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Original Investigation

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Advantages and Limitations of Zero-Profile Spacers in the Treatment of Cervical Spinal Cord Injury Without Fracture or Dislocation: A 5-Year Retrospective Analysis

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ABSTRACT

AIM: To evaluate the five-year outcomes of zero-profile spacers and plate-cage constructs in cervical spinal cord injury without fracture or dislocation (CSCIWFD).

MATERIAL and METHODS: A retrospective review was conducted on patients undergoing anterior cervical discectomy and fusion (ACDF) for CSCIWFD using zero-profile spacers (n=46) (ZP group) or plate-cage constructs (n=59) (PC group) between June 2014 and December 2019. Neurological function was assessed using the American Spinal Injury Association Impairment Scale (AIS), motor score (AMS), and Japanese Orthopaedic Association (JOA) score. Radiographic parameters included intervertebral height (IH), cervical lordosis, adjacent segment degeneration (ASD), and fusion rate.

RESULTS: The ZP group had shorter operative times and less blood loss than the PC group ($p<0.05$). Both groups showed comparable neurological improvement. Postoperative IH and cervical lordosis were restored in both groups but declined over time, with greater decline in the ZP group (IH loss: 31.12% vs. 16.38%; cervical lordosis loss: 40.20% vs. 14.98%, $p<0.05$). The incidence of early and moderate-to-severe dysphagia was significantly lower in the ZP group. Subsidence occurred in 5 of 78 levels in the ZP group and in 1 of 106 levels in the PC group ($p<0.05$). ASD was observed in 6 ZP vs. 14 PC patients ($p<0.05$). Both groups achieved complete fusion.

CONCLUSION: In the long-term follow-up of ACDF for CSCIWFD, zero-profile spacers demonstrated comparable clinical outcomes to plate-cage constructs. While offering advantages like shorter surgical time, reduced intraoperative blood loss, and a lower incidence of ASD, zero-profile spacers had significantly greater loss of correction for IH and cervical lordosis. Surgeons must carefully weigh these risks and benefits when selecting the optimal treatment for CSCIWFD.

KEYWORDS: Cervical spinal cord injury without fracture or dislocation, Anterior cervical discectomy and fusion, Zero-profile spacer, anterior plate, Intervertebral height

ABBREVIATIONS: CSCIWFD: Cervical spinal cord injury without fracture or dislocation, **ACDF:** Anterior cervical decompression and fusion, **AIS:** American Spinal Injury Association Impairment Scale, **AMS:** American Spinal Injury Association motor score, **JOA:** Japanese Orthopedics Association, **IH:** Intervertebral height, **ASD:** Adjacent segment degeneration, **BMI:** Body mass index, **BMD:** Bone mineral density, **LOC:** Loss of correction

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INTRODUCTION

Cervical spinal cord injury without fracture or dislocation (CSCIWFD) is a unique type of spinal cord injury that is caused by an external force but for which there is an absence of evidence of spinal fracture or dislocation by X-ray or computed tomography (CT) (24). This condition was first described by Pang in 1982 in children with spinal cord injuries (19). While CSCIWFD was thought to be rare in adults, with the widespread adoption of magnetic resonance imaging (MRI), the number of clinical diagnoses of CSCIWFD has increased in recent years (9). A multicenter study conducted in Japan revealed that CSCIWFD accounted for approximately 32.2% of cervical spinal cord injuries, with elderly individuals being particularly affected (10). The predominant mechanism of injury has been identified as minor trauma, such as hyperextension injuries (10,28).

Although most CSCIWFD cases involve incomplete injuries, conservative treatment often results in suboptimal neurological recovery and a high risk of recurrence, potentially leading to secondary spinal cord injury (29). Consequently, there is a compelling need to explore the most efficacious treatment for CSCIWFD to ensure standardization of clinical treatment, mitigation of the socioeconomic burden, and optimization of the allocation of medical resources. For patients with severe CSCIWFD, surgical intervention, such as anterior cervical discectomy and fusion (ACDF), is usually necessary. However, the use of stand-alone instrumented cervical fusions is often ineffective in ensuring clinical outcomes, fusion rates, or maintenance of cervical curvature (15). Therefore, anterior cervical plates are frequently needed. However, anterior plates often result in increased dysphagia and adjacent segment degeneration (ASD) rates (23). The need for extensive exposure during surgery to properly place the plate can also potentially compromise the integrity of vital structures, such as the trachea, carotid arteries, and esophagus.

The widespread use of zero-profile interbody fusion devices in surgical interventions for degenerative cervical diseases has demonstrated the devices' advantages in relation to minimal trauma and few complications (1,31). However, there is a paucity of literature addressing their use in traumatic cervical spine pathologies. In the present study, we collected data from patients treated with zero-profile spacers for CSCIWFD who were followed for up to 5 years postoperatively. By comparing the data of these cases with those of patients treated with anterior cervical plate-cage constructs, we attempted to provide more specific information about the long-term performance of zero-profile spacers in CSCIWFD, particularly their radiologic outcomes.

MATERIAL and METHODS

Patients

This was a retrospective study of patients diagnosed with CSCIWFD who underwent ACDF surgery between 06/01/2014 and 12/31/2019 at our institution. The inclusion criteria were as follows: 1) a clear history of trauma leading to symptoms of cervical spinal cord injury; 2) X-ray and CT findings showing no cervical spine fractures or dislocations, while MRI demonstrating spinal cord edema, hemorrhage, or contusion on T2-weighted images; 3) treatment with an ACDF using zero-profile spacers or plate-cage constructs; and 4) a follow-up of more than 5 years. The exclusion criteria were as follows: 1) spinal cord injury caused by fractures or dislocations; 2) hybrid surgical techniques (combined zero-profile spacer and plate); 3) a history of cervical spine surgery or tumors; 4) multiple concurrent injuries, severe osteoporosis or metabolic diseases; and 5) mental illness, craniocerebral injury, peripheral nerve injury, or other diseases affecting the evaluation of spinal cord function. The study protocol was approved by the ethics committee of our hospital (Decision number: KY25078; date: 02.16.2025), and all procedures were conducted in accordance with the principles of the Declaration of Helsinki. All participants provided written informed consent. Prior to surgery, patients were thoroughly informed about the advantages and disadvantages of zero-profile spacers and anterior plates with cages. Ultimately, patients were divided into the ZP group (zero-profile spacers) and the PC group (plate-cage constructs) on the basis of the implant used.

Surgical Management

After the induction of general anesthesia, all procedures were performed by experienced spinal surgeons using a right-sided Smith-Robinson approach for surgical exposure. The affected segments were then localized using C-arm fluoroscopy, followed by the placement of a Caspar retractor along the medial border of the contralateral longus colli muscles. Under microscopic guidance, the annulus fibrosus was excised to complete the discectomy and decompression. Residual cartilaginous endplates, nucleus pulposus tissue, and annulus fibrosus were removed with a curette, and the posterior longitudinal ligament was incised. Subsequently, a probe was used to examine for any compression or obstruction posterior to the dural sac or along the posterior walls of adjacent vertebrae. After assessing intervertebral space height and depth, trial implants were employed to determine the appropriate implant size. Intraoperative radiography confirmed restoration of disc height and cervical alignment while preventing over-distraction. Midline implant positioning was verified using uncinate processes and longus colli muscles as landmarks before the insertion of either a zero-profile spacer or pre-curved locking plate-cage construct. Screws were placed divergently in the sagittal plane to transfer the load to the interbody implant and convergently axially to prevent pullout, followed by fluoroscopic confirmation of correct placement. During upper cervical fixation, cervical hyperextension with mandibular elevation was maintained to enhance exposure and facilitate screw placement while protecting the superior thyroid artery and superior laryngeal nerve. For lower cervical fixation, protection of the inferior thyroid artery and recurrent laryngeal nerve was ensured by accessing via the superior aspect of the omohyoid muscle to prevent injury. The zero-profile spacer or cage was filled with β-tricalcium phosphate material. Postoperatively, patients were immobilized with semi-rigid cervical collars for 4 weeks.

Clinical Assessment

Patient demographic information and perioperative metrics were obtained from the electronic medical records system. The demographic information included sex, age, body mass index (BMI), bone mineral density (BMD), smoking history, and comorbidities such as hypertension and diabetes. The perioperative metrics encompassed the surgical level, operation time, intraoperative blood loss, and duration of hospital stay. The American Spinal Injury Association impairment scale (AIS) grade, American Spinal Injury Association motor score (AMS) and Japanese Orthopedic Association (JOA) score were utilized to evaluate neurological function and quality of life. The presence of dysphagia was closely monitored during follow-up (48 hours postoperatively and at 1-month, 6- month, 12- month and final follow-ups). The severity of dysphagia was classified according to the Bazaz grading system (2), which categorizes it into four grades: none, mild, moderate, and severe.

Radiological Assessment

Preoperative radiographs, MRI, and CT scans were obtained, and cervical spine radiographs were also obtained postoperatively and at subsequent annual outpatient visits. Implant subsidence was assessed by measuring the intervertebral height (IH) of the fused segment, defined as the distance between the inferior endplate of the upper vertebral body and the superior endplate of the lower vertebral body at the surgical level (Figure 1). The loss of correction (LOC) for IH was calculated using the following formula: $(IH_{postop}-IH_{n})/(IH_{postop}-IH_{preop}) \times 100\%$ (*n* represents the follow-up time points). A definitive diagnosis of implant subsidence was made when a decrease of more than 2 mm in the surgical IH was observed on the follow-up radiograph compared to the immediate postoperative radiographs. Cervical curvature was assessed via lateral radiographs by measuring the cervical Cobb angle, which is defined as the angle formed between lines perpendicular to the inferior endplates of the C2 and C7 vertebral bodies in a neutral position (Figure 1). The LOC for the C2-7 Cobb angle was calculated using the formula: $(Cobb_{postop}-Cobb_{n})/(Cobb_{postop}-Cobb_{preop}) \times 100\%$ (*n* represents the follow-up time points). Solid fusion was defined as the absence of bone sclerosis and radiolucency within the fusion area, along with the presence of bony trabeculae bridging across the graft-endplate surfaces (21). Radiological evidence of ASD included new anterior osteophyte formation or enlargement of existing osteophytes, a decrease in disc height (≥30%), and new or increasing anterior longitudinal ligament calcification, as documented on serial plain radiographs (22). The radiological findings were measured by two independent radiologists.

Statistical Analysis

All statistical analyses were conducted using the SPSS 20.0 (IBM Corp, NY). Quantitative data were presented as the mean ± standard deviation (SD), and categorical data were expressed as absolute frequencies and absolute percentages. For quantitative data that met the assumption of normality, paired and independent samples t-tests were used; otherwise, non-parametric tests were used. The chi-square tests were used to assess the heterogeneity of qualitative data.

RESULTS

Clinical Outcomes

Following the study protocol outlined above, 105 patients (68 males and 37 females) who completed a five-year follow-up were included in the study. The ZP group comprised 46 patients, and the PC group comprised 59 patients. All patients presented with symptoms of neurological injury, including limb numbness, muscle weakness, or diminished sensation. No significant differences were observed between the two groups in terms of sex, age, BMD, BMI, smoking history, comorbidities, or operation level ($p>0.05$). With respect to intraoperative parameters, the ZP group exhibited a significantly shorter operative time (100.6 minutes vs. 115.5 minutes, $p<0.05$) and less intraoperative blood loss (76.8 mL vs. 91.7 mL, $p<0.05$). No significant difference was found in the length of hospital stay. Table I provides a comprehensive overview of the clinical data. Prior to surgery, there was no statistically significant difference in the AIS grade, AMS score, or JOA score between the two groups. During the follow-up period, both groups exhibited comparable improvements in the AIS grade, AMS score, and JOA score ($p>0.05$) (Table II).

At 48 hours postoperatively, dysphagia was observed in 15 of the 46 patients (8 mild, 7 moderate to severe) in the ZP group

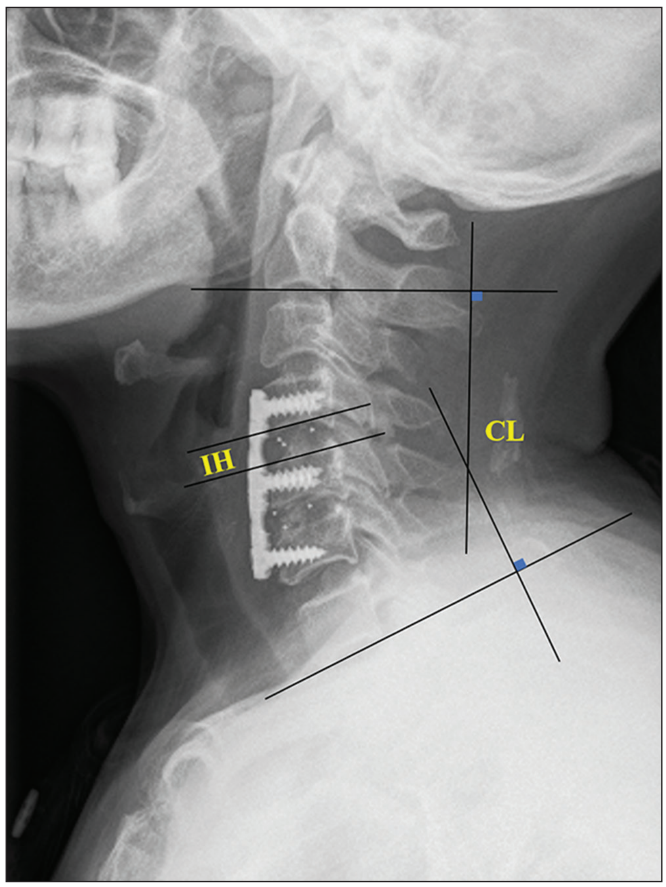

Figure 1: Schematic representation of the radiographic measurements. **IH:** Intervertebral height. **CL:** Cervical lordosis.

and in 33 of the 59 patients (14 mild, 19 moderate to severe) in the PC group ($p<0.05$). At the one-month follow-up, 8 patients (5 mild, 3 moderate-to-severe) in the ZP group and 24 patients (10 mild, 14 moderate-to-severe) in the PC group experienced dysphagia ($p<0.05$). The incidence of early and moderate-to-severe dysphagia was lower in the ZP group than in the PC group. Although at the final follow-up, the majority of dysphagia symptoms had resolved, 1 patient (1 mild) in the ZP group and 4 patients (3 mild and 1 moderate-to-severe) in the PC group still experienced dysphagia ($p>0.05$) (Table III).

Table I: Demographic Outcomes and Intraoperative Data of Both Groups

Parameters	ZP Group (n=46)	PC Group (n=59)	p-value
Age (years) (mean ± standard deviation)	62.9 ± 12.1	60.0 ± 9.8	0.186
Sex (male/female)	32/14	36/23	0.363
BMD (g/cm^2) (mean ± standard deviation)	-0.54 ± 1.10	-0.71 ± 0.95	0.325
BMI (kg/m^2) (mean ± standard deviation)	21.9 ± 2.5	21.6 ± 3.1	0.638
Hypertension (Yes/no)	29/17	40/19	0.611
Diabetes (Yes/no)	18/28	17/42	0.266
Smoking (Yes/no)	20/26	23/36	0.642
Operation levels			0.646
one-level	22 (47.8%)	23 (39.0%)	
two-level	16 (34.8%)	25 (42.4%)	
three-level	8 (17.4%)	11 (18.6%)	
Operation time (minutes) (mean ± standard deviation)	100.6 ± 21.9	115.5 ± 32.5	**0.009***
Blood loss (ml) (mean ± standard deviation)	76.8 ± 26.0	91.7 ± 33.2	**0.014***
Hospital stays (days) (mean ± standard deviation)	7.9 ± 1.4	8.2 ± 1.7	0.494

***BMD:** Indicates bone mineral density, **BMI:** Body mass index, *p<0.05 demonstrated significant statistical difference between the two groups.*

Table II: Comparison of AIS Grade, AMS Score and JOA Score Between Two Groups

	ZP Group (n=46)	PC Group (n=59)	p-value
AIS grade			
Preoperative (A/B/C/D)	0/2/15/29	1/3/22/33	0.432
Postoperative (A/B/C/D)	0/2/14/30	1/3/19/36	0.610
5-yr follow-up (A/B/C/D)	0/2/8/36*	1/3/9/47*	0.891
AMS score (mean ± standard deviation)			
Preoperative	58.35 ± 17.55	56.63 ± 20.27	0.648
Postoperative	62.46 ± 18.81*	63.08 ± 18.60*	0.865
5-yr follow-up	78.13 ± 20.38*	75.44 ± 18.10*	0.476
JOA score (mean ± standard deviation)			
Preoperative	7.07 ± 2.08	6.92 ± 2.23	0.726
Postoperative	9.52 ± 2.03*	9.41 ± 2.04*	0.774
5-yr follow-up	13.33 ± 1.97*	13.54 ± 1.92*	0.573

***AIS:** American Spinal Injury Association impairment scale; **AMS:** American Spinal Injury Association motor score; **JOA:** Japanese Orthopedic Association, *p<0.05, compared with preoperative value.*

Table III: Postoperative Complications and Fusion Rate

	ZP Group (n=46) n (%)	PC Group (n=59) n (%)	p-value
Total dysphagia incidence			
Postoperative	15 (32.6)	33 (55.9)	**0.017***
1-month follow-up	8 (17.4)	24 (40.7)	**0.001***
6-month follow-up	3 (6.5)	12 (20.3)	0.084
Last follow-up	1 (2.2)	4 (6.8)	0.524
Moderate-to-severe dysphagia			
Postoperative	7 (15.2)	19 (32.2)	**0.045***
1-month follow-up	3 (6.5)	14 (23.7)	**0.035***
6-month follow-up	1 (2.2)	6 (10.2)	0.217
Last follow-up	0 (0.0)	1 (1.7)	NS
Fusion rate (levels)			
1-yr follow-up	69/78 (88.5)	98/106 (92.5)	0.356
5-yr follow-up	78/78 (100)	106/106 (100)	NS
Cage subsidence (levels)	5/78 (6.4)	1/106 (0.9)	0.100
ASD	6 (6.5)	14 (23.7)	**0.035***

ASD:** Adjacent level degeneration; *p<0.05 demonstrated significant statistical difference between the two groups;* ***NS: *No significance.*

Radiologic Outcomes

The IH of the fused segments significantly improved, increasing from 5.48 ± 0.65 mm to 7.83 ± 0.60 mm in the ZP group and from 5.36 ± 0.68 mm to 7.87 ± 0.63 mm in the PC group (p>0.05). While the IH was superior to the preoperative state at all follow-up time points, it decreased in both groups. However, the decline was more pronounced in the ZP group, with a significant difference observed at the one-year follow-up. At the five-year follow-up, the IH in the ZP group had diminished to 7.20 ± 0.63 mm, with an LOC of 31.12%. In comparison, the LOC in the PC group was 16.38% at the five-year follow-up (Table IV). Notably, both groups demonstrated stabilization after two years postoperatively, in comparison with the preoperative period of one year (Figure 2).

Cervical lordosis was effectively restored in both groups following surgery. At the 2-day, one-year, and two-year postoperative follow-ups, there were no significant differences in cervical lordosis between the two groups. Starting at the one-year postoperative follow-up, the LOC of the ZP group was greater than that of the PC group. At four years postoperatively, a significant difference in cervical lordosis was observed between the two groups (17.03 ± 4.99 vs. 19.12 ± 4.91, p<0.05) (Figure 3). The Cobb angle in the ZP group continued to decrease, and the LOC increased significantly annually. Conversely, the Cobb angle in the PC group remained stable after 3 years, and the LOC rate remained unchanged. At the five-year follow-up, the cervical lordosis LOC was 40.20% ± 53.34% in the ZP group and 14.98% ± 18.28% in the PC group (p<0.05) (Table V).

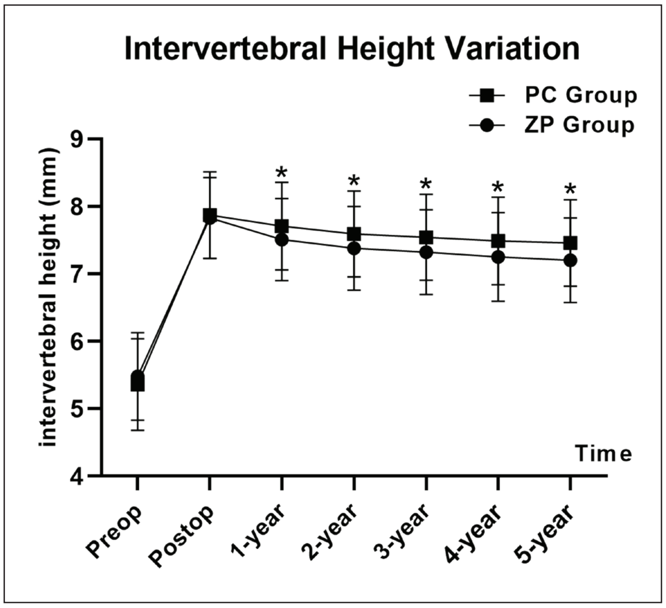

Figure 2: Changes of mean IH during the 5-year follow-up for two groups. IH indicates intervertebral height; Preop, preoperative; Postop, postoperative; *p<0.05.

At the one-year follow-up, the fusion rate was 88.5% (69/78) in the ZP group and 92.5% (98/106) in the PC group (p>0.05). Solid fusion was achieved in all patients at the five-year follow-up (Figure 4). Six patients in the ZP group and 14 in the

Table IV: Intervertebral Height of Surgical Level at Different Time Points

Parameters	ZP Group (n=78)	PC Group (n=106)	p-value
IH (mean ± standard deviation)			
Preoperative	5.48 ± 0.65	5.36 ± 0.68	0.202
Postoperative	7.83 ± 0.60#	7.87 ± 0.63#	0.628
1-year follow-up	7.51 ± 0.61#	7.71 ± 0.65#	**0.043***
2-year follow-up	7.38 ± 0.62#	7.59 ± 0.64#	**0.020***
3-year follow-up	7.32 ± 0.63#	7.54 ± 0.64#	**0.027***
4-year follow-up	7.25 ± 0.66#	7.49 ± 0.65#	**0.022***
5-year follow-up	7.20 ± 0.63#	7.46 ± 0.64#	**0.015***
LOC in IH (mean ± standard deviation)			
1-year follow-up	16.18 ± 13.54	6.63 ± 4.22	**<0.05***
2-year follow-up	22.62 ± 16.32	11.05 ± 5.84	**<0.05***
3-year follow-up	25.69 ± 18.37	13.35 ± 7.33	**<0.05***
4-year follow-up	29.54 ± 19.62	15.34 ± 7.77	**<0.05***
5-year follow-up	31.12 ± 21.98	16.38 ± 8.41	**<0.05***

IH: *Intervertebral height;* ***LOC:*** *Loss of correction;* *******$p<0.05$ *demonstrated significant statistical difference between the two groups;* #$p<0.05$ *compared with postoperative.*

Table V: Cervical Curve (C2-7 Cobb Angle) at Different Time Points

	ZP Group (n=46)	PC Group (n=59)	p-value
C2-7 Cobb Angle (mean ± standard deviation)			
Preoperative	10.22 ± 6.19	9.57 ± 5.24	0.567
Postoperative	19.85 ± 6.52#	20.14 ± 4.68#	0.788
1-year follow-up	18.69 ± 6.48#	19.56 ± 4.83#	0.433
2-year follow-up	18.00 ± 6.27#	19.36 ± 4.85#	0.210
3-year follow-up	17.42 ± 5.36#	19.19 ± 4.89#	0.080
4-year follow-up	17.03 ± 4.99#	19.12 ± 4.91#	**0.034***
5-year follow-up	16.72 ± 5.66#	19.06 ± 4.95#	**0.026***
LOC in C2-7 Cobb Angle (mean ± standard deviation)			
1-year follow-up	16.64 ± 17.27	8.17 ± 13.04	**0.005***
2-year follow-up	28.63 ± 30.38	10.76 ± 14.98	**<0.05***
3-year follow-up	35.26 ± 51.92	13.17 ± 16.64	**<0.05***
4-year follow-up	38.08 ± 45.46	14.06 ± 17.38	**<0.05***
5-year follow-up	40.20 ± 53.34	14.98 ± 18.28	**<0.05***

LOC, *loss of correction; **$P<0.05$ *demonstrated significant statistical difference between the two groups;* **#**$p<0.05$ *compared with postoperative.*

PC group were diagnosed with ASD (p<0.05) (Figure 5). No patients underwent revision surgery.

DISCUSSION

Previous studies have reported that CSCIWFD is most often seen in children, with potential mechanisms including hyperextension/flexion, longitudinal straining, and ischemic injury to the spinal cord (11). However, recent clinical studies have revealed that the prevalence of CSCIWFD in adults is very high and has been underestimated. Unlike children's CSCIWFD, the pathogenesis of CSCIWFD in adults is complex and often associated with cervical spine degenerative lesions. Degenerative changes in the cervical spine, including vertebral hyperostosis, degenerative disc herniation, ossification of the posterior longitudinal ligament, and ligamentum flavum calcification, can result in spinal stenosis, which significantly reduces the compensatory space for the cervical spinal cord (27). Consequently, even low-energy impacts can result in severe damage due to insufficient cushioning space. Kumar et al. reported that CSCIWFD occurs mostly in adults over the age of 45 years. In our study, in which the mean age of the patients was 61.3 years, hyperextension injuries being more prevalent than flexion injuries, and minor injuries more common than severe injuries (12). Preoperative imaging in our study also revealed varying degrees of cervical degenerative changes in all patients, some with spinal stenosis.

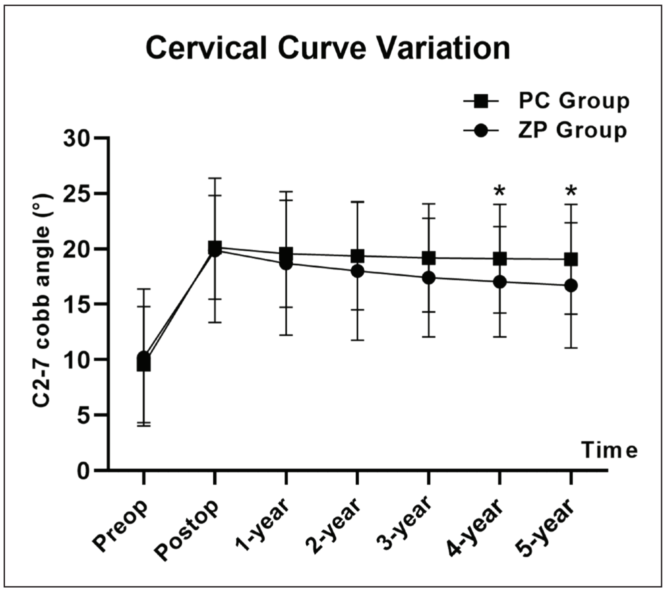

Figure 3: Variations of cervical curve (C2-7 cobb angle) during the 5-year follow-up for two groups. Preop, preoperative; Postop, postoperative; *p<0.05.

In light of the underlying mechanism of injury, it is imperative to reduce compressive factors and enhance blood circulation to the spinal cord. A variety of surgical approaches are available, and despite some controversy, most physicians agree that adequate decompression is the pivotal criterion for selecting a surgical approach, irrespective of the specific technique employed. Feng et al. reported that surgical intervention, even long after the initial injury, yielded superior clinical outcomes compared with conservative treatment (5). When conservative treatment is ineffective, ACDF is regarded as the treatment of choice for CSCIWFD. Owing to ligamentous injury and cervical instability, titanium plates are frequently used in decompression and fusion procedures to enhance spinal stability. However, conventional plates used in ACDF increase the risk of complications such as esophageal perforation, dysphagia, and hoarseness, which can severely affect postoperative quality of life (3). Additionally, achieving a precise match between the plate and the cervical curvature poses a

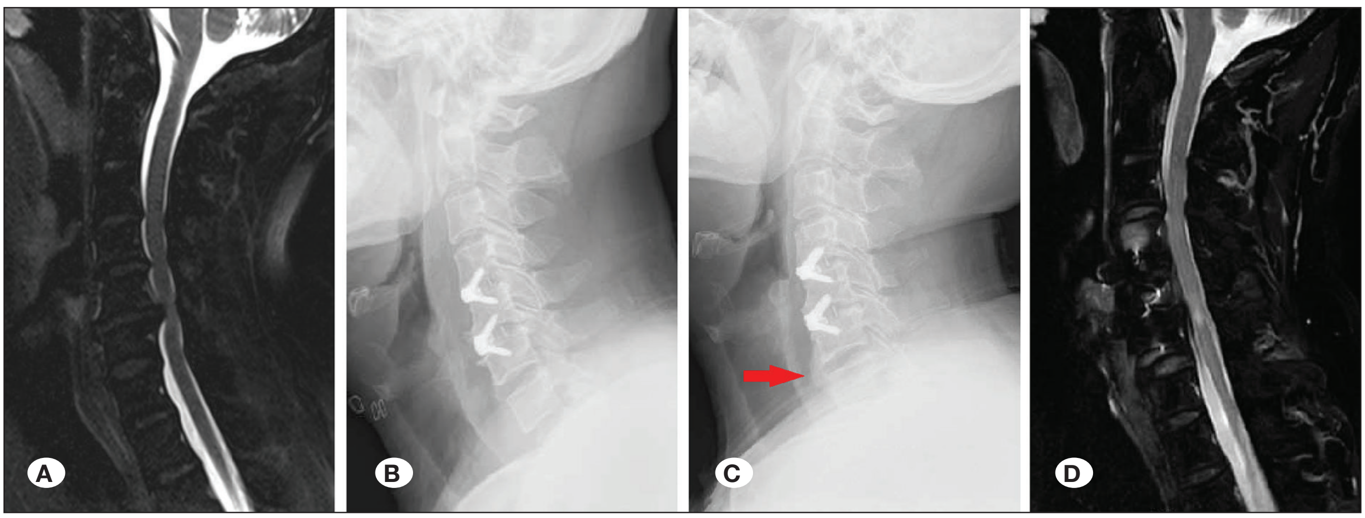

Figure 4: A 51-year-old male underwent ACDF with zero-profile spacers. **A)** Sagittal T2-weighted MRI scan showed herniation of intervertebral disc (C4-5 and C5-6) compressed the posterior spinal cord with high-intensity signal changes. **B)** Lateral radiograph at 1 week postoperatively. **C)** Lateral radiograph at 5 years postoperatively showed significant aggravation of anterior osteophytes in the inferior intervertebral space (red arrow). **D)** Postoperative 1-year follow-up sagittal T2-weighted MRI demonstrated adequate decompression, with persistent intramedullary hyperintensity.

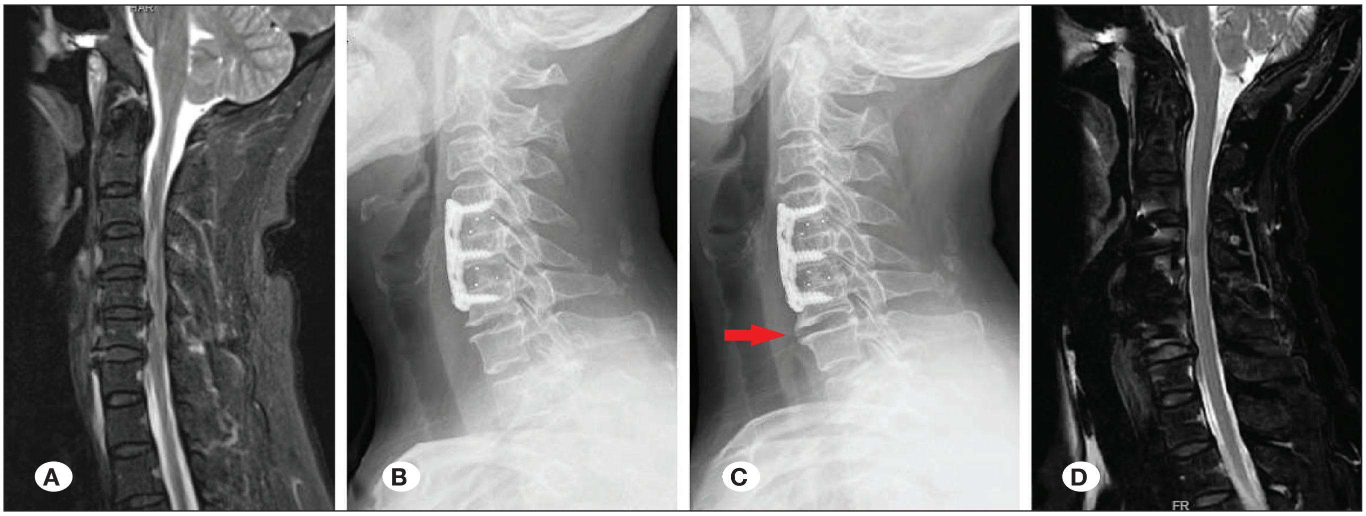

Figure 5: A 53-year-old female underwent ACDF with plate-cage constructs. **A)** Sagittal T2-weighted MRI image showed disc herniation (C4-5 and C5-6) compressing the posterior part of the spinal cord with high-intensity signal changes. **B)** Lateral radiograph at 1 week postoperatively. **C)** Lateral radiograph at 5 years postoperatively showed radiographic adjacent segment disease (red arrow). **D)** Postoperative 4-year follow-up sagittal T2-weighted MRI confirmed adequate decompression with significant improvement in intramedullary hyperintensity.

significant challenge. Consequently, interest in low-profile or zero-profile interbody fusions for the treatment of CSCIWFD has increased.

The zero-profile spacer, composed of screws and a cage, integrates interbody support and supplementary fixation into a single device (6). This unique structure provides a fixation mechanism similar to that of a titanium plate, which theoretically improves postoperative stability while reducing complications associated with anterior internal fixation (7). Our results indicated that both groups experienced similar significant improvements in AIS grade, AMS score, and JOA score postoperatively, with no significant difference. This suggests that the zero-profile spacer is effective and comparable to the conventional plate-cage construct in the treatment of CSCIWFD.

A shorter operative time and less intraoperative blood loss may help reduce perioperative risks and complications. In our study, patients in the ZP group had shorter operating times and less intraoperative blood loss compared with the PC group, which is consistent with findings in the treatment of cervical degenerative diseases (31,36). The possible reasons for this are as follows: the zero-profile spacer is easy to operate, requires less esophageal retraction, and prevents the overexposure of adjacent vertebrae. In particular, for the upper and lower cervical levels, it avoids interference with the mandible and sternum, which can complicate surgical procedures (31).

Effective IH improvement is crucial for good outcomes after cervical spine surgery. Postoperative radiographs in our study showed that IH was effectively restored in both groups, but gradually decreased over time. Previous studies have demonstrated that zero-profile spacers achieved similar efficacy and safety to plate-cage constructs in terms of IH retention and subsidence rate (8,34,36). At the five-year follow up, the subsidence rate of the ZP group was slightly greater than that of the PC group (6.4% vs. 0.9%), but this difference was not statistically significant. Although there was a significant difference in intervertebral disc height reduction between the two groups, it is noteworthy that the long-term clinical outcomes remained excellent in both groups, probably because the intervertebral disc height in patients with subsidence remained significantly greater than it was preoperatively. Abudouaini et al. reported that if postoperative IH changes are maintained between 2-4 mm after one year using a zero-profile device for ACDF (1), satisfactory radiographic parameters and relatively few complications can be achieved. Other studies have also shown similar results (14,18). Achieving solid bony fusion remains the primary goal of ACDF, and in our study, all surgical levels in both groups demonstrated high fusion rates at the final follow-up, which is consistent with previous reports (15,23).

Cervical curvature plays a critical role in maintaining sagittal alignment and spinal balance (30). Some studies have suggested that zero-profile spacers are comparable to plate-cage constructs in maintaining cervical curvature (34). However, these studies usually followed patients for only one to two years. Our research showed significant differences between the two groups at the four-year follow-up, with a higher rate of correction loss in the ZP group. Similar to our study, Sun et al. (26) reported that the loss of cervical lordosis was higher with zero-profile spacers (48.13% ± 44.90%) than that with plate and cages (14.01% ± 25.76%) at final follow-up ($p<0.05$). Loss of normal alignment after surgery can lead to complications such as surgical axial pain, neurological dysfunction, and delayed functional recovery (26,30). Although the clinical outcomes at the final follow-up were satisfactory, concerns remain regarding the long-term maintenance of alignment in patients using zero-profile spacers.

Dysphagia is the most common postoperative complication following ACDF, with reported incidence rates varying widely in the literature, ranging from 0% to 80% (13). This variation may be due to differences in how thoroughly investigators check for dysphagia postoperatively (17). Xiao et al. reported a lower incidence of postoperative dysphagia with a zero-profile spacer compared to plates and cages (33). Similarly, we found that the incidence of early and moderate-to-severe dysphagia was lower in the ZP group than in the PC group. This may be attributed to the fact that the zero-profile spacer can be inserted into the intervertebral space without the need for additional anterior titanium plating, which reduces irritation of the anterior cervical tissues and the esophagus. Most cases of mild dysphagia typically resolve within three months, but 12.5%-35% of patients experience longer-lasting symptoms, which is consistent with our findings (14,25). In our study, both groups had patients with unresolved dysphagia at the final follow-up. The occurrence of prolonged dysphagia after ACDF is associated with multiple factors, including long surgical duration, prior cervical surgery, multilevel surgery, and a history of obstructive sleep apnea, asthma, and heavy smoking (16,20,35). The key factors remain elusive, and further investigations into the mechanisms of prolonged dysphagia and strategies to minimize its occurrence are warranted.

ASD is a long-term complication associated with ACDF. A meta-analysis involving 83 studies found that the annual incidence of radiographic ASD was 2.79% (4). Another study, which followed 219 patients who received ACDF for more than five years, reported that 21% of the patients developed ASD (32). In our study, the incidence of postoperative ASD was significantly lower in the ZP group than in the PC group. Biomechanical research suggests that anterior plates may increase the load on adjacent discs, contributing to a higher incidence of ASD (26), while zero-profile spacers avoid potential plate-induced irritation and reduce the biomechanical burden on adjacent segments.

The current study faced limitations due to its retrospective design and relatively small sample size. In addition, all patients were operated on by a single surgical team at a single center. To address these limitations, it is essential to conduct large, multicenter, prospective, randomized controlled trials with long-term follow-up.

CONCLUSION

During the five-year follow-up of ACDF for CSCIWFD, the zero-profile spacer demonstrated similar neurological outcomes to conventional plate-cage construct. The zero-profile spacer was easy to operate, with a shorter operation time, less intraoperative bleeding, and a lower incidence of postoperative dysphagia. However, compared with plate-cage constructs, zero-profile spacers resulted in a greater loss of cervical lordosis and intervertebral disc height, but this was not associated with long-term complications. In conclusion, spinal surgeons should carefully consider the use of zero-profile spacers in the treatment of CSCIWFD.

Declarations

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AUTHORSHIP CONTRIBUTION

Study conception and design: YG, JW
Data collection: QX, DL
Analysis and interpretation of results: YL, DF
Draft manuscript preparation: LW, AW
Critical revision of the article: YG
Other (study supervision, fundings, materials, etc...): JW, YG
All authors (LW, AW, QX, DL, YL, DF, JW, YG) reviewed the results and approved the final version of the manuscript.

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