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ORIGINAL ARTICLE

Adjacent segment motion following multi-level ACDF: a kinematic and clinical study in patients with zero-profile anchored spacer or plate

Wei Cui[1] · **Bingxuan Wu**[1] · **Baoge Liu**[1] · **Dongmei Li**[2] · **Lei Wang**[1] · **Song Ma**[1]

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Abstract

Purpose To investigate the adjacent segment kinematics, including the instantaneous axis of rotation (IAR) and range of motion (ROM), after anterior cervical discectomy and fusion (ACDF), and to compare between ACDF with zero-profile anchored spacer (ACDF-Z) and ACDF with plate (ACDF-P).

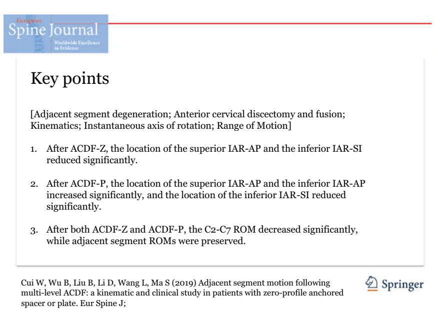
Methods Eighty-seven patients (ACDF-Z = 63; ACDF-P = 24) were included. Flexion, extension and neutral cervical radiographs were obtained before operation and at 1-year follow-up. C2–C7 ROM, adjacent segment ROMs, and IARs were measured. Clinical evaluation was based on the Visual Analogue Scale, Neck Disability Index, and Japanese Orthopaedic Association score.

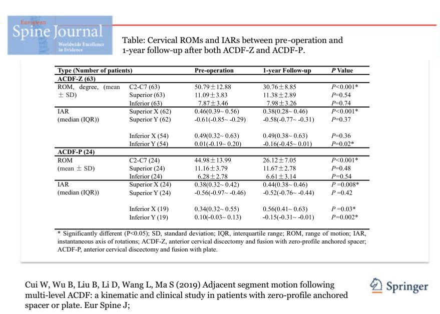
Results After ACDF-Z, location of the superior IAR-AP reduced 1.60 mm, which represents 8% of the vertebral body ($P < 0.001$), and location of the inferior IAR-SI reduced 2.19 mm, 17% of the vertebral body ($P = 0.02$). After ACDF-P, location of the superior IAR-AP increased 0.8 mm, which means 6% of the vertebral body ($P = 0.008$), location of the inferior IAR-AP increased 3.34 mm, 22% of the vertebral body ($P = 0.03$), and location of the inferior IAR-SI reduced 3.14 mm, 25% of the vertebral body ($P = 0.002$). C2–C7 ROM significantly decreased after both ACDF-Z and ACDF-P ($P < 0.001$). Neither ACDF-Z nor ACDF-P significantly affected the adjacent segment ROMs ($P > 0.05$).

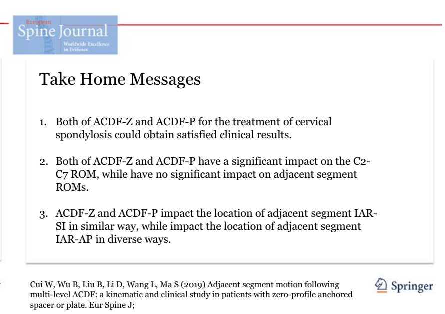
Conclusions Both ACDF-Z and ACDF-P significantly impacted cervical kinematics, although both procedures obtained satisfactory clinical results in the treatment of cervical spondylosis. After both ACDF-Z and ACDF-P, C2–C7 ROM decreased significantly, while adjacent segment ROMs were preserved. ACDF-Z and ACDF-P impact the location of adjacent segment IAR-SI in similar way, while impact the location of adjacent segment IAR-AP in diverse ways.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Wei Cui and Bingxuan Wu made equal contribution to this study.

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Keywords Adjacent segment degeneration · Anterior cervical discectomy and fusion · Kinematics · Instantaneous axis of rotation · Range of motion

Introduction

Anterior cervical discectomy and fusion (ACDF) is a common and successful surgical treatment for patients with cervical spondylosis [1–4]. ACDF via Smith-Robinson approach with various fusion fixation devices, including zero-profile anchored spacer (ACDF-Z) and plate (ACDF-P), are safe and show similar efficacy in improving the functional and radiologic outcomes [1–3]. At 1-year follow-up after operation, ACDF reportedly results in high fusion rates, ranging from 86.8 to 97.9% [4–7]. Nevertheless, long-term complications may occur after ACDF, especially, excessive loading and additional motion in the adjacent segments, which may lead to adjacent segment degeneration (ASD) [8–10].

To assess cervical spine kinematics, range of motion (ROM) of cervical spine is usually measured using the standard lateral radiographs, in the full-flexion and full-extension positions [11, 12]. However, the ROM is an insufficient assessment tool, as it only provides information about the quantity rather than the quality of intervertebral motion [13]. Regarding the quality of vertebral motion, the instantaneous axis of rotation (IAR) during flexion–extension is a major parameter used to depict the motion pattern of the spine [14–16], and an abnormal location of IAR of motion segments adjacent to arthrodesis may forecast the ASD [15, 17]. Therefore, both the IAR and ROM should be used to evaluate the motion quality of cervical adjacent segments after arthrodesis.

Cervical kinematics, especially the ROM, after single-level arthrodesis or arthroplasty have been reported in several studies [17–19]. However, the location of IAR after cervical arthrodesis has rarely been reported. Furthermore, it is controversial whether ASD is more likely to develop following single or multi-level arthrodesis [8, 20]. Therefore, further research is needed into the location of the IAR in patients who have undergone multi-level cervical arthrodesis.

The main purpose of our study was to detect the clear and definite changes in cervical adjacent segment kinematics after multi-level ACDF-Z and ACDF-P by assessing the IAR and ROM. The adjacent cervical segment kinematics of the two kinds of ACDF were also compared.

Materials and methods

This study protocol was approved by the Research Ethics Board of our institution. Informed consent was obtained from all patients. From July 2012 to September 2016, 424 patients that underwent multi-level (2 or 3-level) contiguous ACDF-Z or ACDF-P for cervical radiculopathy and/or myelopathy were included in our study. The study exclusion criteria were: (1) severe neck shoulder pain: visual analogue scale (VAS) scores $\geq$ 3.5 [21]; (2) cervical malformations or fracture/dislocation; (3) continuous ossification of the posterior longitudinal ligament and/or ligamentum flavum calcification; (4) cervical inflammation, tuberculosis or history of metabolic bone disease; (5) previous brain or spinal surgery; (6) implant failure pseudarthrosis; (7) pregnancy; (8) inadequate visibility of the inferior endplate of C-7 on plain radiographs. The remaining 87 patients (28 males and 59 females) with a mean age of 54 years (range 39–71) were included in our study. Of these included patients, 63 underwent ACDF-Z, and 24 underwent ACDF-P. Cervical kyphosis and severe degeneration of endplate were the indications of the use of plate, which might be useful to restore or maintain the cervical lordosis and decrease the rate of cage subsidence.

All patients were followed up for 1 year (12 months $\pm$ 1 month). Flexion, extension and neutral cervical plain radiographs were obtained before the operation and at the 1-year follow-up. ACDF-Z or ACDF-P was selected preoperatively in accordance with the symptoms, and the findings on cervical radiographs, computed tomography, magnetic resonance imaging, and electromyography. The demographic data of patients are summarized (Table 1).

Surgical procedure

All surgical procedures were performed via the anterior Smith-Robinson approach by the same senior spine surgeon at one institution. After routine preoperative preparation for ACDF and general anaesthesia, the patient was placed in supine position with mild neck extension. A right-sided transverse incision was implemented to expose the targeted segment. The targeted levels were then confirmed using C-arm fluoroscopy. When the cervical intervertebral space had been propped open, the herniated disc, osteophytes and posterior longitudinal ligament causing mechanical compression of the nerve root or spinal cord were removed. After removal of the cartilage endplate, the bony endplate was preserved to prevent device subsidence.

ACDF-Z group: trial spacers were used to determine the appropriate implant shape and size. The corresponding zero-profile anchored spacer (LDR Medical Company, France), which was filled with artificial bone (Mastergraft, Medtronic, USA), was then inserted into the prepared intervertebral space. After implant insertion, fluoroscopy was performed to confirm that the device was correctly located in the centre

Table 1 Demographic and operation data of patients

Variable	ACDF-Z	ACDF-P
Number of patients	63	24
Mean age at surgery (range), years	53 (39–69)	54 (42–68)
Follow-up (range), months	12 (11–13)	12 (11–13)
Sex (male/female)	22/41	6/18
Classifications		
Myelopathy	13	4
Radiculopathy	16	2
Myeloradiculopathy	34	18
Levels		
C4–C5, C5–C6	25	14
C5–C6, C6–C7	11	6
C4–C5, C5–C6, C6–C7	27	4
Cages, height		
5 mm	127	45
6 mm	24	7
7 mm	2	0

ACDF-Z anterior cervical discectomy and fusion with zero-profile anchored spacer, *ACDF-P* anterior cervical discectomy and fusion with plate

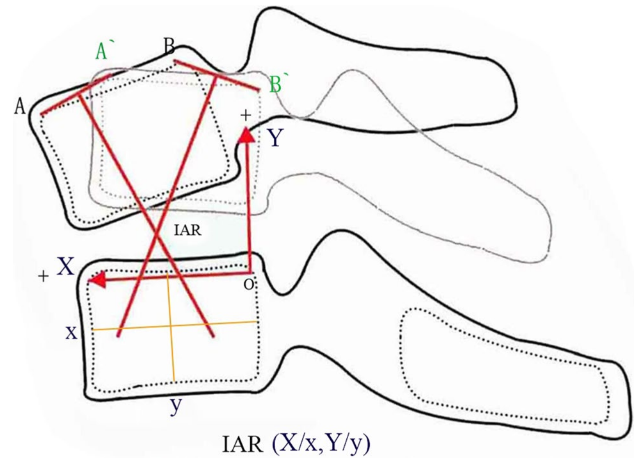

Fig. 1 Measurement of the instantaneous axis of rotation (IAR) on flexion–extension plain lateral radiographs by superimposing the inferior cervical vertebrae in accordance with the method involving the perpendicular bisectors of AA′ and BB′ intervals and the establishment of coordinates

of the intervertebral disc space. Patients were instructed to wear a soft collar for 1 month after operation.

ACDF-P group: the appropriate cage was also determined by intraoperative evaluation utilizing trial cages. The cage (Solis, Stryker Corporation, USA) packed with artificial bone (Mastergraft, Medtronic, USA) was inserted into the disc space, and an anterior cervical titanium plate (Hybrid, Stryker Corporation, USA) was added. A soft collar was also used for 1 month after operation.

Radiographical assessment

Standard lateral radiographs of the cervical spine in neutral, full-flexion, and full-extension positions were obtained prior to and one year after surgery using the same digital radiography equipment (GE Discovery XR656, USA). Each patient stood with the left side of the body closest to the radiographic film, keeping the head straight in the neutral position. The focus of the beam was directed horizontally to the C4 vertebral body. The distance between the X-ray tube and the film was 150 cm. Patients were instructed to flex the neck as much as possible to obtain the flexion view and then to extend their neck as much as possible to obtain the extension view.

The measurement of the IAR was based on the method reported in the previous literature [15, 22]. Four dots were separately marked on the anterior and posterior vertebral corners of segments on the extension and flexion plain radiographs. To reduce measurement errors, we adopted the corticomedullary margin as the contour of the vertebral body [16]. Mimics 16.0 software (Materialise, Leuven, Belgium) was used for superimposing images automatically and measuring the IAR. After overlapping the inferior vertebra, the relative displacement of superior vertebra was revealed. IAR was found by connecting AA′ and BB′ of the superior vertebra, constructing the perpendicular bisectors of AA′ and BB′ intervals, and recording the point of intersection of these bisectors as the location of IAR (Fig. 1).

A coordinate system was established to express the determined location of the IAR. The posterosuperior corner of the inferior vertebra was considered as the origin of the (*X*, *Y*) two-dimensional landmark, the *X*-axis was directed forwards along the superior endplate of the inferior vertebral body, and the *Y*-axis was directed upwards perpendicular to the *X*-axis. The "*X*" was defined as positive in the anterior direction, while the "*Y*" was defined as positive in the cranial direction. The coordinates (*X*, *Y*) of the IAR were normalized as percentages based on the width (*x*) and height (*y*) of the inferior vertebral body to offset individual variations in the sizes of the vertebrae (Figs. 1, 2). Normalized locations of IAR were represented as IAR-anterior/posterior (IAR-AP) and IAR-superior/inferior (IAR-SI).

The C2–C7 ROM and adjacent segment ROM were measured using the Cobb angle method and superimposing the two images for image registration by Mimics 16.0 software [13]. All data were measured and blindly assessed by two junior and one senior spine surgeons for three times at 1-week intervals. Finally, the mean C2–C7 ROM, adjacent segment ROMs and IARs were analysed. To reduce errors, the adjacent segment IAR was calculated only if the adjacent

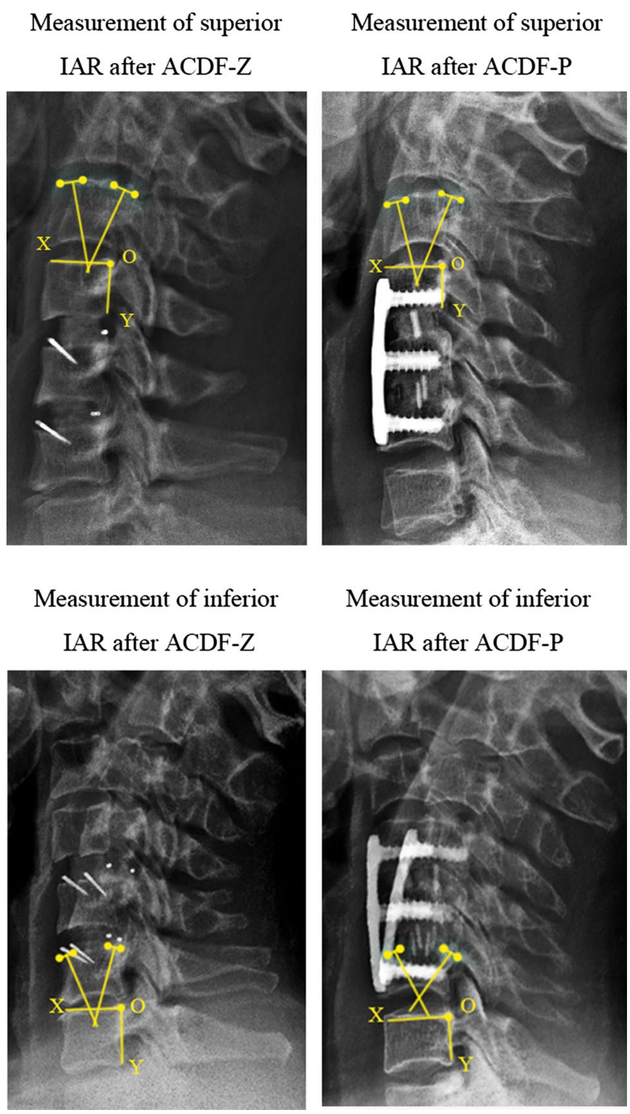

Fig. 2 Measurement of the adjacent segment instantaneous axis of rotations (IARs) after anterior cervical discectomy and fusion with zero-profile anchored spacer (ACDF-Z) and anterior cervical discectomy and fusion with plate (ACDF-P)

segment ROM of the same level was greater than 5° in the sagittal plane [15, 23] (Table 1).

Clinical evaluation

The clinical outcomes were evaluated using VAS, Neck Disability Index (NDI), and Japanese Orthopaedic Association (JOA) score, before operation and at 1-year follow-up.

Statistical analysis

All data were analysed using SAS 9.4 software (SAS Institute Inc., USA). Measurement data were presented as the mean ± standard deviation or median with interquartile range. The inter- and intra-observer reliabilities of each measurement procedure were assessed by intraclass correlation coefficients (ICCs). The paired-samples *t*-test was used to compare continuous variables. If the data were non-normally distributed, comparisons were performed using the Wilcoxon signed-rank test. $P < 0.05$ was considered statistically significant.

Results

Kinematics—instantaneous axis of rotation

After ACDF-Z, the location of the superior IAR-AP reduced 1.60 mm (from 7.41 to 5.81 mm), which means 8% (from 0.46 to 0.38) of the vertebral body ($Z = -4.69$, $P < 0.001$), and the location of the inferior IAR-SI reduced 2.19 mm (from 0.15 to − 2.04 mm), which means 17% (from 0.01 to − 0.16) of the vertebral body ($Z = -2.31$, $P = 0.02$) (Fig. 3; Table 2). After ACDF-P, the location of the superior IAR-AP increased 0.8 mm (form 6.06 to 6.86 mm), which means 6% (from 0.38 to 0.44) of the vertebral body ($Z = -2.67$, $P = 0.008$), the location of the inferior IAR-AP increased 3.34 mm (from 5.71 to 9.05 mm), which means 22% (from 0.34 to 0.56) of the vertebral body ($Z = -2.16$, $P = 0.03$), and the location of the inferior IAR-SI reduced 3.14 mm (from 1.22 to − 1.92 mm), which means 25% (from 0.10 to − 0.15) of the vertebral body ($Z = -3.16$, $P = 0.002$) (Fig. 3; Table 2).

Kinematics—range of motion

The C2–C7 ROM decreased from 50.79° ± 12.88° to 30.76° ± 8.85° at 1-year follow-up after ACDF-Z ($t = 12.90$, $P < 0.001$). The C2–C7 ROM decreased from 44.98° ± 13.99° to 26.12° ± 7.05° at 1-year follow-up after ACDF-P ($t = 7.62$, $P < 0.001$) (Fig. 4; Table 2). Neither ACDF-Z nor ACDF-P showed significant differences in the adjacent segment ROMs between pre-operation and 1-year follow-up ($P > 0.05$) (Fig. 4; Table 2).

The measurements of IAR and ROM showed excellent intra-rater agreement (ICC for IAR: 0.90, range 0.85–0.94; ICC for ROM: 0.94, range 0.92–0.96) and excellent inter-rater agreement (ICC for IAR: 0.84, range 0.74–0.90; ICC for ROM: 0.88, range 0.82–0.93).

Clinical outcomes

In the ACDF-Z group, the VAS scores for the cervical spine and the upper limbs significantly reduced from 1.68 ± 0.78 to 0.94 ± 1.09 and from 3.17 ± 2.59 to 0.67 ± 1.19, respectively ($t = 4.71$, $P < 0.001$; $t = 7.58$, $P < 0.001$). In the ACDF-P group, the VAS scores of the cervical spine and the upper

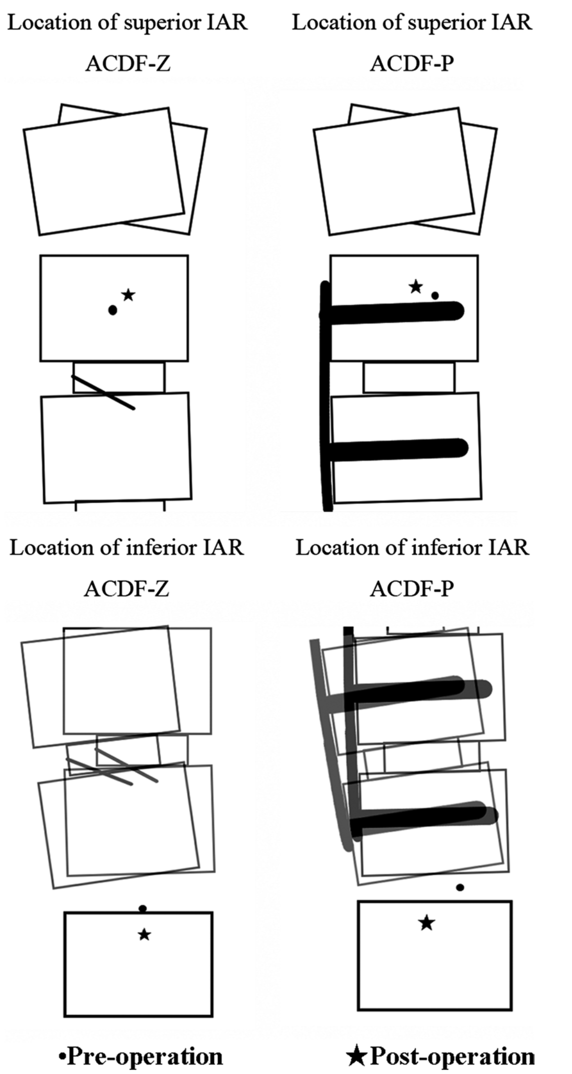

Fig. 3 Pre- and postoperative locations of instantaneous axis of rotation (IAR) of adjacent segments after anterior cervical discectomy and fusion with zero-profile anchored spacer (ACDF-Z) and anterior cervical discectomy and fusion with plate (ACDF-P)

limbs significantly decreased from 1.75 ± 0.79 to 0.83 ± 1.01 and from 3.83 ± 2.66 to 0.75 ± 1.29, respectively ($t = 3.82$, $P < 0.001$; $t = 6.51$, $P < 0.001$). The NDI significantly decreased after both ACDF-Z and ACDF-P ($P < 0.001$). The JOA scores significantly improved after both ACDF-Z and ACDF-P ($P < 0.001$) (Fig. 5).

Discussion

The present study demonstrated that both ACDF-Z and ACDF-P achieved successful clinical outcomes. Nevertheless, some cervical kinematic parameters were affected by both the ACDF-Z and ACDF-P. The parameter most commonly used for evaluating spinal kinematics is ROM [20, 24–26]. However, the ROM only provides information about the quantity of intervertebral motion while failing to characterize the quality of motion [27, 28]. In contrast, the IAR is a sensitive, reliable and accurate parameter that defines the quality of vertebral motion [28]. Therefore, assessing both the IAR and the ROM enables abnormal cervical spine kinematics to be identified and assessed more objectively and reasonably. The path of the IAR can be obtained using the continuous radiographs during the dynamic flexion–extension [17, 25], while the continuous radiographs means extra radiation dose. In the present retrospective study, the location of IAR was obtained by two radiographs in the fully flexed and fully extended positions; this method has been used in previous studies of the cervical kinematics [16, 29]. As abnormal IAR and ROM are significantly correlated with the presence of neck or back pain [14, 28], only patients with mild musculoskeletal pain were included in the present study to reduce the impact of neck pain on the ROM and the IAR [21].

Displacement of the IAR from its normal location results from altered biomechanics and a change in compression, shear, and moments in the interbody space [27]. The IAR after ACDF have been investigated by few studies. Park et al. reported that the locations of the adjacent segment IARs did not change significantly after one-level ACDF [29]. However, this previous study evaluated only single-level ACDF using undefined implants. Different elasticity modulus of implants may influence load sharing and stress distribution on the cervical kinematics, which may impact the location of the IAR [30]. A kinematic cadaver study found that the locations of the inferior and superior IARs changed significantly after the two-Level ACDF-P [31]. Similarly, we also demonstrated that the locations of the IARs changed significantly after the two kinds of ACDFs. Location of the superior IAR-SI had a tendency to shift superiorly, and location of the inferior IAR-SI had a tendency to shift inferiorly after both ACDF-Z and ACDF-P.

On the other hand, we found that the locations of IAR moved in different directions after each of the two kinds of ACDF. Specific abnormalities in the IAR may correspond to specific pathologies, and the reduced anterior muscle force reportedly displaces the centre of reaction backwards [27]. Peterson et al. found that location of the IAR is significantly affected by stiffness of plate, stiffer plates resulted in more posterior element strain, and a more anteriorly located IAR [32]. The present results showed that the location of the superior IAR-AP shifted posteriorly after ACDF-Z, while it had a tendency to shift anteriorly after ACDF-P. With or without front titanium plate might be the reason for the differences in the changes in the IAR location after each of the two kinds of ACDF, especially when the continuity of the anterior longitudinal ligament has been disrupted. The more compliant plates, even without plate, resulted in a more

Table 2 Cervical ROMs and IARs between pre-operation and 1-year follow-up after both ACDF-Z and ACDF-P

Type (number of patients)	Pre-operation	1-year follow-up	*P* value
ACDF-Z (63)			
ROM, degree (mean ± SD)			
C2–C7 (63)	50.79 ± 12.88	30.76 ± 8.85	$P<0.001$*
Superior (63)	11.09 ± 3.83	11.38 ± 2.89	$P=0.54$
Inferior (63)	7.87 ± 3.46	7.98 ± 3.26	$P=0.74$
IAR (median (IQR))			
Superior X (62)	0.46 (0.39 to 0.56)	0.38 (0.28 to 0.46)	$P<0.001$*
Superior Y (62)	− 0.61 (− 0.85 to − 0.29)	− 0.58 (− 0.77 to − 0.31)	$P=0.37$
Inferior *X* (54)	0.49 (0.32 to 0.63)	0.49 (0.38 to 0.63)	$P=0.36$
Inferior *Y* (54)	0.01 (− 0.19 to 0.20)	− 0.16 (− 0.45 to 0.01)	$P=0.02$*
ACDF-P (24)			
ROM (mean ± SD)			
C2–C7 (24)	44.98 ± 13.99	26.12 ± 7.05	$P<0.001$*
Superior (24)	11.16 ± 3.79	11.67 ± 2.78	$P=0.48$
Inferior (24)	6.28 ± 2.78	6.61 ± 3.14	$P=0.54$
IAR (median (IQR))			
Superior *X* (24)	0.38 (0.32 to 0.42)	0.44(0.38 to 0.46)	$P=0.008$*
Superior *Y* (24)	− 0.56 (− 0.97 to − 0.46)	− 0.52 (− 0.76 to − 0.44)	$P=0.42$
Inferior *X* (19)	0.34 (0.32 to 0.55)	0.56 (0.41 to 0.63)	$P=0.03$*
Inferior *Y* (19)	0.10 (− 0.03 to 0.13)	− 0.15 (− 0.31 to − 0.01)	$P=0.002$*

*Significantly different ($P<0.05$)

SD standard deviation, *IQR* interquartile range, *ROM* range of motion, *IAR* instantaneous axis of rotations, *ACDF-Z* anterior cervical discectomy and fusion with zero-profile anchored spacer, *ACDF-P* anterior cervical discectomy and fusion with plate

posteriorly located IAR and subsequently demonstrated less posterior element loading, which might reduce cervical facet joint arthrosis [32]. This hypothesis needs to be tested in further research.

The present results also showed that the C2–C7 ROM in flexion and extension significantly decreased after both ACDF-Z and ACDF-P. However, we found no significant changes in the adjacent segment ROMs after both kinds of ACDFs, which is similar to previous studies [25, 33–35]. This means that although the C2–C7 ROM was markedly decreased at 1-year follow-up, the adjacent segment ROMs were preserved. However, the adjacent segment ROMs tended to increase after both ACDF-P and ACDF-Z; these may have been significant changes in a larger sample size.

The present study had several limitations. First, there were possible measurement errors. To minimize these errors, three spine surgeons each measured the plain radiographs three times, and the reliability of the measurement was represented by the ICC; additionally, flexion and extension radiographs of each patient's cervical spine were superimposed using Mimics software to reduce the steps involving manual measurement. Second, there are differences in the IAR or the ROM among different spinal levels. The present study included adjacent segments of arthrodesis at various spinal levels; however, the postoperative changes at these levels were compared with the same level preoperatively, and so the statistical analysis is credible. Finally, the follow-up period was relatively short, and additional researches might be needed to prove the development of ASD after ACDF.

Conclusion

The present retrospective study evaluated the cervical kinematics after multi-level ACDF using a zero-profile anchored spacer or plate device. We demonstrated that satisfactory clinical outcomes were obtained after both ACDF-Z and ACDF-P for the treatment of cervical spondylosis. Both kinds of ACDFs had a significant impact on kinematics at 1-year follow-up. The C2–C7 ROM decreased obviously after both ACDF-Z and ACDF-P, while the adjacent segment ROMs were preserved. The locations of IARs were markedly shifted, even though the adjacent segment ROMs were not significantly changed; this suggests that the IAR is a more sensitive parameter than the ROM in detecting abnormal mobility of the cervical spine. Different implants may influence load sharing and stress distribution on the cervical kinematics, and ACDF-P and ACDF-Z impact the location of the IAR in diverse ways.

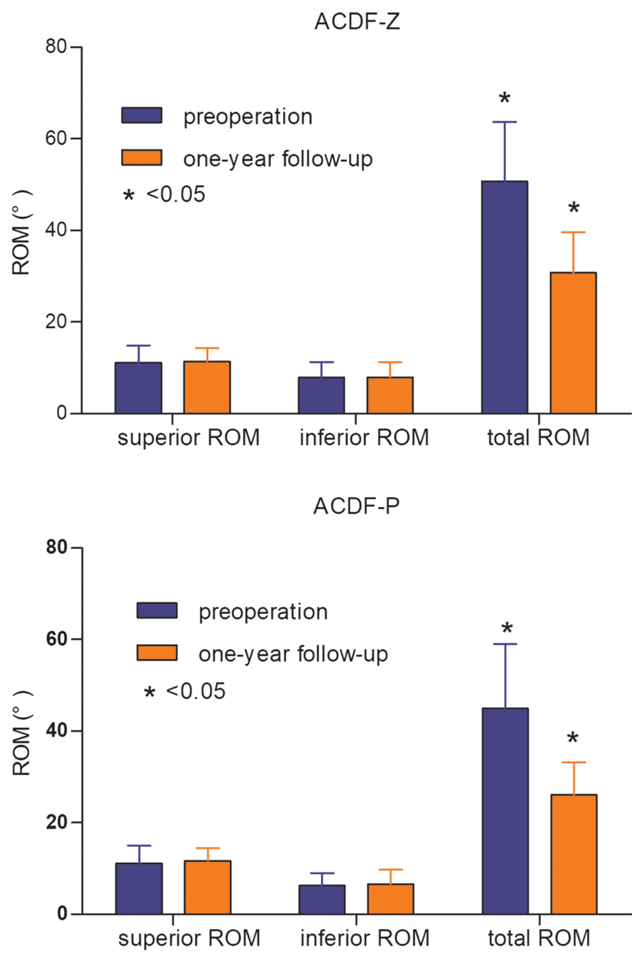

Fig. 4 Pre- and postoperative C2–C7 range of motion (ROM) and adjacent segment ROMs after anterior cervical discectomy and fusion with zero-profile anchored spacer (ACDF-Z) and anterior cervical discectomy and fusion with plate (ACDF-P)

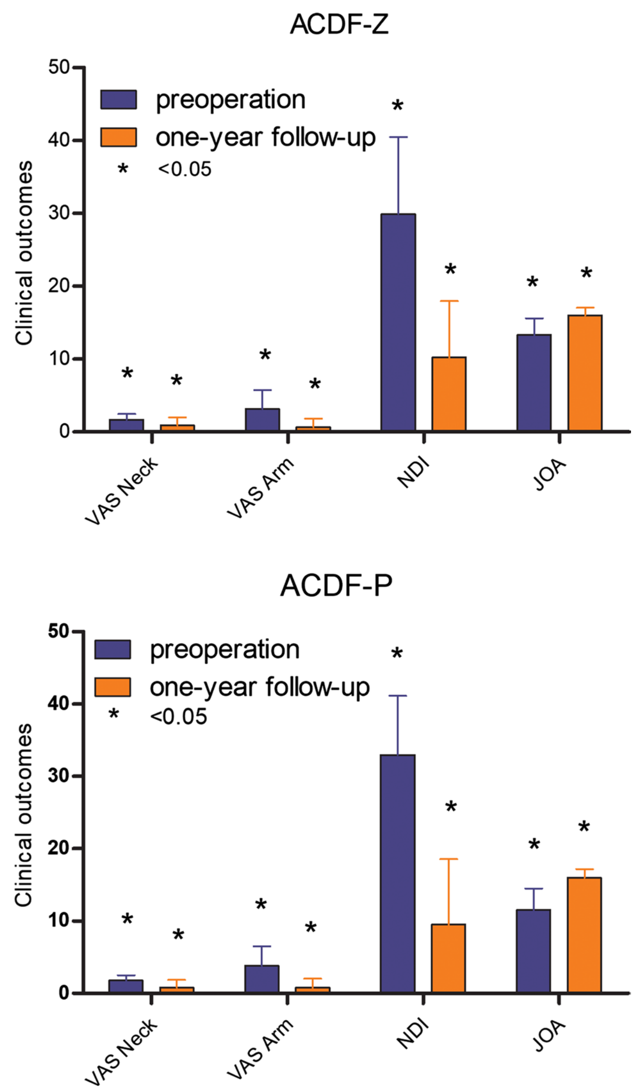

Fig. 5 Pre- and postoperative visual analogue scale (VAS), Neck Disability Index (NDI) and Japanese Orthopaedic Association (JOA) scores after anterior cervical discectomy and fusion with zero-profile anchored spacer (ACDF-Z) and anterior cervical discectomy and fusion with plate (ACDF-P)

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Compliance with ethical standards

Conflict of interest No conflict of interest for all authors regarding this paper.

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Affiliations

Wei Cui[1] · Bingxuan Wu[1] · Baoge Liu[1] · Dongmei Li[2] · Lei Wang[1] · Song Ma[1]

✉ Baoge Liu
baogeliu@hotmail.com

1 Department of Orthopaedics, Beijing Tiantan Hospital, Capital Medical University, No. 119 South 4th Ring West Road, Fengtai District, Beijing, China

2 Department of Orthopaedics, Beijing Shunyi Hospital, Beijing, China