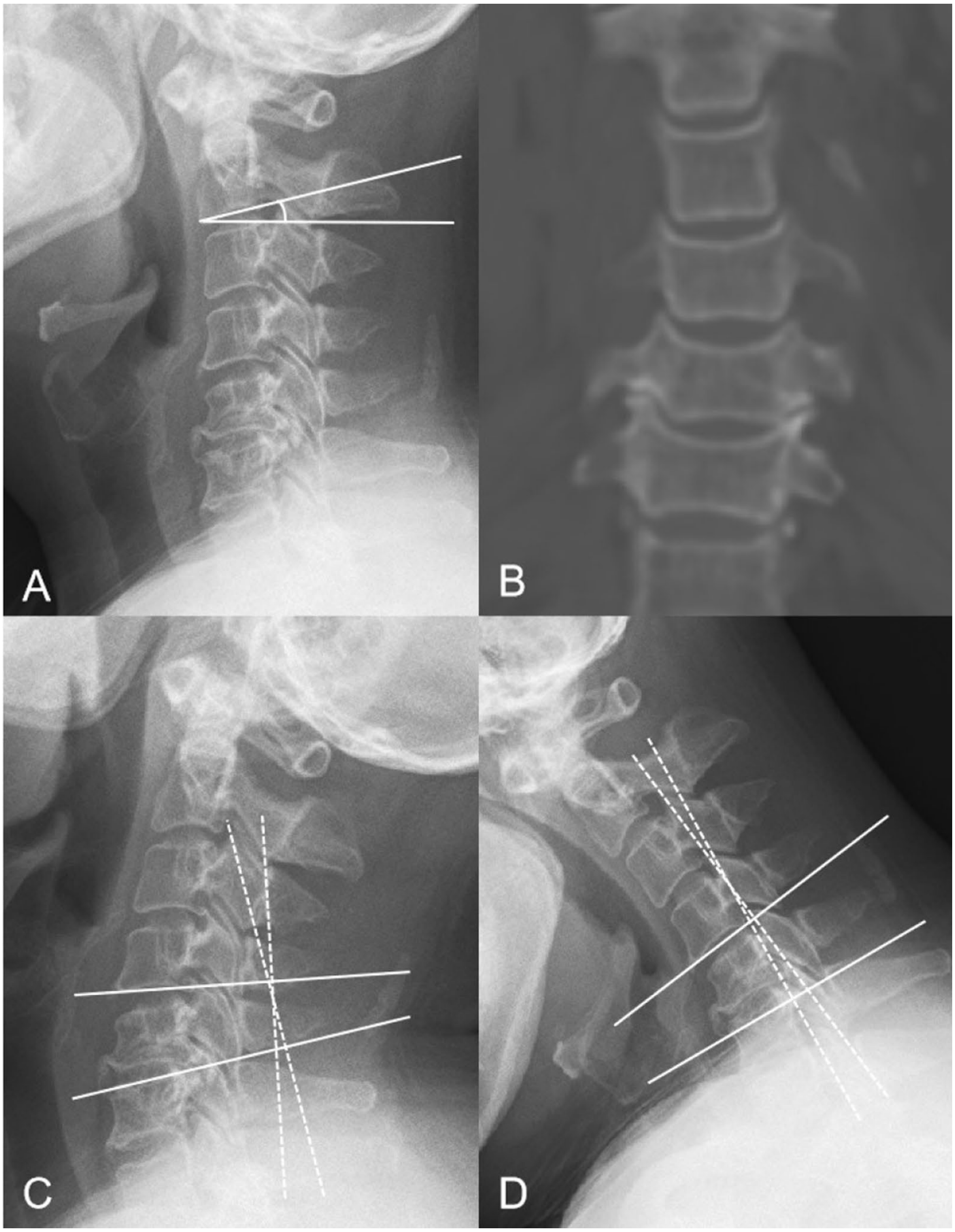

Fig. 4 Representative preoperative images of case that achieved fusion. Radiographic parameters of the case presented in Fig. 3A. **A** Preoperative C2S was 17.8°, **B** the UVJ degeneration grade was 8 (C4-5 left: Grade 1; C4-5 right: Grade 1; C5-6 left: Grade 3; C5-6 left: Grade 3) and **C**-**D** segment ROM was 15.1°

sagittal alignment and UVJ degeneration grades, as we believe variations in cervical alignment reflect different biomechanical environments of the cervical spine [7, 8], while UVJ degeneration is a key site for early bony fusion and may indicate osteogenic potential [22, 23], ultimately influencing fusion outcomes. Other radiological and clinical parameters were also included as potential risk factors or to control for confounding bias. However, following multivariable analysis, only C2S, UVJ degeneration, and segment ROM were identified as significant risk factors for pseudarthrosis, with no significant intergroup differences observed among the other parameters.

The C2S can serve as a mathematical substitute for T1 slope minus cervical lordosis (T1S-CL), a parameter

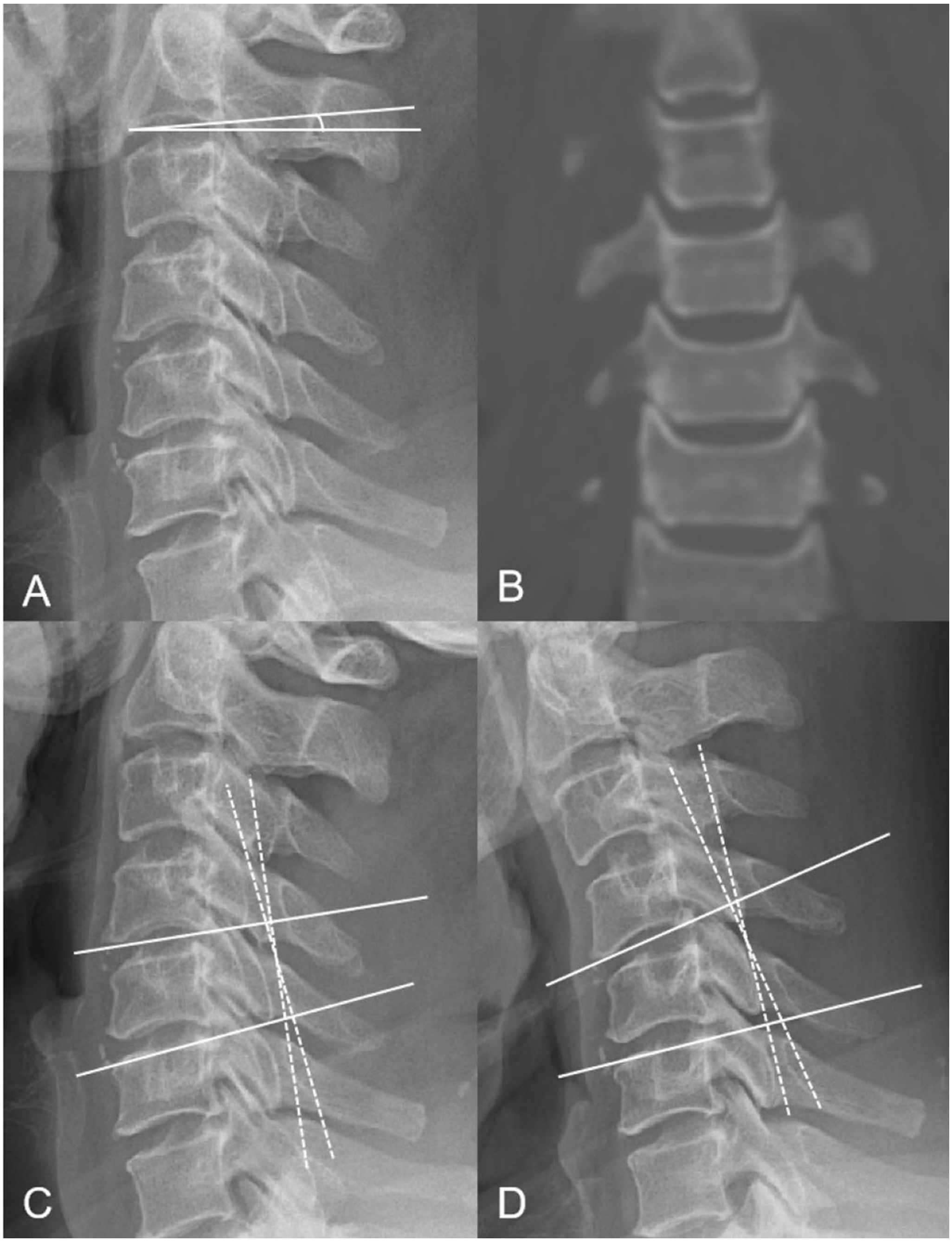

Fig. 5 Representative preoperative images of case with pseudarthrosis. Radiographic parameters of the case presented in Fig. 3B. **A** Preoperative C2S was 6.5°, **B** the UVJ degeneration grade was 6 (C4-5 left: Grade 1; C4-5 right: Grade 1; C5-6 left: Grade 2; C5-6 left: Grade 2) and **C**–**D** segment ROM was 20.6°

that has been highlighted in previous studies due to its significance as a predictor of postoperative outcomes in patients with spinal deformities [16, 17, 26, 27]. Previous research has also reported an association between C2S and postoperative outcomes [28], such as distal junctional failure [29], reoperation rates, and mJOA scores [30]. However, no studies have examined the role of C2S in pseudarthrosis following ACCF. Given the significant positive correlation between C2-7 SVA and C2S observed in both previous studies [13, 30] and our data ($r = 0.644$, $p < 0.001$), we hypothesize that the association between C2S and pseudarthrosis may be explained

Table 2 Univariate analysis comparing radiographic parameters between fusion and pseudarthrosis group

	Fusion group (n = 65)	Pseudarthrosis group (n = 37)	*P*-value
C2-7 SVA	19.56 ± 11.16	17.37 ± 11.91	0.368
Segment SVA	13.99 ± 3.85	14.43 ± 5.04	0.628
C2-7 Cobb	6.31 ± 11.85	11.45 ± 9.72	0.029*
Segment Cobb	1.18 ± 8.89	1.69 ± 7.81	0.783
Segment ROM	12.45 ± 6.68	19.52 ± 6.02	< 0.001*
C2 Tilt	5.78 ± 8.68	− 0.53 ± 9.88	0.001*
C2 Slope	14.62 ± 7.44	7.96 ± 7.45	< 0.001*
C7 Slope	18.25 ± 7.40	16.73 ± 6.76	0.314
Segment slope	15.61 ± 7.99	15.26 ± 7.10	0.942
UVJ degeneration grades	8.81 ± 2.10	7.25 ± 2.05	0.001*
Average CT value of adjacent segments	329.46 ± 86.23	335.19 ± 73.93	0.670

*$p<0.05$

SVA sagittal vertical axis, *ROM* range of motion, *UVJ* uncovertebral joint, *CT* computed tomography

Table 3 Multivariate logistic regression analysis of risk factors for pseudarthrosis

	B	OR	95%CI for OR	*P*-value
C2-7 Cobb				0.229
Segment ROM	0.136	1.145	(1.047,1.253)	0.003
C2 Slope	−0.112	0.894	(0.826,0.968)	0.006
UVJ degeneration grades	−0.297	0.743	(0.575,0.960)	0.023

ROM range of motion, *UVJ* uncovertebral joint, *CT* computed tomography, *OR* odds ratio, *CI* confidence interval

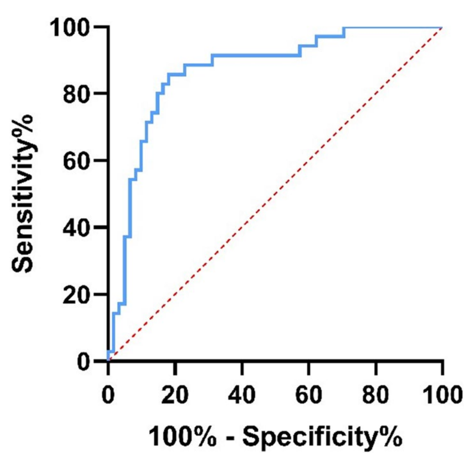

Fig. 6 ROC curve of the multivariate logistic regression model. The AUC was 0.867 as shown above

by the fact that patients with a smaller C2S tend to have a more vertical cervical alignment. In this condition, the load is more likely to be transmitted through the middle and posterior columns, while the anterior column and implant site experience reduced load. According to Wolff's Law, decreased mechanical stimulation may lead to diminished osteogenic activity, thereby increasing the risk of pseudarthrosis [31, 32]. However, the underlying biomechanical mechanisms require further investigation. Segment ROM was identified as another important risk factor in this study. These findings are consistent with those of Choi et al., who reported that a preoperative segment ROM greater than 12° is a risk factor for pseudarthrosis following ACDF [7]. The potential underlying mechanism may be that a smaller segment ROM reflects a more stable muscular and ligamentous complex surrounding the surgical segment, creating favorable conditions for successful fusion. In contrast, significant cervical mobility before surgery increases the likelihood of micromotion in the fixed segments postoperatively, which may impede the fusion process [33].

The UVJ region is a potential site for cervical fusion. Sheng et al. proposed that anterior decompression with UVJ fusion may result in a significantly higher early fusion rate compared to endplate fusion [22]. Tissue analysis in a goat ACDF model demonstrated greater osteogenesis in the UVJ compared to the endplate space [23]. Additionally, UVJ degenerative changes are positively correlated with other imaging indicators of bone hyperplasia, such as heterotopic ossification [34] and facet joint degeneration [21, 35]. This correlation suggests that the degree of UVJ degeneration may reflect osteogenic potential. Furthermore, in cases of severe UVJ degeneration, more pronounced degenerative changes in other bony structures, such as bony fusion within the facet joint, are commonly observed [21]. These changes reduce segmental mobility [36] in the cervical spine, creating a more stable local environment that may facilitate fusion. Based on these findings, this study assessed the degree of UVJ degeneration as a potential influencing factor. The results revealed that milder preoperative UVJ degeneration is a significant risk factor for pseudarthrosis after ACCF. This finding supports the hypothesis that UVJ degeneration reflects osteogenic tendencies, although the underlying mechanisms warrant further experimental investigation.

Based on our findings, surgeons can develop more tailored surgical and rehabilitation strategies for patients with the identified risk factors. For example, in patients with milder preoperative UVJ degeneration, surgeons may focus on roughening the UVJ during surgery and consider using UVJ fusion devices [22]. Additionally, for patients with a smaller C2S or greater segment ROM, the duration of postoperative collar use can be extended to provide prolonged support for cervical stability. Identifying these risk factors also aids in risk stratification for pseudarthrosis, enabling early detection of potential nonunion and facilitating more proactive interventions to prevent adverse outcomes, such as revision surgery. High-risk patients should undergo more frequent postoperative follow-up and receive personalized preventive strategies, as discussed earlier.

This study has several limitations. First, it is a retrospective analysis with a limited sample size. While the sample size is sufficient for constructing a logistic regression model, future studies with a prospective design and larger sample sizes would enable more comprehensive data collection and the identification of additional risk factors. Furthermore, the conclusions of this study may not fully reflect the factors influencing long-term pseudarthrosis after surgery, highlighting the need for further research with extended follow-up periods to provide more accurate assessments of fusion outcomes.

Conclusions

Lower C2S, greater preoperative segment ROM, and milder UVJ degeneration grades may be risk factors for pseudarthrosis following ACCF. These characteristics should be considered during surgical planning to identify patients at high risk for pseudarthrosis.

Abbreviations

ACCF	Anterior cervical corpectomy and fusion
CS	Cervical spondylosis
OPLL	Ossification of the posterior longitudinal ligament
VB	Vertebral body
ACDF	Anterior cervical discectomy and fusion
ACEI	Angiotensin-converting enzyme inhibitors
C2S	C2 slope
UVJ	Uncovertebral joint
PACS	Picture archiving and communication system
SVA	Sagittal vertical axis
C2T	C2 tilt
ROI	Regions of interest
ROM	Range of motion
ExGBB	Extra graft bridging bone
ROC	Receiver operating characteristic
AUC	Area under the curve
BMI	Body mass index
VAS	Visual analogue scale
mJOA	Modified Japanese Orthopaedic Association
NDI	Neck disability index
T1S-CL	T1 slope minus cervical lordosis
CD	Cervical deformity
OR	Odds ratio
CI	Confidence interval

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Author contributions
HW, TX, and RQ were responsible for the study design, data collection and measurement, and manuscript writing. HG, YS, FZ, SP, XC, and YZ assisted with data collection. FZ oversaw and reviewed the study design and manuscript writing.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Review Board of Peking University Third Hospital (M2024132). The requirement for informed consent has been waived by the Ethics Review Board due to the retrospective nature of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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