Turk Neurosurg 33(6):996-1004, 2023

Original Investigation

Received: 16.06.2022
Accepted: 08.11.2022

DOI: 10.5137/1019-5149.JTN.41249-22.2

Published Online: 10.04.2023

Comparison of the Efficacy of an Anchored Cage with Unidirectional and Bidirectional Screw Fixation in Single-Level Cervical Discectomy and Fusion Surgery

Jung Jae LEE[1], Hong Kyung SHIN[2], Byong Gon PARK[3], Sang Ku JUNG[4], Su Bum LEE[5], Jin Hoon PARK[2]

[1]University of Ulsan College of Medicine, Gangneung Asan Hospital, Department of Neurosurgery, Gangneung, South Korea
[2]University of Ulsan College of Medicine, Asan Medical Center, Department of Neurosurgery, Seoul, South Korea
[3]Catholic Kwandong University, College of Medicine, Department of Physiology, Gangneung-si, Gangwon-do, South Korea
[4]University of Ulsan College of Medicine, Gangneung Asan Hospital, Department of Emergency Medicine, Gangneung, South Korea
[5]Korea University Medicine, Department of Neurosurgery, Seoul, South Korea

Corresponding author: Jin Hoon PARK ✉ jhpark@amc.seoul.kr

ABSTRACT

AIM: To compare, and to analyze the clinical and radiological signs between bidirectional and unidirectional screw fixation in single level cervical discectomy and fusion surgery.

MATERIAL and METHODS: We retrospectively reviewed the data collected from 90 patients and divided them into the upper or lower spine fixation group (unidirectional) and the normal upper and lower spine fixation group (bidirectional). The patients' demographic data and preoperative and postoperative (24 months) clinical outcomes were collected. Pre- and postoperative (immediately and at 3, 6, 12, and 24 months) changes in the segmental angle in the operating field (SA), cervical lordosis, C2–7 sagittal vertical axis, and active disc height (aDH) were evaluated. We also compared the rate of fusion and muscle size change between the groups.

RESULTS: The operation time in the bidirectional screw fixation group was significantly longer than that in the unidirectional screw fixation group (>6 min; p=0.03). There was no significant difference between the two groups in radiographic parameters before and immediately after surgery. From 3 months postoperatively, the unidirectional group had significantly higher SA and aDH than the bidirectional group (p=0.03). The fusion rate was higher in the bidirectional screw fixation group than in the unidirectional group, but this was not statistically significant (97% vs. 88%, p=0.07).

CONCLUSION: The results of this study suggest that unidirectional screw fixation surgery can be useful as it has been associated with simple surgery, short surgery time, and maintenance of the lordotic curvature of SA and disc height.

KEYWORDS: Cervical spine, Screw direction, Spinal curvatures, Spinal fusion, Discectomy

ABBREVIATIONS: ACDF: Anterior cervical discectomy and fusion, **ACIF:** Anterior cervical interbody fusion, **aCSA:** Adjusted cross-sectional area, **aDH:** Active disc height, **BMD:** Bone marrow density, **CL:** Cervical lordosis, **CSA:** Cross-sectional area, **CT:** Computed tomography, **DH:** Disc height, **IRB:** Institutional review board, **MRI:** Magnetic resonance imaging, **NDI:** Neck disability index, **SA:** Segmental angle, **SVA:** Sagittal vertical axis, **VAS:** Visual analog scale

Jung Jae LEE : 0000-0002-1887-0069
Hong Kyung SHIN : 0000-0001-8182-3321
Byong Gon PARK : 0000-0002-0154-6596
Sang Ku JUNG : 0000-0002-9606-0440
Su Bum LEE : 0000-0003-4732-8137
Jin Hoon PARK : 0000-0002-0903-3146

INTRODUCTION

Anterior cervical discectomy and fusion (ACDF) is considered to be the best surgical option for treating cervical disc disease if conservative treatment for cervical spine disease fails (9,10). Some studies found that the addition of assisted fixation by a cervical plate can stabilize the segment, improve results, and reduce the risk of pseudarthrosis (9,26). However, complications associated with the anterior cervical plate, such as esophageal soft tissue damage, neurovascular damage, and dysphagia, have been reported in traditional ACDF surgery (2,30).

The interbody cage is designed to provide stability and promote fusion between the cervical vertebrae without using an anterior plate to address these complications (21). Its purpose is to restore physiological cervical disc height (DH), provide immediate and stable load support, and promote joint fixation with satisfactory clinical results (1,14,33). Anchored cages are currently used in many cervical spine surgeries. Furthermore, anchored cages have the following advantages over plate cage surgery: shorter than average operating time and lesser blood volume loss (25).

Regarding surgery with the anchored cage, there were cases where the screw was fixed in only one direction, typically caught in the sternum or jaw. Although a dedicated driver was used when the screw was caught in the jaw or sternum, the use of the driver was difficult because of the complexity of its assembly and operation difficulty, and plate fixation was used instead in most cases. However, as adjacent segment disease occurred in the affected area, some surgeons inevitably used the unidirectional screw fixation method, and there were no significant postoperative complications. Henceforth, we used the unidirectional screw fixation method.

This study aimed to compare and analyze the clinical and radiological signs between unidirectional and conventional bidirectional screwing surgeries.

MATERIAL and METHODS

This study was approved by the Institutional Review Board of our institution (Date: 2 August 2021; No: 2022-07-010).

Demographic Data

This was a multicenter, retrospective, observational, clinical, and radiological study involving a collection of patients who received single-level ACDF using the anchored cage at our institution from May 2012 to June 2019 (Figure 1). Patient groups excluded were those who underwent ≥two-level ACDF operations and those who had cervical spine trauma, cervical spine surgery, history of posterior instrumentation in the cervical spine, rheumatoid arthritis, systemic infection, posterior ligament ossification, and/or malignant tumors.

We recruited 90 patients with cervical degeneration who met the inclusion criteria. These patients were divided into an upper or lower spine fixation group (unidirectional screw fixation group) and a normal upper and lower spine fixation group (bidirectional screw fixation group) according to the fixed vertebrae. All surgeries were performed by two neurosurgeons. The patients with the same surgical indication were randomly selected for surgery from May 2012 to June 2019. Data of variables, including sex, age, underlying disease, occupation, alcohol and tobacco use, body mass index (BMI), surgical level, and bone marrow density (BMD, T-score) were collected for all the patients.

Operative Technique

A standard left Smith–Robinson anteromedial approach to the cervical spine, as described by Kim et al., was conducted (17). First, a complete discectomy was performed, the cartilage endplate was removed via curettage, and the upper and lower endplates were minimally decorated to enhance allograft-bone fusion. Next, the posterior longitudinal ligament was removed, and the spinal cord and nerve root were decompressed (17). Spurs were removed from the upper and lower endplates after discectomy, and the cartilage endplate was removed to a minimal extent. For fusion, cage size was determined by inserting a predetermined test cage (relative to patient height). After inserting the anchored cage, four (bidirectional) or two (unidirectional) screws were inserted according to each group to secure it.

Clinical Outcome

All patients were followed up preoperatively and at 24 months postoperatively. Clinical outcomes were evaluated using the visual analog scale (VAS) for neck and arm pain and the neck disability index (NDI). Additionally, we collected data on the measures of pain intensity and its impact on disability and quality of life, calculated using the VAS, NDI questionnaire, as well as the satisfaction questionnaire for received treatment. In cases where it was difficult for patients to complete a written questionnaire, the clinical results were checked via phone call.

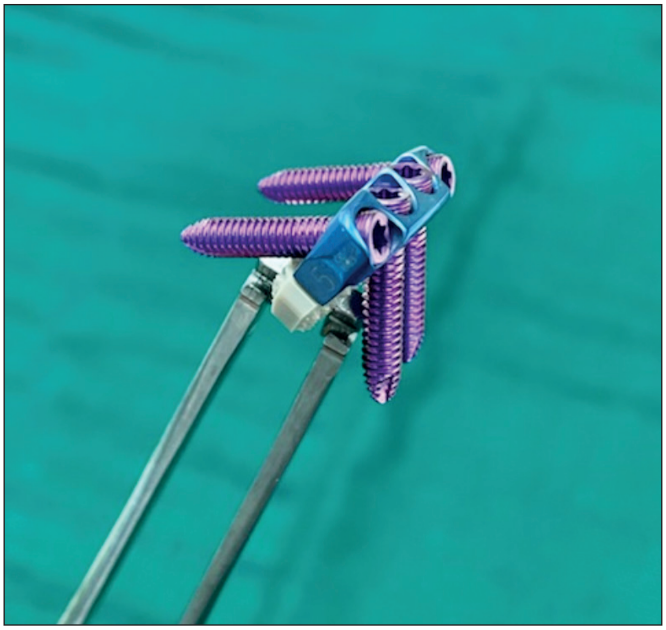

Figure 1: Photograph of the anchored cage; ACDF device. **ACDF:** Anterior cervical discectomy and fusion.

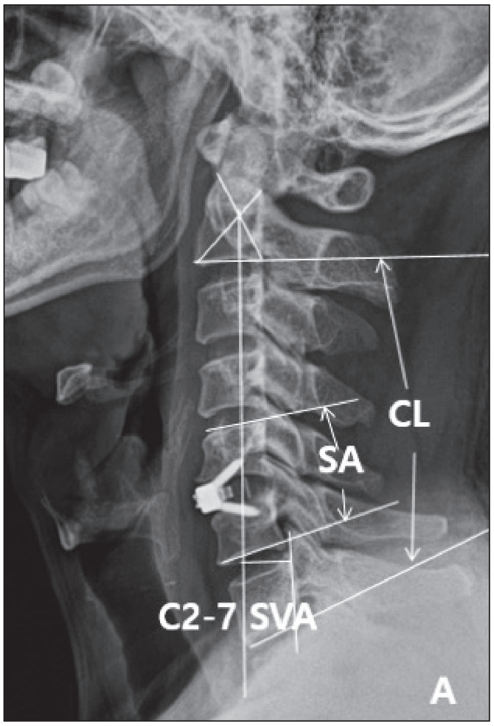

Figure 2: Lateral view of standard cervical radiography of a patient operated on with an anchored cage. CL represents the angle (°) between the lower edge of the C2 and C7 vertebrae; SA represents the angle (°) between the upper edge of the cranial vertebral body and the lower edge of the caudal vertebral body at the surgical level. SVA is the distance between the vertical line away from the C2 center and the posterior upper edge of the C7 vertebral body. (A) **AP:** anteroposterior length; **SVA:** sagittal vertical axis.

Radiologic Evaluation

Radiological follow-up examination was performed preoperatively and postoperatively (immediately and at 3, 6, 12, and 24 months postoperatively) using cervical X-ray radiographs. Cervical lordosis (CL) and the segmental angle (SA) were measured using the Cobb angle. CL was determined from the Cobb angle from C2 to C7, and the SA was defined as the angle between the upper margin of the cranial vertebral body and the lower margin of the caudal vertebral body of the operated level (3). The cervical sagittal vertical axis (SVA) yielded positive and negative indicators representing lordosis and kyphosis alignment (Figure 2).

This study also investigated the rate of fusion between the two groups. Fusion was defined as a movement of <2° in the lateral flexion/extension view, the presence of the bridging trabecular bone between the endplates in the anteroposterior/lateral view, and <50% radiation transmittance around the cage perimeter (11) (Figure 3).

For cervical muscle measurements, axial T2-weighted magnetic resonance imaging (MRI) or computed tomography (CT) was used to measure the transverse cross-sectional area (CSA) of the transverse area muscles at the level of the spine where surgery was performed. The CSA was defined by manually tracking the fascia boundary using digital image processing software (Petavision for clinics, version 2.0; Asan Medical Center, Seoul, Republic of Korea). The adjusted cross-sectional area (aCSA) ratio was defined as the “CSA of the cervical spine muscle/CSA of the spine in the same axial image.” This proportion was adjusted to the patients’ body size (22). We calculated the aCSA values preoperatively and at 24 months postoperatively for each size at the surgical level and confirmed the change in the values (Figure 4).

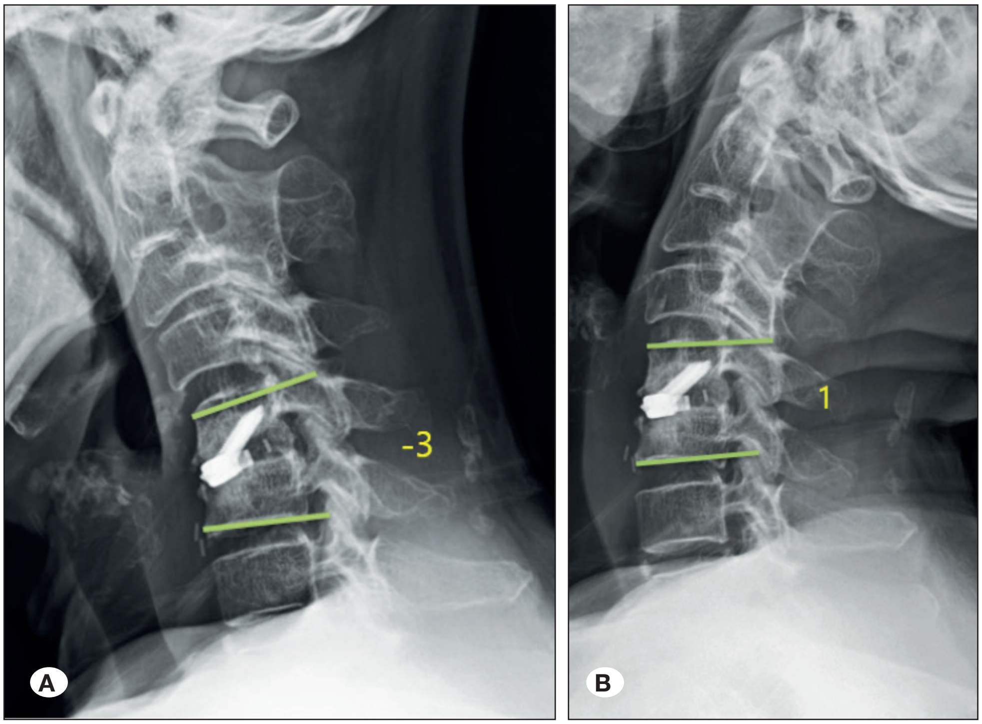

Figure 3: Implant fusion failure case. Lateral radiographs showing fusion failure at 2 years after initial ACDF fixation. **A)** Flexion and **B)** extension shows a difference of more than 4°. **ACDF:** Anterior cervical discectomy and fusion.

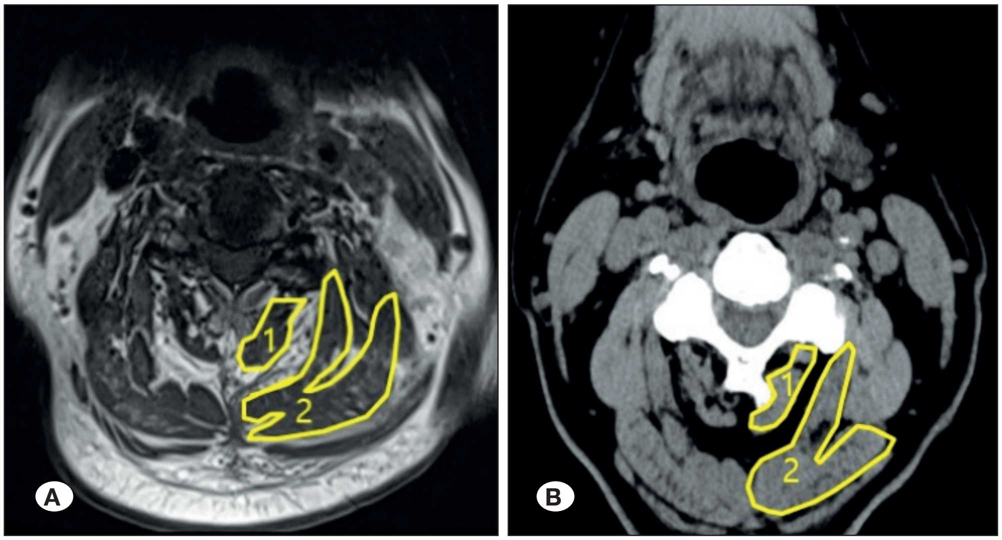

Figure 4: Measurement of the transversospinalis muscle. The transverse area was measured at the surgical site level using preoperative axial T1-weighted magnetic resonance imaging **(A)** and postoperative computed tomography **(B)**. The muscles involved were the multifidus, semispinalis cervices, and rotator (A1-2), as well as the semispinalis capitis, splenius capitis, and splenius cervices (B1-2).

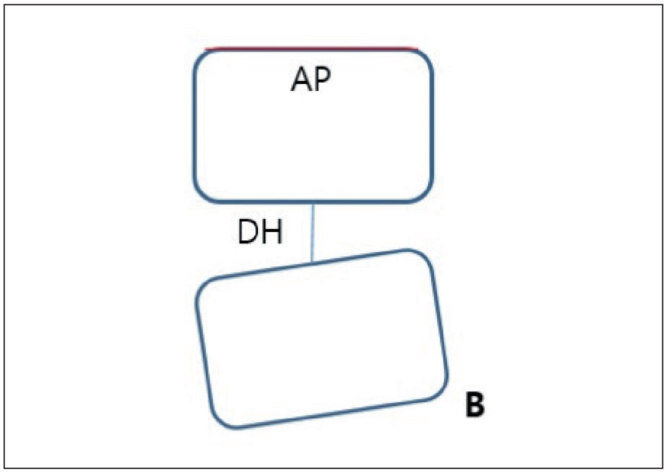

Figure 5: DH represents the length (mm) between the midline of the upper and lower edges of the disc space at the surgical level. AP (red line) represents the length of the upper margin in the cranial vertebral body relative to the working level (mm).
DH: Disc height.

We estimated the degree of cage sedimentation to estimate the state of spinal alignment indirectly; we compared the preoperative DH on a regular X-ray image (3). To obtain the active disc height (aDH), the anteroposterior length of the upper vertebrae was measured at the surgical level on the basis of the preoperative CT (aAP) and radiograph (AP). The aDH was measured using the DH formula (aDH, DHx aAP/AP) (Figure 5) (17).

Statistical Analysis

The results are presented as the mean values ± standard deviation (SD); SD was determined for quantitative data, such as cervical parameters, degree of cage sedimentation, NDI, and VAS scores. Additionally, Student's *t*-test, chi-square test, and Fisher's exact test were used to confirm the statistical significance of differences in radiological and clinical outcomes. All statistical analyses were conducted using the SPSS software (v.24.0; IBM Corp., Armonk, NY, USA), and statistical significance was defined as $p<0.05$.

RESULTS

Demographic and Clinical Outcome

Of the total 90 patients, 43 and 47 were included in the unidirectional and bidirectional screw fixation groups, respectively. There were no statistically significant differences in age, sex (male/female), BMI, BMD, alcohol and tobacco history, underlying diseases, surgical level, and blood loss during operation between the two groups (Tables I and II). However, it was confirmed that the operation time in the bidirectional screw fixation group was significantly longer than that in the unidirectional screw fixation group by more than 6 min ($p=0.03$) (Table II).

In the preoperative clinical results, no significant difference was observed in the VAS (neck and arm) scores in the unidirectional screw fixation group. However, in the postoperative (24 months) clinical results, the VAS (neck and arm) and NDI scores in the unidirectional screw fixation group had lower values than those in the bidirectional screw fixation group, although no statistical significance was observed (Table III).

Radiographic Outcome

There was no significant difference between the two groups in radiographic parameters before and immediately after surgery. However, at 3 months postoperatively, the unidirectional screw fixation group continued to show higher SA and aDH than the bidirectional screw fixation group; this lasted until 24 months postoperatively (Table IV, Figures 6 and 7). Similarly, in cervical alignment, higher CL and smaller C2-7 SVA were continuously observed at 3 months postoperatively in the unidirectional screw fixation group, although this difference was not statistically significant (Table IV). The fusion rate was higher in the bidirectional screw fixation group than in the unidirectional screw fixation group, although there was no statistically significant difference (97% *vs*. 88%, p=0.07; Table I). The change in the surgical site muscle aCSA between the two groups was not significantly different between the preoperative and 2-years postoperative periods (Table II).

DISCUSSION

The anchored cage provides an excellent fusion rate and biomechanical stability and can be used to correct cervical kyphosis and improve cervical alignment (1). To date, few studies have been conducted on the usefulness of unidirectional screw fixation of the anchored cage.

In this study, we performed clinical and radiographic comparisons between a unidirectional screw fixation group (only upper or lower vertebra screw-fixed) and a conventional bidi-

Table I: Demographic Summary of the Patients

	Unidirectional screw fixation group (n=43)	Bidirection screw fixation group (n=47)	p-value
Age ± SD	60.79 ± 11.06	58.34 ± 11.86	0.31
Sex (M/F)	28 : 15	32 : 15	0.76
Fusion rate (%)	88	97	0.07
Hypertension (n)	20	25	0.35
Diabetes mellitus (n)	7	11	0.37
Smoking (n)	15	16	0.90
Body mass index	24.19 ± 2.66	24.47 ± 3.56	0.79
Bone mineral density (T-score)	−1.17 ± 2.10	−1.27 ± 1.99	0.82

***SD:** Standard deviation.*

Table II: Comparison Between the Two Groups Regarding Intraoperative Bleeding, Operation Time, and Changes in Paraspinal Muscle Size at the Surgical Site Level Before and After the Operation (24 months)

	Unidirectional screw fixation group (n=43)	Bidirectional screw fixation group (n=47)	p-value
*aCSA	9.98 ± 6.35	10.65 ± 5.93	0.60
Operation Time (min)	117.20 ± 15.32	123.70 ± 13.75	**0.03**
Estimated blood loss (mL)	106.51 ± 57.97	126.80 ± 68.08	0.13

Preoperative value – 2-year follow-up value;* ***aCSA:* *Adjusted cross-sectional area ratio.*

Table III: Comparison of Clinical Parameters Between the Two Groups

	Unidirectional screw fixation group (n=43)	Bidirectional screw fixation group (n=47)	p-value
VAS (neck)			
Preoperative	5.27 ± 1.90	5.51 ± 2.05	0.58
Postoperative (24 months)	1.53 ± 1.66	2.19 ± 1.67	0.06
VAS (arm)			
Preoperative	5.88 ± 1.19	5.76 ± 1.21	0.64
Postoperative (24 months)	1.53 ± 1.66	2.00 ± 1.57	0.13
NDI			
Preoperative	21.53 ± 7.09	21.72 ± 7.14	0.90
Postoperative (24 months)	7.37 ± 6.25	8.97 ± 5.30	0.19

VAS: *Visual analog scale;* ***NDI:*** *Neck disability index.*

Table IV: Continuous Follow-up of Cervical Parameters and Radiographic Images for the Two Groups

	Unidirectional screw fixation group (n=43)	Bidirectional screw fixation group (n=47)	p-value
CL			
Preoperative	11.41 ± 6.45	10.59 ± 7.99	0.59
Immediately postoperative	14.11 ± 6.34	16.68 ± 7.95	0.09
Post 3 months	13.69 ± 6.23	11.14 ± 7.60	0.08
Post 6 months	13.51 ± 6.15	11.04 ± 7.56	0.09
Post 12 months	13.11 ± 5.78	10.72 ± 7.51	0.10
Last f/u (24 months)	12.76 ± 5.81	10.42 ± 7.47	0.10
SA			
Preoperative	2.16 ± 2.22	0.85 ± 3.94	0.07
Immediately postoperative	4.39 ± 2.61	4.85 ± 3.43	0.48
Post 3 months	3.67 ± 2.39	2.53 ± 2.59	**0.03**
Post 6 months	3.51 ± 2.41	2.25 ± 2.39	**0.01**
Post 12 months	3.18 ± 2.35	2.14 ± 2.33	**0.03**
Last f/u (24 months)	3.06 ± 2.17	2.00 ± 2.24	**0.02**
aDH			
Preoperative	5.66 ± 1.20	5.38 ± 1.67	0.36
Immediately postoperative	8.14 ± 1.22	7.83 ± 1.43	0.28
Post 3 months	7.22 ± 1.13	6.62 ± 1.52	**0.03**
Post 6 months	7.10 ± 1.15	6.45 ± 1.64	**0.03**
Post 12 months	7.04 ± 1.14	6.29 ± 1.66	**0.01**
Last f/u (24 mon)	6.95 ± 1.11	6.22 ± 1.66	**0.01**
C2-7 SVA			
Preoperative	19.52 ± 12.70	20.22 ± 10.71	0.77
Immediately postoperative	12.32 ± 8.96	13.40 ± 6.62	0.51
Post 3 months	12.80 ± 8.41	16.07 ± 7.66	0.06
Post 6 months	13.18 ± 7.40	16.44 ± 7.93	0.07
Post 12 months	13.38 ± 8.14	16.69 ± 7.96	0.06
Last f/u (24 months)	13.60 ± 8.50	16.92 ± 7.85	0.06

***CL:** Cervical lordosis, **f/u:** follow-up, **SA:** Segmental angle, **aDH:** Actual length of disc height, **SVA:** Sagittal vertical axis.*

rectional screw-fixation vertebrae group in patients who underwent one-level ACDF with an anchored cage.

The results of this study demonstrated that SA and DH were better maintained after surgery in the unidirectional screw fixation group, but significant differences in cervical lordosis and C2–7 SVA were not found between the two groups. In the study by Li et al., C2–7 cervical curvatures and the segmental Cobb angle decreased after 24 months of follow-up compared to those at the 1-month follow-up examination (20). However, a significant decrease was observed in the anchored cage group when compared to the plate-cage construct group, which can be explained by the fact that when the screws are placed on the same plane, a cage that is placed in front of the intervertebral space acts as a lever for mechanics and creates an anterior traction force on the upper and lower vertebrae. In the current study, anterior traction was generated only in the upper or lower vertebrae in the unidirectional screw fixation group (Figure 8). Therefore, significant differences were observed in the SA and aDH subsidence. However, no significant difference was observed between CL and C2–7 SVA.

At 3 months postoperatively, the unidirectional screw fixation group continued to show higher SA and aDH than the bidirectional screw fixation group; this lasted until 24 months postoperatively (Table IV, Figures 4 and 5). Similarly, in cervical alignment, higher CL and smaller C2–7 SVA were continuously observed 3 months postoperatively in the unidirectional screw fixation group, but this difference was not statistically significant (Table IV). According to previous studies, (6,7,13) because both initial distractive and subsequent compressive forces affect the cervical spinal alignment and clinical outcome, higher distraction should be avoided during ACDF surgery. Although the bidirectional screw does not exert excessive distraction forces on the interbody space, it seems obvious that bidirectional screws apply bigger distraction forces than unidirectional screws. Because biomechanical stability is associated with a contact surface, we believe that the initial distraction force after ACDF surgery, in contrast to the distraction force during surgery, does not affect the interbody space for better alignment.

Several previous studies have reported that the intraoperative bleeding and operation times were significantly lower in the anchored cage group than in the plate fixation group (5,31). In this study, even among patients using the anchored cage, it was confirmed that the operation time was shorter in the unidirectional screw fixation group than in the bidirectional screw fixation group.

Although no statistically significant difference was observed in the union rate in this study, a higher union rate was observed in the bidirectional screw fixation group than that in the unidirectional screw fixation group. In the unidirectional screw fixation group, fusion failure was observed in five patients, whereas in the bidirectional group, fusion failure was observed in only one patient. Additionally, all patients who failed to have fusion had a BMD (T-score) of ≤-3.5, which was much smaller than the average BMD (-0.35 ± 0.29) of patients who had a successful fusion.

Osteoporosis is a well-known risk factor for fusion failure (15,16). In many studies, biomechanical tests have shown a high correlation between BMD and pedicle screw stability (4,27,32). The number of inserted screws is considered a risk factor for fusion failure. In the study by Lee et al., the fusion rate in the standalone cage case was lower than that in the anchored cage case (19).

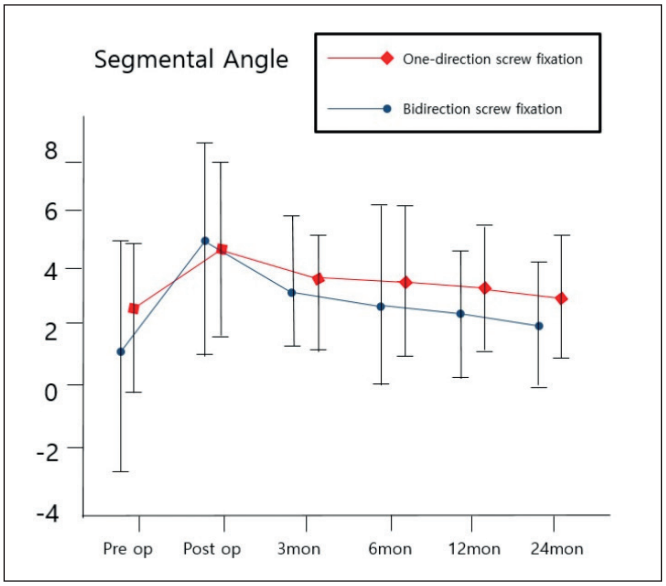

Figure 6: Continuous follow-up graph of the SA angle (°) from preoperative to immediately postoperatively and at 3, 6, 12, and 24 months postoperatively.

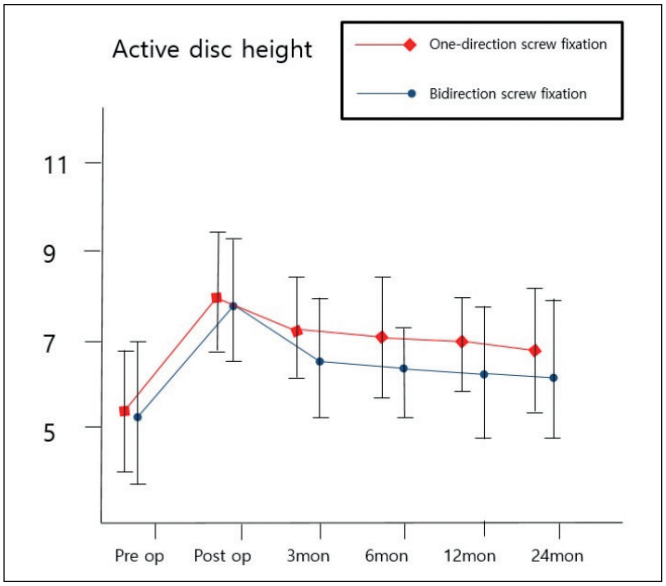

Figure 7: Continuous follow-up graph of aDH (mm) from preoperatively to immediately postoperatively and 3, 6, 12, and 24 months postoperatively
aDH, active disc height.

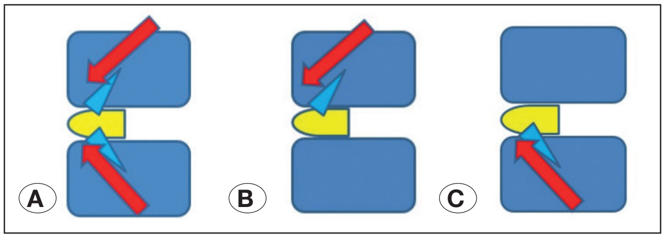

Figure 8: The bidirectional screw fixation system contains four screws located on the upper and lower vertebral bodies, respectively **(A)**. In the one-direction screw fixation system, two screws are inserted into the upper or lower vertebral body. **(B, C)** The cage placed in front of the intervertebral space acts as a lever for the dynamics, creating an anterior traction force on the spine (red arrow) only in the upper part with the screws located in the same plane as that being placed.

In the study by Jiang et al., double screws in thoracolumbar spine surgery show mechanical advantages over standard single-screw techniques (12). Therefore, unidirectional screw fixation may not be sufficient for stability in cases of severe osteoporosis, and additional stabilization should be considered. In this study, fusion failure was radiographically observed in six patients, but revision surgery was not performed due to a lack of symptoms. However, due to the small number of patients (five vs. one), there was no statistically significant difference in fusion failure; it was, therefore, difficult to accurately analyze this. In addition, since the follow-up period of this study was short, the number of patients was small, and only single-level patients were treated, a study that compares more patients who undergo multilevel surgery and long-term prognoses is needed.

Several studies have reported an association between vertebral misalignment and the paravertebral muscle CSA (8,28,29). However, there was no significant difference in the changes in muscle aCSA before and after surgery (24 months) between the two groups in this study. Owing to the small surgical level (single level) performed in this study, it is likely that either uni- or bidirectional screw fixation did not affect the muscle size. Pourtaheri et al. also confirmed that the change in muscle size was greater at the multilevel than at the single level (24). Further research considering a larger surgery range needs to be conducted in the future. Moreover, in other studies, aCSA was obtained using MRI during muscle evaluation, and a pseudo-coloring technique was used to measure the fat infiltration ratio to observe the degenerative change in muscle (18,23,28). Therefore, MRI examination was necessary for accurate measurement and fat ratio measurement. However, in our study, CT was solely used to examine many patients after surgery; this was inevitable due to the current Korean insurance policy.

There were some limitations in this study. First, the patient selection bias could not be excluded. Many patients with improved prognosis after surgery were not followed up for 2 years because many of them stopped attending their outpatient visits; all these individuals were excluded from the study. Second, we used a small sample size of patients with a follow-up period of only 2 years. Future research will require longer follow-up periods and more participants. Finally, this study was retrospective, and a more accurate analysis is expected if prospective studies are conducted.

CONCLUSION

In this study, we compared two surgical methods, unidirectional and bidirectional screw fixation, using an anchored cage in patients with cervical degenerative diseases. Our results effectively demonstrated the usefulness of the unidirectional screw fixation surgical method in terms of shorter surgery time, maintenance of the lordotic curvature of SA, and DH.

AUTHORSHIP CONTRIBUTION

Study conception and design: JJL, JHP
Data collection: SGJ, JHP
Analysis and interpretation of results: JJL, HKS
Draft manuscript preparation: JJL, BGP
Critical revision of the article: JHP, SBL
All authors (JJL, HKS, BGP, SKJ, SBL, JHP) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Barsa P, Suchomel P: Factors affecting sagittal malalignment due to cage subsidence in standalone cage assisted anterior cervical fusion. Eur Spine J 16:1395-1400, 2007
2. Chen Y, Chen H, Wu X, Wang X, Lin W, Yuan W: Comparative analysis of clinical outcomes between zero-profile implant and cages with plate fixation in treating multilevel cervical spondilotic myelopathy: A three-year follow-up. Clin Neurol Neurosurg 144:72-76, 2016
3. Cho HJ, Hur JW, Lee JB, Han JS, Cho TH, Park JY: Cervical stand-alone polyetheretherketone cage versus zero-profile anchored spacer in single-level anterior cervical discectomy and fusion: Minimum 2-year assessment of radiographic and clinical outcome. J Korean Neurosurg Soc 58:119-124, 2015
4. Coe JD, Warden KE, Herzig MA, McAfee PC: Influence of bone mineral density on the fixation of thoracolumbar implants. A comparative study of transpedicular screws, laminar hooks, and spinous process wires. Spine (Phila Pa 1976) 15:902-907, 1990
5. Dong J, Lu M, Lu T, Liang B, Xu J, Zhou J, Lv H, Qin J, Cai X, Huang S, Li H, Wang D, He X: Meta-analysis comparing zero-profile spacer and anterior plate in anterior cervical fusion. PLoS One 10:e0130223, 2015
6. Francke EI, Demetropoulos CK, Agabegi SS, Truumees E, Herkowitz HN: Distractive force relative to initial graft compression in an in vivo anterior cervical discectomy and fusion model. Spine (Phila Pa 1976) 35:526-530, 2010
7. Ha SM, Kim JH, Oh SH, Song JH, Kim HI, Shin DA: Vertebral distraction during anterior cervical discectomy and fusion causes postoperative neck pain. J Korean Neurosurg Soc 53: 288-292, 2013
8. Hiyama A, Katoh H, Sakai D, Tanaka M, Sato M, Watanabe M: The correlation analysis between sagittal alignment and cross-sectional area of paraspinal muscle in patients with lumbar spinal stenosis and degenerative spondylolisthesis. BMC Musculoskelet Disord 20:352, 2019
9. Jacobs W, Willems PC, Kruyt M, van Limbeek J, Anderson PG, Pavlov P, Bartels R, Oner C: Systematic review of anterior interbody fusion techniques for single- and double-level cervical degenerative disc disease. Spine (Phila Pa 1976) 36: E950-960, 2011
10. Jacobs WC, Anderson PG, Limbeek J, Willems PC, Pavlov P: Single or double-level anterior interbody fusion techniques for cervical degenerative disc disease. Cochrane Database Syst Rev 1:CD004958, 2004

11. Ji GY, Oh CH, Shin DA, Ha Y, Kim KN, Yoon DH, Yudoyono F: Stand-alone cervical cages versus anterior cervical plates in 2-level cervical anterior interbody fusion patients: Analysis of adjacent segment degeneration. J Spinal Disord Tech 28: E433-438, 2015
12. Jiang L, Arlet V, Beckman L, Steffen T: Double pedicle screw instrumentation in the osteoporotic spine: A biomechanical feasibility study. J Spinal Disord Tech 20:430-435, 2007
13. Jin ZY, Teng Y, Wang HZ, Yang HL, Lu YJ, Gan MF: Comparative analysis of cage subsidence in anterior cervical decompression and fusion: Zero profile anchored spacer (ROI-C) vs. Conventional cage and plate construct. Front Surg 8:736680, 2021
14. Kandziora F, Pflugmacher R, Schafer J, Born C, Duda G, Haas NP, Mittlmeier T: Biomechanical comparison of cervical spine interbody fusion cages. Spine (Phila Pa 1976) 26:1850-1857, 2001
15. Karikari IO, Metz LN: Preventing pseudoarthrosis and proximal junctional kyphosis: How to deal with the osteoporotic spine. Neurosurg Clin N Am 29:365-374, 2018
16. Kawabata A, Yoshii T, Hirai T, Ushio S, Kaito T, Yamashita T, Fujiwara H, Nagamoto Y, Matsuoka Y, Suzuki H, Nishimura H, Terai H, Tamai K, Tagami A, Yamada S, Adachi S, Watanabe K, Katsumi K, Ohashi M, Shibuya Y, Harimaya K, Kawaguchi K, Yokoyama N, Oishi H, Doi T, Kimura A, Inoue H, Inoue G, Miyagi M, Saito W, Nakano A, Sakai D, Nukaga T, Ikegami S, Shimizu M, Futatsugi T, Ohtori S, Furuya T, Orita S, Imagama S, Ando K, Kobayashi K, Kiyasu K, Murakami H, Yoshioka K, Seki S, Hongo M, Kakutani K, Yurube T, Aoki Y, Oshima M, Takahata M, Iwata A, Endo H, Abe T, Tsukanishi T, Nakanishi K, Watanabe K, Hikata T, Suzuki S, Isogai N, Okada E, Funao H, Ueda S, Shiono Y, Nojiri K, Hosogane N, Ishii K: Effect of bisphosphonates or teriparatide on mechanical complications after posterior instrumented fusion for osteoporotic vertebral fracture: A multi-center retrospective study. BMC Musculoskelet Disord 21:420, 2020
17. Kim CH, Chung CK, Hahn S: Autologous iliac bone graft with anterior plating is advantageous over the stand-alone cage for segmental lordosis in single-level cervical disc disease. Neurosurgery 72:257-265; discussion 266, 2013
18. Lee JC, Cha JG, Kim Y, Kim YI, Shin BJ: Quantitative analysis of back muscle degeneration in the patients with the degenerative lumbar flat back using a digital image analysis: Comparison with the normal controls. Spine (Phila Pa 1976) 33:318-325, 2008
19. Lee YS, Kim YB, Park SW: Does a zero-profile anchored cage offer additional stabilization as anterior cervical plate? Spine (Phila Pa 1976) 40:E563-570, 2015
20. Li T, Yang JS, Wang XF, Meng CY, Wei JM, Wang YX, Zou P, Chen H, Liu TJ, Liu P, Hao DJ, Chu L: Can zero-profile cage maintain the cervical curvature similar to plate-cage construct for single-level anterior cervical diskectomy and fusion? World Neurosurg 135:e300-e306, 2020
21. Liu Y, Wang H, Li X, Chen J, Sun H, Wang G, Yang H, Jiang W: Comparison of a zero-profile anchored spacer (ROI-C) and the polyetheretherketone (PEEK) cages with an anterior plate in anterior cervical discectomy and fusion for multilevel cervical spondylotic myelopathy. Eur Spine J 25:1881-1890, 2016
22. Matsumoto M, Watanabe K, Hosogane N, Tsuji T, Ishii K, Nakamura M, Chiba K, Toyama Y: Impact of lamina closure on long-term outcomes of open-door laminoplasty in patients with cervical myelopathy: Minimum 5-year follow-up study. Spine (Phila Pa 1976) 37:1288-1291, 2012
23. Min SH, Kim MH, Seo JB, Lee JY, Lee DH: The quantitative analysis of back muscle degeneration after posterior lumbar fusion: Comparison of minimally invasive and conventional open surgery. Asian Spine J 3:89-95, 2009
24. Pourtaheri S, Issa K, Lord E, Ajiboye R, Drysch A, Hwang K, Faloon M, Sinha K, Emami A: Paraspinal muscle atrophy after lumbar spine surgery. Orthopedics 39:e209-214, 2016
25. Qi M, Chen H, Liu Y, Zhang Y, Liang L, Yuan W: The use of a zero-profile device compared with an anterior plate and cage in the treatment of patients with symptomatic cervical spondylosis: A preliminary clinical investigation. Bone Joint J 95-B:543-547, 2013
26. Song KJ, Taghavi CE, Lee KB, Song JH, Eun JP: The efficacy of plate construct augmentation versus cage alone in anterior cervical fusion. Spine (Phila Pa 1976) 34:2886-2892, 2009
27. Soshi S, Shiba R, Kondo H, Murota K: An experimental study on transpedicular screw fixation in relation to osteoporosis of the lumbar spine. Spine (Phila Pa 1976) 16:1335-1341, 1991
28. Takayama K, Kita T, Nakamura H, Kanematsu F, Yasunami T, Sakanaka H, Yamano Y: New predictive index for lumbar paraspinal muscle degeneration associated with aging. Spine (Phila Pa 1976) 41:E84-90, 2016
29. Tamai K, Romanu J, Grisdela P, Jr., Paholpak P, Zheng P, Nakamura H, Buser Z, Wang JC: Small C7-T1 lordotic angle and muscle degeneration at C7 level were independent radiological characteristics of patients with cervical imbalance: A propensity score-matched analysis. Spine J 18:1505-1512, 2018
30. Wang Z, Jiang W, Li X, Wang H, Shi J, Chen J, Meng B, Yang H: The application of zero-profile anchored spacer in anterior cervical discectomy and fusion. Eur Spine J 24:148-154, 2015
31. Wang Z, Zhu R, Yang H, Shen M, Wang G, Chen K, Gan M, Li M: Zero-profile implant (Zero-p) versus plate cage benezech implant (PCB) in the treatment of single-level cervical spondylotic myelopathy. BMC Musculoskelet Disord 16:290, 2015
32. Wittenberg RH, Shea M, Swartz DE, Lee KS, White AA 3rd, Hayes WC: Importance of bone mineral density in instrumented spine fusions. Spine (Phila Pa 1976) 16:647-652, 1991
33. Wu WJ, Jiang LS, Liang Y, Dai LY: Cage subsidence does not, but cervical lordosis improvement does affect the long-term results of anterior cervical fusion with stand-alone cage for degenerative cervical disc disease: A retrospective study. Eur Spine J 21:1374-1382, 2012