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A comparison of anterior cervical discectomy and fusion combined with cervical disc arthroplasty and cervical disc arthroplasty for the treatment of skip-level cervical degenerative disc disease

A retrospective study

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Abstract

Anterior cervical discectomy and fusion (ACDF) has been widely performed for the treatment of multilevel cervical degenerative disc disease (CDDD). In recent decades, cervical disc arthroplasty (CDA) and hybrid surgery (HS) have been developed to overcome the shortcomings of ACDF. Controversy still remains with regard to the optimal surgical procedure for skip-level CDDD.

A total of 55 patients who received surgical treatment for skip-level CDDD in our department were reviewed. The patients were divided into the HS group (n = 29) and the CDA group (n = 26). The collected data included Japanese Orthopedic Association (JOA), Neck Disability Index (NDI), and Visual Analog Scale (VAS) scores, and cervical lordosis (CL), range of motion (ROM), and intervertebral disc height (IDH). Radiological changes at the intermediate segment (IS) were also collected. All data were collected preoperatively and at routine postoperative intervals of 1 week and 3, 6, and 12 months and at the last follow-up period.

Compared with preoperative values, mean JOA, NDI, and VAS scores significantly improved after surgery in both the HS and CDA groups ($P < .05$). However, there were no significant differences between the groups ($P > .05$). The HS group had better CL recovery than the CDA group after surgery ($P < .05$). There was no significant difference in the ROM of C2–C7 between the 2 groups ($P > .05$). A significant difference in the ROM of the IS was found at the last follow-up between the 2 groups ($P < .05$). At the last-follow-up, 4 discs (14.29%) in the CDA group and 6 discs (19.36%) in the HS group had adjacent segment degeneration (ASD) without symptoms.

Both HS and CDA might be considered safe and effective surgical strategies for the treatment of skip-level CDDD. Although the clinical outcomes were similar in the 2 groups, CDA altered the ROM of the IS to a lesser degree.

Abbreviations: ACDF = anterior cervical discectomy and fusion, ASD = adjacent segment degeneration, CDA = cervical disc arthroplasty, CDDD = cervical degenerative disc disease, CL = cervical lordosis, CT = computed tomography, FSU = functional spinal unit, HO = heterotopic ossification, HS = hybrid surgery, IDH = intervertebral disc height, IS = intermediate segment, JOA= Japanese Orthopedic Association, MRI = magnetic resonance imaging, NDI = Neck Disability Index, OPLL = ossification of posterior longitudinal ligament, ROM = range of motion, SD = standard deviation, VAS = Visual Analog Scale.

Keywords: cervical disc arthroplasty, cervical discectomy and fusion, hybrid surgery, intermediated segment, radiographic changes, skip-level cervical degenerative disc disease

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1. Introduction

Anterior cervical discectomy and fusion (ACDF) has proven to be an effective treatment for single- or multilevel cervical degenerative disc disease (CDDD) with successful fusion rates and satisfactory clinical outcomes since the 1950s, when it was introduced by Robinson and Smith.[1] However, ACDF sacrifices mobility at the operated level which may be an important risk factor for adjacent segment degeneration (ASD). Moreover, multilevel fusion could significantly alter the normal biomechanics of the cervical spine by increasing intradiscal pressure and mobility at the adjacent segment.[1,2]

Compared with ACDF, outcomes after CDA are less established. However, it has been demonstrated that this surgical technique is beneficial for preserving motion at the operated level and theoretically for adjacent level degeneration. Moreover, multilevel CDA produced statistically significant greater outcome improvement compared with single-level CDA.[3] Nevertheless, the difficult surgical techniques, more strict inclusion criteria, and higher medical costs have restricted application of multilevel CDA.[4–6]

Studies in recent years have shown that hybrid surgery (HS), incorporating ACDF at the spondylotic segment with CDA at the mobile segment, can produce good clinical outcomes while preserving cervical mobility to a large degree, thus reducing the risk of adjacent segment diseases.[2,5–9] HS is based on the fact that ACDF or CDA may not be appropriate to each level due to multilevel CDDD with different degeneration statuses at each level in clinical practice. In this regard, HS can be considered a promising surgical strategy. However, most of studies have focused on the treatment of contiguous levels. Currently, there is no consensus on which technique is the best for the treatment of multilevel CDDD, and especially for skip-level CDDD due to a lack of clinical data from these patients. The primary aim of the current study was to compare clinical and radiographic outcomes between HS and CDA for the treatment of skip-level CDDD. Furthermore, features and radiological changes at the intermediate segment (IS) in these patients were described and evaluated.

2. Materials and methods

2.1. Patient population

Between January 2008 and January 2015, a total of 55 patients (28 men and 27 women) underwent surgical treatment for skip-level CDDD and were reviewed in our department. All patients provided written informed consent and the study protocol was approved by the Ethics Committee of West China Hospital of Sichuan University. All patients enrolled were diagnosed with skip-level CDDD with symptomatic radiculopathy and/or myelopathy not responding to conservative treatment for at least 6 weeks at 2 noncontiguous levels from C2 to T1 on the basis of symptoms, signs, preoperative static and dynamic radiographs, computed tomography (CT) scans, and magnetic resonance imaging (MRI) findings. The exclusion criteria included single-level CDDD or contiguous multilevel CDDD requiring surgery, prior cervical spine surgery, previous trauma to the C2–T1 levels, cervical stenosis caused by posterior compression and ossification of the posterior longitudinal ligament (OPLL). Osteoporosis, rheumatoid arthritis, diabetes mellitus, and cancer were considered further exclusion criteria. Fusion or CDA was determined preoperatively using evidence from radiographs, CT and MRI. ACDF was performed at the level on the condition that there was radiographic confirmation of severe facet joint disease, obvious cervical instability (i.e., >3 mm translation or 20° angular motion at the index level) or loss of segmental mobility (i.e., $<2°$ range of motion) on radiographs. According to different surgical procedures, the patients were divided into the HS group (n=29; Fig. 1) and the CDA group (n=26; Fig. 2).

2.2. Surgical procedure

All operations were performed by the same senior spine surgeon. After general anesthesia induction and proper positioning of the patient with the neck slightly extended, a standard right-sided anterior cervical approach and exposure was performed. First, the surgeon completely removed the disc tissue, posterior longitudinal ligament and osteophytes at the index levels for thorough decompression. The more sever degenerative segment should be decompressed primarily. Second, for CDA, after preparing the endplates and inserting trials, a proper size Prestige-LP (Medtronic Sofamor Danek, Memphis, TN) was inserted along with channels in the endplates. Third, for fusion, after determination of the appropriate size of the trail spacer, a corresponding Zero-P implant (Synthes, Oberdorf, Switzerland) packed with β-tricalcium phosphate or local excised bone was inserted into the well-prepared intervertebral space. Next, the 4 locking screws were tightened cranially and caudally to fix the implant. Then, C-arm fluoroscopy was used to certify the proper placement of the implants. During the operation, the natural structure and prevertebral tissues of the IS were preserved. Finally, a drain was inserted before closure of the incision.

Drainage was removed 2 days after the operation. All patients were instructed to perform neck function training within the first 3 weeks postoperatively, and immobilized with a collar for 4 to 12 weeks. Following those guidelines, patients may have excellent cervical lordosis (CL) and range of motion (ROM) and a satisfactory fusion rate.

2.3. Clinical and radiologic evaluations

The collected data included population characteristics and clinical and radiological outcomes. The Japanese Orthopedic Association (JOA) score was used to evaluate myelopathic status, the Neck Dysfunction Index (NDI) score was used to evaluate neck function and the Visual Analogue Scale (VAS) score was used to evaluate the neck and arm pain intensity. All clinical data were collected preoperatively and at routine postoperative intervals of 1 week and 3, 6, and 12 months and at the last follow-up period. The CL was measured using Cobb angle method. The ROM of C2–C7 was defined as the difference in Cobb angle between full flexion and extension in lateral radiographs. The functional spinal unit (FSU) angle was formed by lines drawn at the superior endplate of the cephalad vertebral body and inferior endplate of the caudal vertebral body. The ROM of local segments was defined as the sum of the FSU angles, which was measured in full flexion and extension at the IS. Lordosis is described as a positive value while kyphosis is shown as a negative value. The intervertebral disc height (IDH) was measured as the distance between the midpoint of the lower endplate of the cephalad vertebral body and the midpoint of the upper endplate of the caudal vertebral body on lateral radiographs. Radiographs and CT scans were routinely taken preoperatively and at postoperative intervals of 1 week and 3, 6, and 12 months and the last follow-up period. MRIs were collected preoperatively and at the last follow-up period.

A solid fusion was evaluated according to Bridwell classification.[10] Radiological changes at the IS were assessed according to radiological grading system created by Hilibrand et al[1] (Table 1). Heterotopic ossification (HO) was evaluated according to McAfee classification.[11] Radiological evaluation was carried out by a senior surgeon who was unfamiliar with the patients' conditions. Information on hoarseness, dysphagia, hematoma, cerebral fluid leakage, and prosthesis-related complications were collected.

2.4. Statistical analysis

Results are indicated as the mean ± standard deviation (SD). Paired *t* tests were used to evaluate quantitative data between preoperative and postoperative parameters for each group. Student *t* tests were used for independent samples or Mann–Whitney tests were used to evaluate qualitative data from the 2 groups. Chi-square tests or Fisher exact tests were used for comparing qualitative data between the 2 groups. All data were

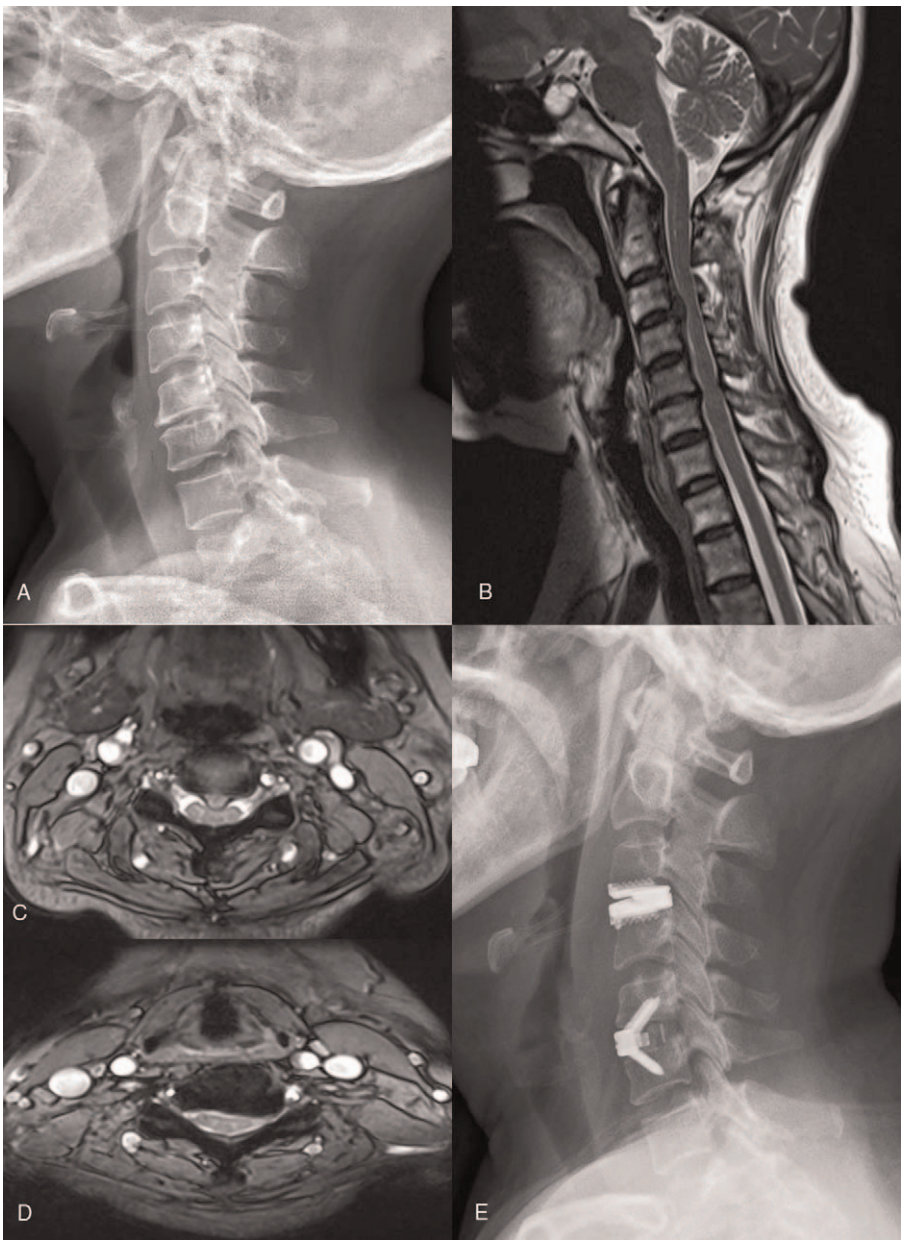

Figure 1. A 47-year-old man diagnosed with disc herniation at C3–C4 and C5–C6 with cervical spondylotic myelopathy. Preoperative lateral radiograph (A) and magnetic resonance images (B, C, D) showing that disc herniation occurred at C3–C4 and C5–C6 and significantly compressed the spinal cord and narrowed the disc space at C5–C6. The postoperative lateral radiograph (E) showing that cervical disc arthroplasty was performed at C3–C4 and anterior cervical discectomy and fusion was performed at C5–C6.

analyzed using SPSS (version 19.0; SPSS Inc., Chicago, Illinois), and $P < .05$ was considered statistically significant.

3. Results

3.1. Patient populations

Regarding patient demographics (Table 2), although mean age at the time of performing surgery was higher in the HS group, there was no statistically significant difference between the 2 groups ($P > .05$). There was no statistically significant difference in sex ratio ($P > .05$). In each of the groups, the most commonly involved levels were C3/4 and C5/6 (72.41% in the HS group and 69.23% in the CDA group, respectively). With respect to surgical parameters (Table 2), the HS group required a significantly longer operative time than the CDA group ($P < .05$), whereas there was no statistically significant difference in blood loss between the 2 groups ($P < .05$).

3.2. Clinical outcomes

Compared with preoperative values, mean JOA, NDI, and VAS scores significantly improved after surgery in both the HS and CDA groups, and remained highly improved throughout the follow-up period ($P < .05$). However, there were no significant differences between the 2 groups ($P > .05$). The main clinical outcomes are presented in Table 3, and the changes in JOA, NDI, and VAS scores over the follow-up are shown in Fig. 3.

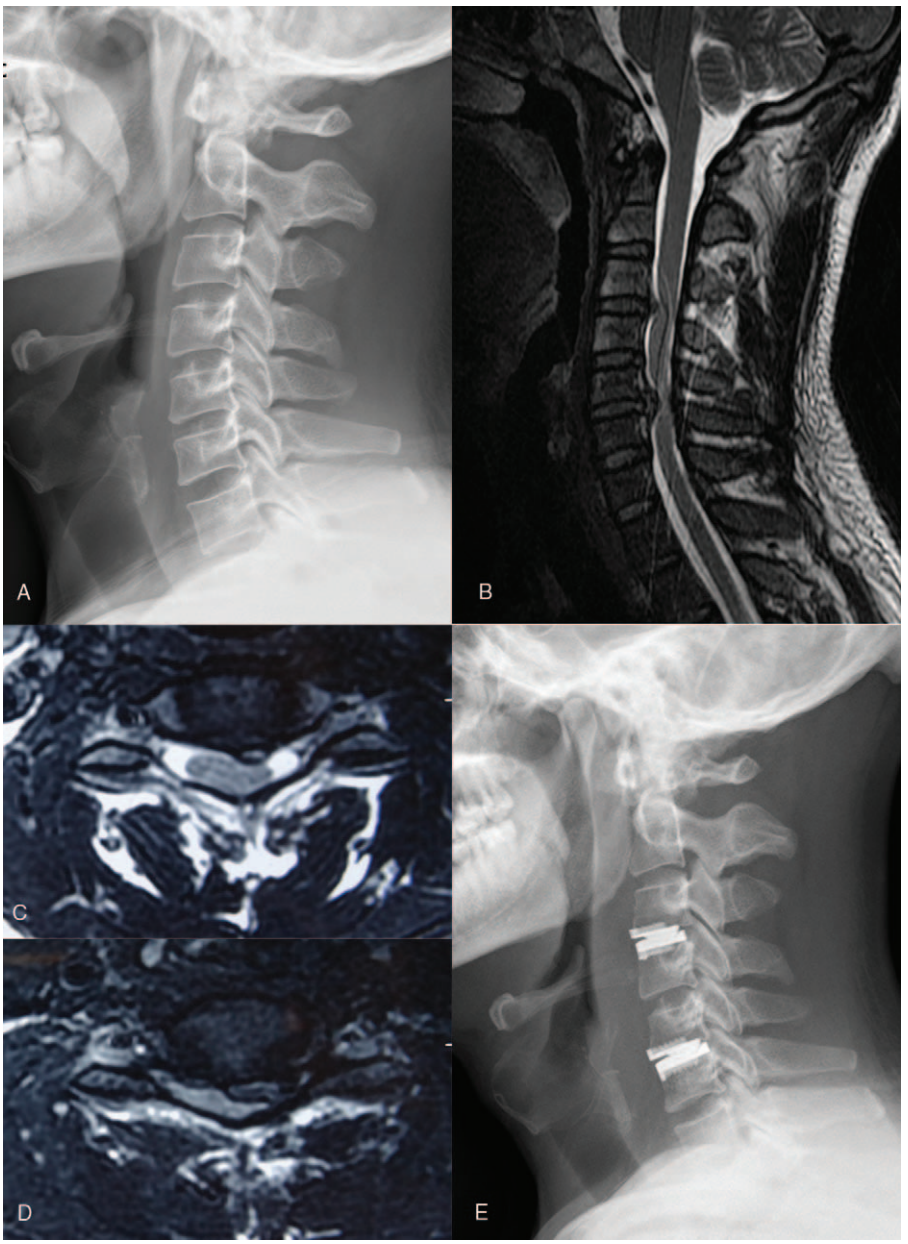

Figure 2. A 42-year-old man was diagnosed with disc herniation at C3–C4 and C5–C6 with cervical spondylotic myelopathy. Preoperative lateral radiograph (A) and magnetic resonance images (B, C, D) showing that disc herniation occurred at C3–C4 and C5–C6 and significantly compressed the spinal cord with signal intensity change. The postoperative lateral radiograph (E) showing cervical disc arthroplasty with a Prestige-LP prosthesis was implanted at C3–C4 and C5–C6.

Table 1

Radiographic grading of degenerative changes at the intermediate segments.

Grade	Disease	Findings		
		Plain radiography	Magnetic resonance imaging	Computed tomography
I	None	Normal	Normal	Normal
II	Mild	Narrowing of disc space, no posterior osteophytes	Signal change in intervertebral disc	Normal
III	Moderate	<50% of normal disc height, posterior osteophytes	Herniated nucleus pulposus without neural compression	Herniated nucleus pulposus; no nerve-root cutoff or spinal cord compression
IV	Severe	Same as for grade III	Spinal cord compression with or without nerve-root compression	Nerve-root cutoff with or without spinal cord compression

According to the scale of Hilibrand et al.[1]

Table 2

Summary of the demographics and perioperative parameters: the HS group versus CDA group (data are displayed as a number or mean ± standard deviation).

Variable	CDA	HS
No. of patients, n	26	29
Age (range), y	44.67 ± 4.72 (37–54)	48.62 ± 6.50 (34- 65)
Sex (M/F)	12/14	16/13
Symptom		
Myelopathy	4	10
Radiculopathy	15	15
Myeloradiculopathy	7	4
Levels		
C3/4 and C5/6	18	21
C3/4 and C6/7	2	2
C3/4, C5/6, and C6/7	0	1
C4/5 and C6/7	5	4
C5/6 and C7/T1	0	1
C2/3 and C4/5	1	0
Operative time (range), min	109.25 ± 41.73 (90–260)*	131.15 ± 35.38 (105–240)
Blood loss (range), mL	98.50 ± 71.74 (30–300)	97.14 ± 72.19 (30–350)
Follow-up (range), months	41.58 ± 24.99 (24–97)	32.05 ± 8.96 (24–51)

ACDF = anterior cervical discectomy and fusion, CDA = cervical disc arthroplasty, HS = hybrid surgery.
* $P < .05$.

3.3. Radiological outcomes

The mean CL was 9.92 ± 9.85° in the HS group on admission which significantly increased to 15.99 ± 6.49° at the last follow-up ($P < .05$). For the CDA group, the corresponding CLs were 8.77 ± 7.96° and 9.39 ± 5.80°, respectively. The difference was not significant compared with the preoperative value ($P > .05$). The HS group exhibited a better CL recovery than the CDA group after surgery ($P < .05$; Table 4). The mean preoperative ROM of C2–C7 of the HS and CDA groups were 47.11 ± 10.84° and 49.12 ± 13.79°, respectively. At the last follow-up, the mean ROM of C2–C7 of the HS and CDA groups were 43.71 ± 9.34° and 48.92 ± 10.80°, respectively. Although the mobility of the cervical spine was better in the CDA group, the difference was not statistically significant ($P > .05$). Compared with the preoperative ROM, there was no statistically significant difference in the last follow-up in the 2 groups. The changes during the follow-up period are shown in Fig. 4. The FSU angle of the IS showed no significant difference before or after surgery in each of the groups, and no significant difference between the 2 groups was found at each follow-up time point ($P > .05$). With respect to the ROM of the IS, there were different changes during the follow-up period (Fig. 5) between the 2 groups. In the HS group, the ROM of the IS averaged 12.24 ± 2.63° preoperatively, was 11.53 ± 2.53° 3 months postoperatively, and gradually increased to 14.18 ± 2.32° at the last follow-up, which was a statistically significant difference ($P < .05$). In the CDA group, the ROM of the IS averaged 11.83 ± 3.39° before surgery, significantly increased to 13.98 ± 3.38° at 3 months postoperatively ($P < .05$), and gradually recovered to 12.07 ± 3.10° at the last follow-up, which was similar to preoperative values ($P > .05$). The significant differences in the ROM of the IS were found at the 3-month and the last follow-up between the 2 groups ($P < .05$). In each of the groups, the DH of the IS was consistent after surgery, and no significant difference between the 2 groups was found at each follow-up time point ($P > .05$; Fig. 5). Fusion was achieved in all fusion segments in the HS group.

Table 3

JOA, NDI, and VAS scores of the 2 groups (mean ± SD).

	CDA	HS	*P*
Pre-JOA scores	8.80 ± 1.65	8.67 ± 2.14	.68
Post-JOA sores	15.40 ± 1.12**	15.12 ± 1.48*	.42
Pre-NDI scores	28.17 ± 6.62	27.71 ± 6.87	.20
Post-NDI sores	7.53 ± 4.98**	8.29 ± 7.48*	.83
Pre-VAS scores	5.67 ± 1.80	5.37 ± 2.06	.68
Post-VAS scores	1.33 ± 1.11**	1.54 ± 1.47*	.36

Compared with preoperative values, there were statistically significant differences in JOA, NDI, and VAS scores at the last follow-up in the 2 groups.
CDA = cervical disc arthroplasty, HS = hybrid surgery, JOA = Japanese Orthopedic Association, NDI = Neck Dysfunction Index, SD = standard deviation, VAS = Visual Analogue Scale.
* $P < .05$.
** $P < .05$.

3.4. Complications

No hematoma, subsidence or migration of artificial cervical disc prostheses, or subsequent surgery occurred in either group. Mild dysphagia occurred in 2 patients and 1 patient in the CDA group and the HS group, respectively. There was no significant difference between the 2 groups. ASD in the 2 groups evaluated by Hilibrand classification is shown in Table 5. A total of 59 skip-level discs were involved (28 discs in the CDA group and 31 in the HS groups, respectively). At the last follow-up, 4 discs (14.29%) in the CDA group and 6 discs (19.36%) in the HS group had ASD without symptoms (Figs. 6 and 7). There was no significant difference in the incidence of ASD between the 2 groups ($P > .05$). The disc signal intensity was changed in most of the patients whose IS started to degenerate (Fig. 8). HO was detected in 2 discs (1 in Class III and 1 in Class II, respectively; Fig. 7) in the CDA group and 2 discs of Class II in the HS group, which was not a significant difference ($P > .05$).

4. Discussion

For over 60 years, ACDF has been widely performed to treat multilevel CDDD, including skip-level CDDD.[12] It has been demonstrated to succeed in stability after decompression as well as in symptoms relief. However, long-segment ACDF has resulted in complications that have been reported in the literature.[3,13–18] Swank et al[13] revealed that the incidence of nonunion for ACDF varied depending on the number of disc levels involved: 10% in single-level fusion, 44% in 2-level fusion, and 54% in 3-level fusion. Lowery and McDonough[14] reported that the incidence of anterior plating failures was associated with the number of operated levels: 20% in single-level fusion, 36% in 2-level fusion, 71% in 3-level fusion, and 80% in 4-level fusion. Geisler et al[17] reported the reoperation rates after cervical plate stabilization increased as the number of operated levels increased: 5.8% in single-level fusion, 6.5% in 2-level fusion, 8% in 3-level fusion, and 16.8% in 4-level fusion. Chung et al[19] concluded that multilevel fusion was an important predictor of the development of ASD: 13.2% in single-level fusion and 32.1% in multilevel fusion. With respect to skip-level CDDD, another problem that cannot be neglected if we perform long-segment ACDF was that the function and structure of the normal segments must be destroyed. Therefore, long-segment fusion is not recommended for the treatment of skip-level CDDD.

Studies in recent years have been reported improved surgical procedures with different fusion devices that preserve the

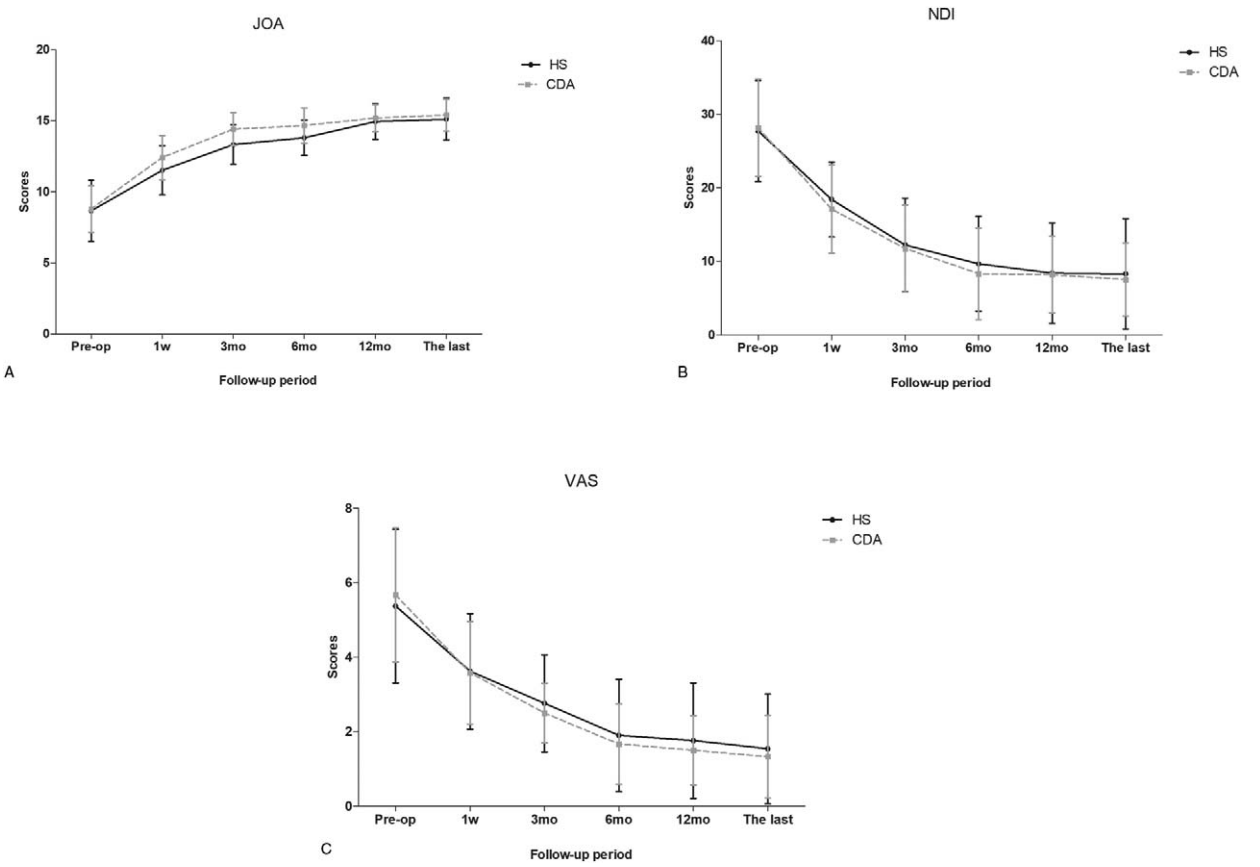

Figure 3. The changes in clinical outcomes in the HS and CDA groups including (A) Japanese Orthopedic Association (JOA), (B) Neck Disability Index (NDI), and (C) Visual Analog Scale (VAS) scores. CDA = cervical disc arthroplasty, HS = hybrid surgery.

intermediate normal segment. The guidelines for the surgical strategies included performing skip-level ACDF only at the involved levels using 2 anterior cervical plates (ACP)[12,20] or intervertebral fusion cages[21,22] to preserve the IS and to avoid donor-site complications. The incidence of ASD after skip-level fusion was relatively low, ranging from 6.25% to 20%, possibly due to the short follow-up time. However, hypermobility and additive strain from fusion masses on both sides of the IS may accelerate disc degeneration after a long follow-up. In a cadaveric study by Finn et al,[23] the authors reported that the range of motion increased 35% at the IS in the skip-level fusion compared with the intact spine. Thus, although skip-level fusion preserved an additional motion segment, the altered biomechanical environment theoretically led to accelerating intermediate disc degeneration.

Table 4

Radiographic outcomes of the 2 groups (mean ± SD).

	CDA	HS	*P*
Pre-CL, °	8.77 ± 7.96	9.92 ± 9.85	.67
Post-CL, °	9.39 ± 5.80	15.99 ± 6.49*	.00
Pre-ROM of C2–C7, °	49.12 ± 13.79	47.11 ± 10.84	.65
Post-ROM of C2–C7, °	48.92 ± 10.80	43.71 ± 9.34	.16
Pre-FSU of IS, °	2.36 ± 3.67	2.55 ± 4.64	.89
Post-FSU of IS, °	2.62 ± 2.90	3.12 ± 2.77	.60
Pre-ROM of IS, °	11.83 ± 3.39	12.24 ± 2.63	.69
Post-ROM of IS, °	12.07 ± 3.10	14.18 ± 2.32*	.03
Pre-IDH of IS, mm	6.03 ± 0.66	6.36 ± 0.89	.19
Post-IDH of IS, mm	6.18 ± 0.70	6.21 ± 0.93	.93

Compared with preoperative values, there were statistically significant differences in CL and ROM of IS in the HS group.

CL = cervical lordosis, CDA = cervical disc arthroplasty, FSU = functional spine unit, HS = hybrid surgery, IDH = intervertebral disc height, IS = intermediate segment, ROM = range of motion, SD = standard deviation.

* $P < .05$.

Whether the development of ASD is due to natural progression with age or due to increased motion stress associated with biomechanical factors after fusion remains controversial. However, fusion was an important factor in accelerating adjacent segment pathology as had been reported in the literature. Matsumoto et al[24] conducted a prospective 10-year follow-up MRI study of patients who received ACDF and healthy control subjects and concluded that although both ACDF patients and healthy subjects detected progression of disc degeneration, ACDF patients had significantly higher incidence of progression of disc degeneration at adjacent levels. Gore et al[25] reported that patients who received ACDF had more frequent anterior osteophyte formation at adjacent segments than those in the healthy control group at a 5-year follow-up. Therefore, considering the fusion factor contributing to acceleration of ASD, we took non-fusion techniques including CDA or HS into account for the treatment of skip-level CDDD.

In biomechanical studies, 2-level CDA has been shown to provide near normal mobility at both operated levels without destabilizing or affecting adjacent segment motions,[26,27] and a hybrid construct with Prestige-LP prosthesis has been shown to

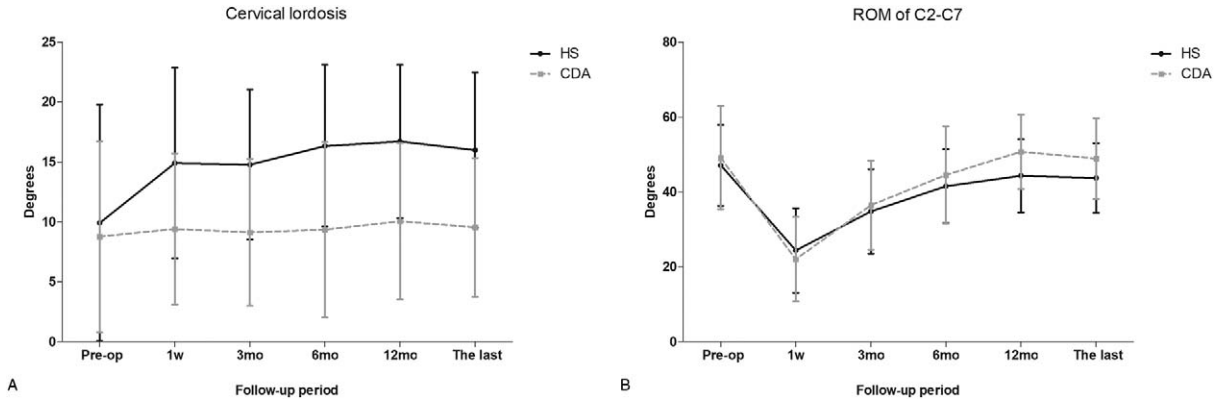

Figure 4. The changes in (A) cervical lordosis and (B) range of motion (ROM) of C2–C7 in the HS and CDA groups. CDA = cervical disc arthroplasty, HS = hybrid surgery.

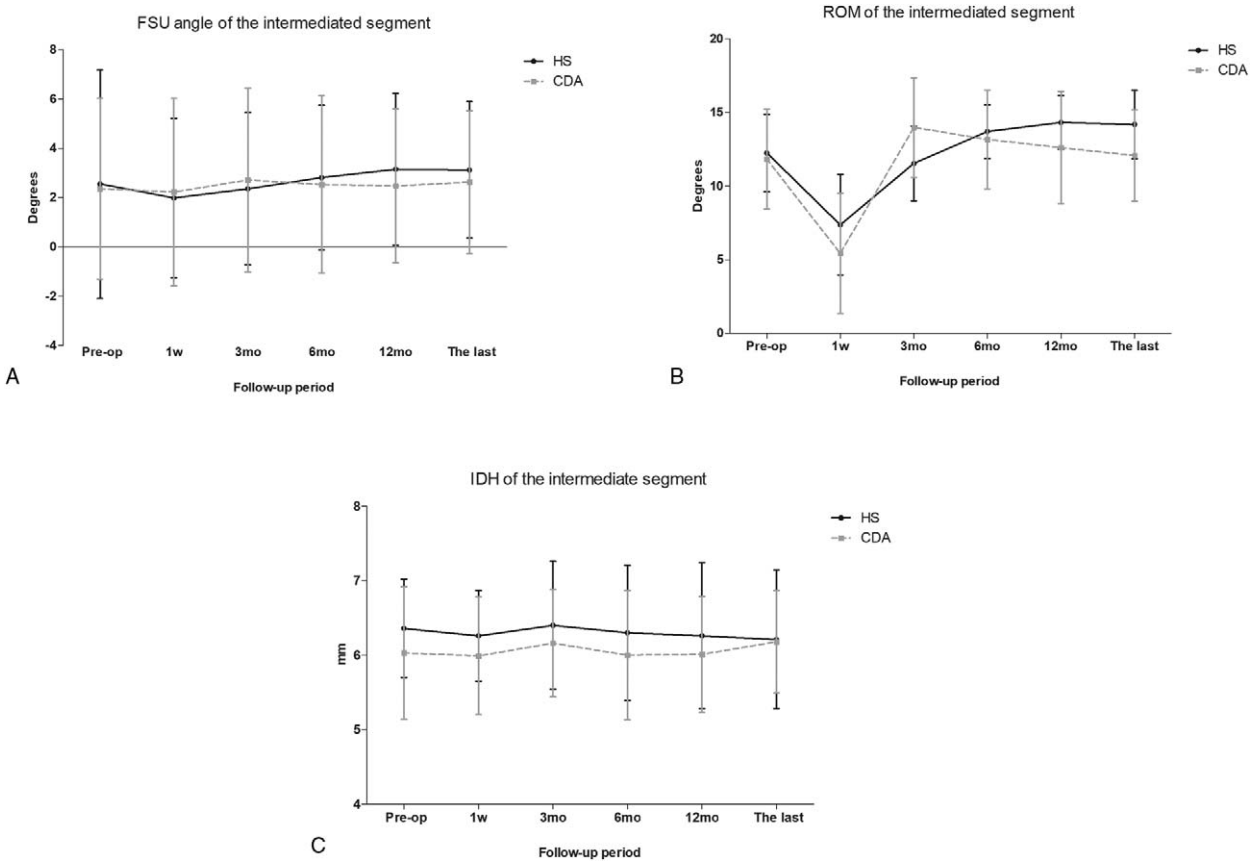

Figure 5. The changes in (A) functional spinal unite (FSU) angle of the intermediate segment (IS), (B) range of motion (ROM) of the IS and (C) intervertebral disc height (IDH) of the IS in the HS and CDA groups. CDA = cervical disc arthroplasty, HS = hybrid surgery.

Table 5

Adjacent segment degeneration (ASD) developed at the intermediate segment in the 2 groups.

	CDA				HS				
	1	2	3	4	1	2	3	4	*P*
Pre-ASD	27	1	0	0	28	3	0	0	.36
Post-ASD	24	4	0	0	25	5	1	0	.68

CDA = cervical disc arthroplasty, HS = hybrid surgery, Pre = preoperative, post = postoperative.

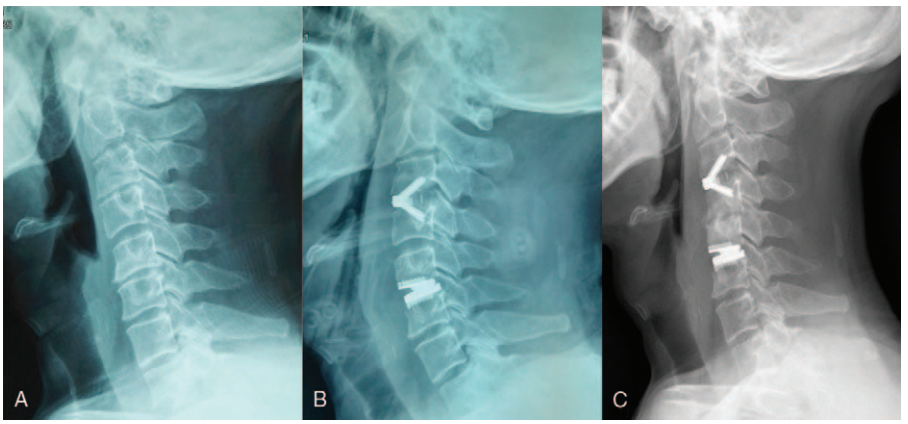

Figure 6. Preoperative lateral radiograph (A) showing the degeneration of the cervical spine. One week postoperative lateral radiograph (B) showing normal disc height at C4–C5 and cervical lordosis substantially improved, but it had obviously narrowed at the 3-month follow-up (C) without symptoms.

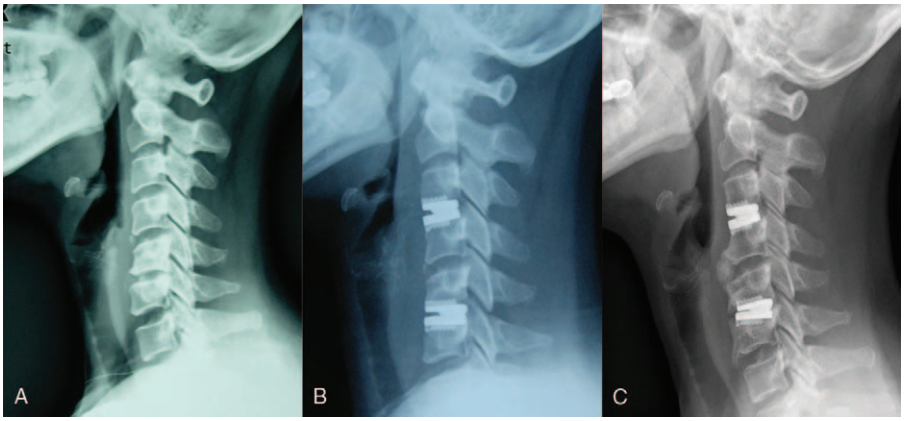

Figure 7. Preoperative lateral radiograph (A) showing the degeneration of the cervical spine and a small anterior osteophyte at C4–C5. One week postoperative lateral radiograph (B) showing implanted prostheses in good positions at C3–C4 and C5–C6. The anterior osteophyte at C4–C5 enlarged and a new anterior osteophyte developed at C6–C7 at the 96-month follow-up (C). Class III heterotopic ossification (HO) was detected at C5–C6 with over 2° range of motion (C).

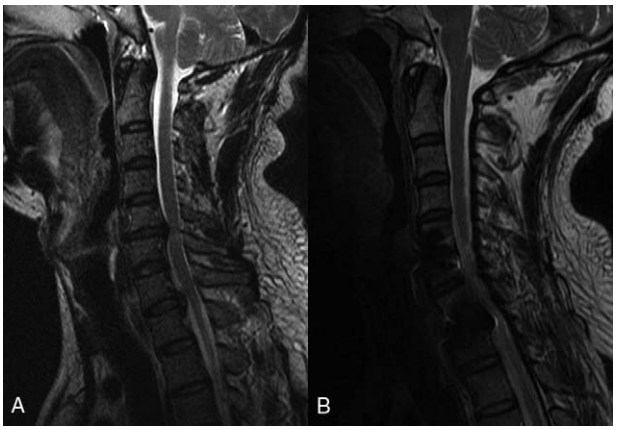

Figure 8. Preoperative magnetic resonance imaging (MRI) (A) showed disc herniation at C5–C6 and C7–T1 with spinal cord compression. MRI 35 months postoperatively showed that signal intensity decreased at C6–C7 compared with the preoperative image.

produce less motion at untreated levels in comparison with 2-level fusion.[28] Furthermore, several prospective studies have demonstrated that multilevel CDA for the treatment of CDDD can be a safe and effective alternative procedure to fusion.[29–33] Additionally, several studies have reported that HS can achieve satisfactory outcomes.[5,6,34,35] In our series, all the patients' symptoms were relieved after surgery due to the thorough decompression and reconstruction of stability of the cervical spine intraoperatively. With respect to cervical kinematic analysis, the HS group had better cervical lordosis after surgery, which might be related to the function of Zero-P implant. Wang et al[36] revealed that the Zero-P implant could correct global cervical lordosis after surgery. Postoperatively, the ROM of the IS slightly increased as compensation for the fused segment. This finding might be a reason for the higher incidence of ASD in the HS group compared with CDA group. Compared with previous studies involving a skip-level fusion construct,[12,22,37] the incidence of ASD in our series was higher. The possible reasons were that ASD is a time-dependent disease and our follow-up period was longer, and we chose MRI, a more sensitive measure than x-ray film, to evaluate disc degeneration at an early stage to evaluate ASD. Our results indicated that both CDA and HS

provided good clinical and radiographic outcomes with low incidence of ASD after over 30 months follow-up.

Some surgeons worried that the mobility and biomechanical stress of disc prosthesis might increase due to its placement adjacent to the fusion level.[35,38] Consequently, the disc prosthesis might be malfunctional and device subsidence or migration might occur after surgery. However, compared with contiguous HS, the operated levels are biomechanically independent to each other in skip-level HS. Theoretically, the arthroplasty level is less affected by the fusion level in skip-level HS. In our series, no device dislodgement or screw backout occurred suggesting the safety of the 2 surgical procedures. Nevertheless, a longer follow-up is necessary to verify the evaluation.

The current study had several limitations. First, this study was a retrospective study with a small sample size due to the rarity of skip-level CDDD, and the follow-up period was too short to draw a stronger conclusion as to whether HS and CDA protected the IS from ASD. However, the current study contained one of the largest groups of patients who received CDA or hybrid surgery by far. Second, the patient population was not completely homogenous because in some patients there was 1 IS and in others there were 2 ISs. The relative placement of implants in the HS group was another inhomogeneity. Third, we didn't compare the 2 surgical procedures with skip-level ACDF due to lack of patients. Furthermore, there was a lack of biomechanical studies involving skip-level HS or skip-level CDA versus skip-level ACDF to provide a strong theoretical basis.

5. Conclusion

The current study was not specifically designed to demonstrate superiority or non-inferiority of HS compared with CDA for the treatment of skip-level CDDD. In this retrospective study of patients with skip-level CDDD, the results indicated that both HS and CDA might be considered safe and effective alternative surgical strategies for the treatment of skip-level CDDD. Furthermore, although the clinical outcomes were similar in the 2 groups, CDA altered the ROM of the IS to a lesser degree than HS. To confirm the positive follow-up results of the 2 surgical strategies, longer-term randomized and controlled studies on larger series of patients are necessary.

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