Can segmental mobility be increased by cervical arthroplasty?

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OBJECTIVE Many reports have successfully demonstrated that cervical disc arthroplasty (CDA) can preserve range of motion after 1- or 2-level discectomy. However, few studies have addressed the extent of changes in segmental mobility after CDA or their clinical correlations.

METHODS Data from consecutive patients who underwent 1-level CDA were retrospectively reviewed. Indications for surgery were medically intractable degenerative disc disease and spondylosis. Clinical outcomes, including visual analog scale (VAS)—measured neck and arm pain, Neck Disability Index (NDI), and Japanese Orthopaedic Association (JOA) scores, were analyzed. Radiographic outcomes, including C2–7 Cobb angle, the difference between pre- and postoperative C2–7 Cobb angle (Δ C2–7 Cobb angle), sagittal vertical axis (SVA), the difference between pre- and postoperative SVA (Δ SVA), segmental range of motion (ROM), and the difference between pre- and postoperative ROM (Δ ROM), were assessed for their association with clinical outcomes. All patients underwent CT scanning, by which the presence and severity of heterotopic ossification (HO) were determined during the follow-up.

RESULTS A total of 50 patients (mean age 45.6 ± 9.33 years) underwent a 1-level CDA (Prestige LP disc) and were followed up for a mean duration of 27.7 ± 8.76 months. All clinical outcomes, including VAS, NDI, and JOA scores, improved significantly after surgery. Preoperative and postoperative ROM values were similar (mean 9.5° vs 9.0° , $p > 0.05$) at each indexed level. The mean changes in segmental mobility (Δ ROM) were $-0.5^\circ \pm 6.13^\circ$. Patients with increased segmental mobility after surgery (Δ ROM $> 0^\circ$) had a lower incidence of HO and HO that was less severe ($p = 0.048$) than those whose Δ ROM was $< 0^\circ$. Segmental mobility (ROM) was significantly lower in patients with higher HO grade ($p = 0.012$), but it did not affect the clinical outcomes. The preoperative and postoperative C2–7 Cobb angles and SVA remained similar. The postoperative C2–7 Cobb angles, SVA, Δ C2–7 Cobb angles, and Δ SVA were not correlated to clinical outcomes after CDA.

CONCLUSIONS Segmental mobility (as reflected by the mean ROM) and overall cervical alignment (i.e., mean SVA and C2–7 Cobb angle) had no significant impact on clinical outcomes after 1-level CDA. Patients with increased segmental mobility (Δ ROM $> 0^\circ$) had significantly less HO and similarly improved clinical outcomes than those with decreased segmental mobility (Δ ROM $< 0^\circ$).

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KEY WORDS cervical alignment; Cobb angle; sagittal vertical axis; range of motion; segmental mobility; cervical disc arthroplasty; heterotopic ossification

IN the past decade cervical disc arthroplasty (CDA) has been considered an effective and safe alternative to anterior cervical discectomy and fusion (ACDF) in selected candidates for management of 1- or 2-level degenerative disc disease (DDD) or spondylosis.^{10,12,15,18,24,26,35} In addition

to satisfactory clinical outcomes, successful preservation of segmental mobility after CDA has been demonstrated in several large-scale, prospective, randomized, controlled trials by the United States Food and Drug Administration (FDA).^{4,15,23,34,37} The averaged range of motion (ROM) pre-

ABBREVIATIONS ACDF = anterior cervical discectomy and fusion; CDA = cervical disc arthroplasty; DDD = degenerative disc disease; FDA = Food and Drug Administration; HO = heterotopic ossification; JOA = Japanese Orthopaedic Association; NDI = Neck Disability Index; ROM = range of motion; VAS = visual analog scale.

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served at each CDA-treated level was reported to be approximately 7°–9° during flexion and extension.^{9,10,17,24,25,34} Although the segmental mobility was preserved regardless of the brand of artificial disc that was tested, there are some variations in ROM. However, there are scarce data focusing on the extent of the post-CDA changes in segmental mobility or their clinical correlations.

While the aforementioned Food and Drug Administration (FDA) trials successfully demonstrated preserved segmental mobility (as reflected by mean ROM) after CDA in hundreds of patients,^{3,4,10,11,17,24,25,28,34} these trials did not address individual differences in change of mobility after CDA—in other words, a patient whose segmental mobility might increase (e.g., preoperative flexion and extension ROM of 6° at C5–6 increasing to 12° after surgery) or decrease after CDA (e.g., preoperative ROM of 12° decreasing to 6° after surgery). These two patients would be summed up as representing preservation of segmental mobility at an average ROM of 9°. The reported radiographic measurement of mean ROM in the literature would not have picked up the differences between increased and decreased segmental mobility. In theory, increased postoperative ROM (a difference between pre- and postoperative [Δ ROM] > 0°) and decreased segmental mobility (Δ ROM < 0°) could imply substantial differences in CDA. Therefore, the current study focused on the changes in ROM (Δ ROM during flexion and extension) after surgery.

The aim of this present study was to analyze the radiographic outcomes after CDA, particularly the changes in segmental mobility (Δ ROM) and cervical alignment and establishing correlations between changes and clinical outcomes. The study cohort included consecutively treated patients who underwent a single-level CDA performed using the same kind of device that was approved by the FDA. To the authors' knowledge, this is the first study to specifically address the changes in segmental mobility preoperatively and postoperatively and the influences on the outcomes.

Methods

Inclusion and Exclusion of Patients

Data obtained in patients in whom a 1-level subaxial (C3–7) CDA was performed using a Prestige LP disc (Medtronic) were retrospectively reviewed. The study's inclusion criteria were medically intractable cervical radiculopathy, myelopathy, or both, caused by DDD and/or spondylosis at only a single level.^{17,24,25} Preoperative MR images and radiographs were reviewed for all patients for confirmation of diagnosis. Patients also underwent CT scanning for evaluation of extensive bone spur formation, calcified disc, or ossification of the posterior longitudinal ligament. In all cases medical treatment and physical therapy failed to resolve symptoms for at least 12 weeks prior to surgery. Exclusion criteria were as follows: 1) traumatic spinal cord injury or fracture; 2) evident segmental instability (i.e., > 3.5 mm translation or 20° angular motion) at the index level; 3) segmental arthrodesis without mobility; 4) severely incompetent facet joints at the index level; 5) adjacent-segment disease after previous cervical fusion; 6) ossification of the posterior longitudinal ligament; 7) ky-

phosis at the index level or severe global kyphotic deformity; 8) discitis; or 9) long-term steroid use. Patients with chronic systemic diseases, including severe osteoporosis, malignancy, metabolic bone disease, autoimmune disease or spondyloarthropathy such as rheumatoid arthritis or ankylosing spondylitis, infection, or severe cerebrovascular disease such as stroke, were excluded from the current study as well.

Surgical Technique

All surgeries were performed by 3 experienced neurosurgeons and also the senior authors of the study (J.C. Wu, W.C. Huang, and H. Cheng). A consistent technique of anterior cervical discectomy was adopted, as described in previous studies.^{5–8} Generous decompression of the neural element and resection of bilateral uncovertebral joints and all the bone spurs were carefully performed. The posterior longitudinal ligament was routinely removed for direct visual confirmation of decompression in the spinal canal. We always aimed for decent technique, including meticulous endplate preparation and selection of the most appropriately sized artificial disc to minimize heterotopic ossification (HO) formation.³³ Also, copious irrigation with normal saline to wash away the bone dust when drilling the osteophytes was applied in every case. After thorough decompression, a Prestige LP artificial disc was inserted in each patient in the current series. A closed-system drainage catheter was routinely placed, followed by layer-by-layer wound closure.

Measurement of Radiological Parameters and Clinical Outcomes

Preoperative MR images, CT scans, and radiographs were reviewed for surgical indication. Our follow-up protocol involves patient-reported scores and radiographs (standing anteroposterior, lateral, and lateral dynamic flexion and extension views) at each specific follow-up time point after surgery. Patient-reported scores, including visual analog scale (VAS) of the neck and arm, Neck Disability Index (NDI) scores, and Japanese Orthopaedic Association (JOA) scores, were collected by two physician assistants under the physicians' supervision during clinic visits. The detection and grading of HO were established by careful review of postoperative radiographs and CT scans, and by application of McAfee's classification (Grade 0–4).²¹ We found that the 3D reconstructed CT scans were particularly useful for final assessment of HO if there was any ambiguity or discrepancy during the assessment.

Radiographic measurements included segmental ROM and overall cervical alignment. The segmental ROM of the index level was measured on standing dynamic lateral flexion/extension radiographs, obtained at 24-month follow-up examinations, using the Cobb angle method, which was the same as that previously reported on in the US FDA trials.²⁴ The change of segmental mobility (Δ ROM) was defined as the differences between preoperative and postoperative segmental ROM (24-month postoperative value minus the preoperative value). Cervical alignment was assessed by using the C2–7 Cobb angle and C2–7

sagittal vertical axis (SVA), which were measured on the standard lateral radiographs at the 24-month follow-up visit, as described previously in the literature³⁰ (Fig. 1). Lordosis was defined as positive values of the C2–7 Cobb angle, while kyphosis was defined as negative values of the C2–7 Cobb angle. The changes in C2–7 Cobb angles and SVAs after surgery were also evaluated and yielded Δ C2–7 Cobb angle and Δ SVA, defined as the differences between pre- and postoperative values (postoperative minus preoperative Cobb angle and SVA values). The current series did not measure T-1 slope because the T-1 vertebral body was frequently obscured by soft-tissue shadow on lateral radiographs and could not be consistently evaluated. Radiological assessments and measurements were conducted by a radiologist and 2 neurosurgeons independently using picture archiving and communication system (PACS) software, SmartIris (Taiwan Electronic Data Processing Co.) on a medical-use screen in our institute.

Statistical Analysis

For analysis of continuous variables, we used t-tests,

FIG. 1. Measurement of the C2–7 Cobb angle (CA) and the SVA.

1-way ANOVA tests, and correlation coefficients. Pearson's chi-square test was used for categorical variables analysis. All statistical analysis was performed using the SPSS software. Statistical significance was set at $p < 0.05$.

Results

Demographics and Patient-Reported Clinical Outcomes

As demonstrated in Table 1, a total of 50 patients who underwent 1-level CDA were analyzed in the current study. The Prestige LP device was implanted in all 50 patients. The mean age of the population was 45.6 ± 9.33 years. There was a slight female predominance (male/female ratio 21:29). The mean follow-up period was 27.7 ± 8.76 months. The C5–6 level was the level most commonly treated ($n = 36$, 72%). The pre- and postoperative patient-reported clinical outcomes, including neck and arm VAS, NDI, and JOA scores, are also summarized in Table 1. There was significant improvement in each of the outcome measurements at 24 months after surgery ($p = 0.001$, 0.000, 0.000, and 0.000 for VAS neck, VAS arm, NDI, and JOA score, respectively).

TABLE 1. Demographic data

Variable	Value (%)*	p Value
Age (yrs)	45.6 ± 9.33	
Male/female ratio	21:29	
Device	Prestige LP (100)	
Follow-up (mos)	27.7 ± 8.76	
Level		
C3–4	5 (10)	
C4–5	7 (14)	
C5–6	36 (72)	
C6–7	2 (4)	
Segmental ROM (°)		0.596
Preop	9.5 ± 4.28	
Postop 24 mos	9.0 ± 5.81	
C2–7 Cobb angle (°)		0.386
Preop	10.8 ± 12.22	
Postop 24 mos	12.0 ± 11.19	
C2–7 SVA (cm)		0.733
Preop	1.8 ± 1.40	
Postop 24 mos	1.7 ± 1.18	
VAS neck score		0.001
Preop	4.5 ± 3.42	
Postop 24 mos	2.8 ± 2.86	
VAS arm score		0.000
Preop	4.4 ± 3.18	
Postop 24 mos	1.8 ± 2.36	
NDI score		0.000
Preop	15.5 ± 11.48	
Postop 24 mos	8.6 ± 7.40	
JOA score		0.000
Preop	13.1 ± 2.97	
Postop 24 mos	14.7 ± 2.39	

Boldface indicates statistical significance.

* Values are presented as the number (%) or as the mean $\pm$ SD.

Segmental ROM and HO

The segmental ROM at the index level was well maintained at 24 months after surgery compared with that of the same level before surgery ($9.0^\circ \pm 5.81^\circ$ vs $9.5^\circ \pm 4.28^\circ$, $p = 0.596$, Table 1). The postoperative reduction in segmental mobility (ROM) was significantly correlated ($p = 0.012$) with formation of HO (Fig. 2). Patients in whom greater segmental ROM was achieved after CDA had a lower-grade HO at the index level. Once changes of ROM (Δ ROM) were determined postoperatively, patients were then divided into two groups accordingly: those with increased segmental mobility (Δ ROM $> 0^\circ$) and those with decreased or unchanged segmental mobility (Δ ROM $< 0^\circ$). All the clinical outcomes in the two groups were compared. The overall mean Δ ROM was $-0.5^\circ \pm 6.13^\circ$ in the current series, and there were no significant differences in segmental mobility after CDA. Patients in whom segmental mobility increased (Δ ROM $> 0^\circ$) had significantly less HO and less severe HO (Figs. 3 and 4). In contrast, patients who had signs of decreased segmental mobility postoperatively (i.e., Δ ROM $< 0^\circ$) had significantly higher grades of HO. ($p = 0.048$, Figs. 3 and 5). The clinical outcomes of these two groups of patients were similar during the follow-up. The changes in segmental mobility (Δ ROM) after CDA did not affect clinical outcomes in the current series of patients.

Cervical Alignment and HO

The mean postoperative C2–7 Cobb angle did not change significantly from the mean preoperative angle ($12.0^\circ \pm 11.19^\circ$ vs $10.8^\circ \pm 12.22^\circ$, respectively; $p = 0.386$). The mean postoperative C2–7 SVA also did not change

FIG. 2. The relationship between the HO grade and segmental mobility at the 24-month follow-up. The segmental mobility (ROM measured on lateral flexion and extension radiographs) was significantly higher in patients with lower grades of HO than in those with higher grades of HO ($p = 0.012$).

FIG. 3. Number of patients with increased segmental mobility (Δ ROM $> 0^\circ$) and decreased segmental mobility (Δ ROM $< 0^\circ$) in each HO grade. Patients with increased segmental mobility (Δ ROM $> 0^\circ$) after CDA tended to have significantly less HO ($p = 0.048$).

significantly ($1.7 \text{ cm} \pm 1.18 \text{ cm}$ [postoperative] vs $1.8 \text{ cm} \pm 1.40 \text{ cm}$ [preoperative], $p = 0.733$). Overall cervical alignment, including both C2–7 Cobb angle and SVA, did not demonstrate significant changes after 1-level CDA (Table 1).

The postoperative cervical alignment, including both C2–7 Cobb angle and SVA, did not correlate with the severity of HO formation or the clinical outcomes (i.e., neck and arm pain VAS, NDI, and JOA scores) (Tables 2 and 3). The changes in cervical alignments, including both Δ C2–7 Cobb angle and Δ SVA, also did not correlate with the severity of HO formation or the clinical outcomes. There was no statistical significance between cervical alignment parameters (C2–7 Cobb angle, C2–7 SVA, Δ C2–7 Cobb angle, and Δ SVA) and degree of HO formation (Table 2) or between cervical alignment parameters and patient-reported outcomes (i.e., neck and arm VAS, NDI, and JOA scores [Table 3]). These alignment parameters had no association with postoperative neck pain, arm pain, neck disability, or myelopathy.

In the present series, 1 (2%) of the 50 patients had intraoperative CSF leakage, which did not cause problems and required no further management. One patient (2%) had transient C-5 palsy, which was self-limited and resolved after 3 weeks. Overall, there was no need for secondary surgery (i.e., reoperation, revision, removal of implant, or conversion of arthroplasty to fusion) and no other major surgical complications such as nerve injury, permanent dysphagia or hoarseness, wound infection, or postoperative hematoma. However, a longer time is required to follow up for complications.

Discussion

Although many FDA trials have proven the effectiveness of preserving segmental mobility after CDA at approximately 7° – 9° during flexion and extension for each

FIG. 4. Preoperative (A) (extension [left] and flexion [right]) and 24-month postoperative (B) (extension [left] and flexion [right]) dynamic lateral radiographs obtained in a female patient who underwent a C5–6 CDA. The Δ ROM was $+7^\circ$, and there was very little HO formation 2 years after CDA.

level of disc replaced,^{3,17,24,25,28,34} it is still not clear if the extent of changes in segmental mobility affects clinical outcomes. Given the fact that the postoperative ROM averaged approximately 9° in the present study, there were variations among patients' segmental mobility after CDA. It is possible that CDA increased ROM in some patients while reducing ROM in others, and it might affect clinical outcomes. The present study aimed to investigate the differences between the patients whose segmental mobility was increased (Δ ROM $> 0^\circ$) and those whose segmental mobility decreased (Δ ROM $< 0^\circ$). Thus, the present series analyzed 50 consecutively treated patients who underwent 1-level CDA between C-3 and C-7. This was a single-institute experience that uniformly chose an FDA-approved

device, the Prestige LP artificial disc and followed up these patients for more than 24 months. The surgical indications were 1-level symptomatic and medically intractable DDD and/or spondylosis. All imaging parameters, including segmental mobility (ROM), cervical alignment (C2–7 Cobb angle), and sagittal balance (C2–7 SVA) were assessed. Additionally, the postoperative changes in these parameters, including Δ ROM, Δ C2–7 Cobb angle, and Δ C2–7 SVA, were calculated and correlated with clinical outcomes, including VAS neck pain, VAS arm pain, NDI, and JOA scores.

In the present study, 2 years after CDA, the segmental mobility was well preserved at the index level (mean $9.0^\circ \pm 5.81^\circ$), and cervical alignment exhibited little change. All

FIG. 5. A female patient who underwent a C5–6 CDA. **A:** Preoperative extension (left) and flexion (right) dynamic lateral radiographs demonstrated satisfactory segmental mobility. **B:** Three months after surgery, dynamic lateral extension (left) and flexion (right) radiographs already demonstrated decreased C5–6 segmental mobility (Δ ROM -8° degrees). **C:** By 24 months after surgery, the segmental mobility was still limited and Grade 4 HO had developed.

TABLE 2. Relationship between HO grade and cervical alignment parameters

Parameter	HO Grade					p Value
	0	1	2	3	4	
Postop C2–7 Cobb angle (°)	13.9 ± 15.94	9.9 ± 9.87	8.7 ± 10.07	17.3 ± 13.17	15.1 ± 10.27	0.453
ΔC2–7 Cobb angle (°)*	–2.0 ± 10.88	1.7 ± 8.47	0.9 ± 11.47	–1.0 ± 11.51	1.9 ± 7.11	0.918
Postop SVA (cm)	2.4 ± 0.40	1.4 ± 1.10	1.9 ± 1.24	1.3 ± 1.24	2.2 ± 1.40	0.255
ΔSVA (cm)†	0.6 ± 0.67	–0.1 ± 1.15	0.2 ± 0.64	–0.1 ± 0.89	–0.3 ± 1.61	0.490

Values are presented as the mean ± SD.

* ΔC2–7 Cobb angle = postoperative C2–7 Cobb angle minus preoperative C2–7 Cobb angle.

† ΔSVA = postoperative SVA minus preoperative SVA.

patients had improved clinical outcomes, and the changes in segmental mobility (ΔROM) averaged $-0.5^\circ \pm 6.13^\circ$. Those patients in whom segmental mobility increased (ΔROM > 0°) after CDA had similar clinical outcomes to those in whom segmental mobility decreased (ΔROM < 0°) after surgery. However, the incidence and severity of HO were significantly higher in patients with decreased segmental mobility (ΔROM < 0°). Moreover, segmental mobility (ROM) was significantly lower in patients with higher grades of HO ($p = 0.012$). This result implied that we should avoid reduction of segmental mobility during CDA surgery, because it might cause more HO and perhaps hinder mobility in the long term.

It was intuitive to infer that decreased segmental mobility after CDA might be associated with greater HO formation, and it was also reasonable to suggest that we should always aim at restoration of disc mobility when performing CDA. However, after implanting many artificial discs, we found it sometimes difficult during surgery to predict the postoperative disc mobility. Although the overall mean ROM in every series reported was similar,^{17,24,25,34} the actual surgical experience indicated that the disc mobility might sometimes be amplified or limited in a relatively acceptable range. The results of this present study demonstrated that mildly increased mobility, although sometimes unpredicted, might be beneficial in preserving motion after surgery because it was associated with less HO severity. In the literature, HO formation was not an uncommon phenomenon after CDA, and its incidence reportedly ranged from 12.5% to 68.2% depending on different classification and measurement tools.^{13,20,32,33} The risk factors for HO remain controversial and diverse in previously reported series and included surgical indication, operative level, male sex, hybrid constructs, surgical technique, and method of detection.^{8,19,32,33,38–41} It was once reported that segmental ROM might be associated with the incidence of HO formation, but the study did not take

HO severity into consideration and failed to address the changes in ROM.²⁷ The current study might add to the literature, in that decreased mobility (ΔROM < 0°) is another risk factor for HO.

The study also demonstrated that cervical alignment did not change significantly after 1-level CDA and that the absolute values and changes in C2–7 Cobb angles and SVAs did not affect clinical outcomes. This observation perhaps corroborates the fact that patients with 1-level DDD or spondylosis should have normal cervical alignment, and if the individuals have any cervical deformity problem, they should never be considered as candidates for CDA. This paper provided evidence that there was actually little change in these alignment parameters and their effects on clinical outcomes; even some subtle mobility change existed after 1-level CDA. Based on the impact of spinopelvic alignment and sagittal balance on surgical outcome after thoracolumbar surgery documented in the past decade,²² there is also growing interest in alignment and sagittal balance of the cervical spine. Recent research has advanced our understanding of cervical alignment. For example, correction of cervical kyphotic deformity improves patients' outcomes after ACDF,³⁰ and cervical sagittal malalignment is related to disability after posterior cervical fusion.³¹ On the other hand, few data address cervical alignment after CDA. It was reported in one study that lordotic alignment was preserved after CDA that involved implantation of the Bryan artificial disc and that this alignment was equivalent to ACDF results in an FDA trial.²⁹ Furthermore, the Mobi-C (LDR) and Prodisc-C (DePuy Synthes Inc.) artificial discs also have been shown to preserve overall lordosis after the surgery.^{1,16} Only one report in the literature demonstrated that postoperative C2–7 Cobb angle had no correlation to NDI scores in patients who underwent Bryan disc-assisted arthroplasty.²⁹ To our knowledge, this is the first study to demonstrate that the C2–7 Cobb angles, ΔC2–7 Cobb angles, SVA,

TABLE 3. Correlation coefficient between clinical outcomes and cervical alignment parameters

Parameter	Correlation Coefficient at 24 Mos Postop (p value)			
	Neck VAS Score	Arm VAS Score	NDI Score	JOA Score
Postop C2–7 Cobb angle (°)	0.14 (0.927)	–0.01 (0.997)	0.145 (0.325)	–0.292 (0.079)
ΔC2–7 Cobb angle (°)	–0.206 (0.169)	–0.182 (0.225)	–0.081 (0.591)	–0.078 (0.611)
Postop SVA (cm)	0.131 (0.375)	0.209 (0.154)	0.135 (0.359)	–0.124 (0.406)
ΔSVA (cm)	0.230 (0.124)	0.147 (0.329)	0.101 (0.503)	–0.066 (0.668)

and Δ SVA were not statistically significant in terms of patients' outcome, including VAS, NDI, and JOA scores, after 1-level CDA.

A few studies have investigated the association between alignment and clinical outcomes after cervical fusion surgery. One prospective, randomized, double-blinded clinical study compared cervical sagittal alignment and clinical outcomes using a lordotic or parallel cage for fusion.³⁶ The authors of that study concluded that there were no statistically significant differences in clinical outcome scores between the lordotic and parallel cage groups. Another study demonstrated that patients with cervical myelopathy treated by anterior corpectomy and fusion would develop more chronic neck pain if there was postoperative kyphosis present.² A paper on posterior fusion surgery written on behalf of an international spine study group also demonstrated significant correlations between C2–7 SVA and SF-36 scores and NDI scores, but it identified no correlations between alignment and VAS scores.³¹ The existing evidence on whether cervical alignment affects patient outcomes is conflicting, and there is no consensus on cutoff values for these radiological parameters suggested for patients' outcomes. Nevertheless, only selected patients (i.e., only those with disc diseases rather than facet arthropathy or deformity) among the fusion candidates should undergo CDA. For example, a patient with negative C2–7 Cobb angle should undergo ACDF even if the DDD is limited to merely 1 or 2 levels anteriorly; and since SVAs were strongly correlated with C2–7 Cobb angle,¹⁴ patients with large SVAs should also avoid CDA. The mean SVA in the present series was 1.7 ± 1.18 cm, whereas that reported by Tang et al. was 3.62 ± 1.59 cm.³¹ This indicates that the cervical alignment of arthroplasty-treated patients fell in a more narrow and specific range than in those patients who underwent fusion.

There were limitations to this study. It was a retrospective analysis of 50 patients who underwent 1-level CDA with Prestige LP disc. The 50 arthroplasty-treated levels were distributed unequally from C-3 to C-7; thus, the radiographic measurements could not represent every disc level or any other brand of CDA device. The changes in segmental mobility (Δ ROM), for which significance was demonstrated, might be caused by the surgical techniques applied during insertion and thus might vary in different hands. Also, the imaging parameters (ROM, C2–7 Cobb angles, and SVAs) could be subject to changes, as cervical spine degeneration continues to occur during longer follow-up periods. However, this study merits analysis of consecutive single-level arthroplasty with the same inclusion and exclusion criteria used in the FDA trials. The differences in changes in mobility separated the CDA patients by the degree of degeneration, which might yield disparities in the propensity for HO development. The relatively short follow-up period, averaging 27 months, was not long enough to yield differences in other clinical outcomes. Furthermore, the T-1 slope, another common radiographic parameter for evaluation of cervical alignment, was not measured in the present series because the lateral radiographs were frequently inadequate for visualization of the entire T-1 vertebra. Future investigations of a larger number of patients, longer follow-up, and optimized

radiological images are required for further corroboration of the results.

Conclusions

Segmental mobility (mean ROM) and overall cervical alignment (SVA and C2–7 Cobb angle) had no significant impact on clinical outcome after 1-level CDA. Patients with increased segmental mobility (Δ ROM $> 0^\circ$) had significantly less HO and similarly improved clinical outcomes as patients with decreased segmental mobility (Δ ROM $< 0^\circ$).

References

1. Ahn PG, Kim KN, Moon SW, Kim KS: Changes in cervical range of motion and sagittal alignment in early and late phases after total disc replacement: radiographic follow-up exceeding 2 years. **J Neurosurg Spine** 11:688–695, 2009
2. Andaluz N, Zuccarello M, Kuntz C: Long-term follow-up of cervical radiographic sagittal spinal alignment after 1- and 2-level cervical corpectomy for the treatment of spondylosis of the subaxial cervical spine causing radiculomyelopathy or myelopathy: a retrospective study. **J Neurosurg Spine** 16:2–7, 2012
3. Burkus JK, Haid RW, Traynelis VC, Mummaneni PV: Long-term clinical and radiographic outcomes of cervical disc replacement with the Prestige disc: results from a prospective randomized controlled clinical trial. **J Neurosurg Spine** 13:308–318, 2010
4. Burkus JK, Traynelis VC, Haid RW Jr, Mummaneni PV: Clinical and radiographic analysis of an artificial cervical disc: 7-year follow-up from the Prestige prospective randomized controlled clinical trial: Clinical article. **J Neurosurg Spine** 21:516–528, 2014
5. Chang HC, Tu TH, Chang HK, Wu JC, Fay LY, Chang PY, et al: Hybrid corpectomy and disc arthroplasty for cervical spondylotic myelopathy caused by ossification of posterior longitudinal ligament and disc herniation. **World Neurosurg** 95:22–30, 2016
6. Chang HK, Huang WC, Wu JC, Chang PY, Tu TH, Fay LY, et al: Should cervical disc arthroplasty be done on patients with increased intramedullary signal intensity on magnetic resonance imaging? **World Neurosurg** 89:489–496, 2016
7. Chang HK, Huang WC, Wu JC, Tu TH, Fay LY, Chang PY, et al: Cervical arthroplasty for traumatic disc herniation: an age- and sex-matched comparison with anterior cervical discectomy and fusion. **BMC Musculoskelet Disord** 16:228, 2015
8. Chang PY, Chang HK, Wu JC, Huang WC, Fay LY, Tu TH, et al: Differences between C3–4 and other subaxial levels of cervical disc arthroplasty: more heterotopic ossification at the 5-year follow-up. **J Neurosurg Spine** 24:752–759, 2016
9. Coric D, Kim PK, Clemente JD, Boltes MO, Nussbaum M, James S: Prospective randomized study of cervical arthroplasty and anterior cervical discectomy and fusion with long-term follow-up: results in 74 patients from a single site. **J Neurosurg Spine** 18:36–42, 2013
10. Coric D, Nunley PD, Guyer RD, Musante D, Carmody CN, Gordon CR, et al: Prospective, randomized, multicenter study of cervical arthroplasty: 269 patients from the Kineflex/C artificial disc investigational device exemption study with a minimum 2-year follow-up: clinical article. **J Neurosurg Spine** 15:348–358, 2011
11. Davis RJ, Kim KD, Hissey MS, Hoffman GA, Bae HW, Gaede SE, et al: Cervical total disc replacement with the Mobi-C cervical artificial disc compared with anterior discectomy and fusion for treatment of 2-level symptomatic degeneration.

- tive disc disease: a prospective, randomized, controlled multicenter clinical trial: clinical article. **J Neurosurg Spine** 19:532–545, 2013
12. Davis RJ, Nunley PD, Kim KD, Hisey MS, Jackson RJ, Bae HW, et al: Two-level total disc replacement with Mobi-C cervical artificial disc versus anterior discectomy and fusion: a prospective, randomized, controlled multicenter clinical trial with 4-year follow-up results. **J Neurosurg Spine** 22:15–25, 2015
 13. Fay LY, Huang WC, Wu JC, Chang HK, Tsai TY, Ko CC, et al: Arthroplasty for cervical spondylotic myelopathy: similar results to patients with only radiculopathy at 3 years' follow-up. **J Neurosurg Spine** 21:400–410, 2014
 14. Gillis CC, Kaszuba MC, Traynelis VC: Cervical radiographic parameters in 1- and 2-level anterior cervical discectomy and fusion. **J Neurosurg Spine** 25:421–429, 2016
 15. Gornet MF, Burkus JK, Shaffrey ME, Argires PJ, Nian H, Harrell FE Jr: Cervical disc arthroplasty with PRESTIGE LP disc versus anterior cervical discectomy and fusion: a prospective, multicenter investigational device exemption study. **J Neurosurg Spine** 23:558–573, 2015
 16. Guérin P, Obeid I, Gille O, Bourghli A, Luc S, Pointillart V, et al: Sagittal alignment after single cervical disc arthroplasty. **J Spinal Disord Tech** 25:10–16, 2012
 17. Heller JG, Sasso RC, Papadopoulos SM, Anderson PA, Fessler RG, Hacker RJ, et al: Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion: clinical and radiographic results of a randomized, controlled, clinical trial. **Spine (Phila Pa 1976)** 34:101–107, 2009
 18. Janssen ME, Zigler JE, Spivak JM, Delamarter RB, Darden BV II, Kopjar B: ProDisc-C total disc replacement versus anterior cervical discectomy and fusion for single-level symptomatic cervical disc disease: seven-year follow-up of the prospective randomized U.S. Food and Drug Administration investigational device exemption study. **J Bone Joint Surg Am** 97:1738–1747, 2015
 19. Jin YJ, Park SB, Kim MJ, Kim KJ, Kim HJ: An analysis of heterotopic ossification in cervical disc arthroplasty: a novel morphologic classification of an ossified mass. **Spine J** 13:408–420, 2013
 20. Kang J, Shi C, Gu Y, Yang C, Gao R: Factors that may affect outcome in cervical artificial disc replacement: a systematic review. **Eur Spine J** 24:2023–2032, 2015
 21. McAfee PC, Cunningham BW, Devine J, Williams E, Yu-Ya-hiro J: Classification of heterotopic ossification (HO) in artificial disk replacement. **J Spinal Disord Tech** 16:384–389, 2003
 22. Mehta VA, Amin A, Omeis I, Gokaslan ZL, Gottfried ON: Implications of spinopelvic alignment for the spine surgeon. **Neurosurgery** 76 (Suppl 1):S42–S56, 2015
 23. Mummaneni PV, Amin BY, Wu JC, Brodt ED, Dettori JR, Sasso RC: Cervical artificial disc replacement versus fusion in the cervical spine: a systematic review comparing long-term follow-up results from two FDA trials. **Evid Based Spine Care J** 3 (S1):59–66, 2012
 24. Mummaneni PV, Burkus JK, Haid RW, Traynelis VC, Zdeblick TA: Clinical and radiographic analysis of cervical disc arthroplasty compared with allograft fusion: a randomized controlled clinical trial. **J Neurosurg Spine** 6:198–209, 2007
 25. Murrey D, Janssen M, Delamarter R, Goldstein J, Zigler J, Tay B, et al: Results of the prospective, randomized, controlled multicenter Food and Drug Administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease. **Spine J** 9:275–286, 2009
 26. Phillips FM, Lee JY, Geisler FH, Cappuccino A, Chaput CD, DeVine JG, et al: A prospective, randomized, controlled clinical investigation comparing PCM cervical disc arthroplasty with anterior cervical discectomy and fusion. 2-year results from the US FDA IDE clinical trial. **Spine (Phila Pa 1976)** 38:E907–E918, 2013
 27. Qi M, Chen H, Cao P, Tian Y, Yuan W: Incidence and risk factors analysis of heterotopic ossification after cervical disc replacement. **Chin Med J (Engl)** 127:3871–3875, 2014
 28. Radcliff K, Coric D, Albert T: Five-year clinical results of cervical total disc replacement compared with anterior discectomy and fusion for treatment of 2-level symptomatic degenerative disc disease: a prospective, randomized, controlled, multicenter investigational device exemption clinical trial. **J Neurosurg Spine** 25:213–224, 2016
 29. Sasso RC, Metcalf NH, Hipp JA, Wharton ND, Anderson PA: Sagittal alignment after Bryan cervical arthroplasty. **Spine (Phila Pa 1976)** 36:991–996, 2011
 30. Scheer JK, Tang JA, Smith JS, Acosta FL Jr, Protopsaltis TS, Blondel B, et al: Cervical spine alignment, sagittal deformity, and clinical implications: a review. **J Neurosurg Spine** 19:141–159, 2013
 31. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, et al: The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. **Neurosurgery** 76 (Suppl 1):S14–S21, 2015
 32. Tu TH, Wu JC, Huang WC, Chang HK, Ko CC, Fay LY, et al: Postoperative nonsteroidal antiinflammatory drugs and the prevention of heterotopic ossification after cervical arthroplasty: analysis using CT and a minimum 2-year follow-up. **J Neurosurg Spine** 22:447–453, 2015
 33. Tu TH, Wu JC, Huang WC, Wu CL, Ko CC, Cheng H: The effects of carpentry on heterotopic ossification and mobility in cervical arthroplasty: determination by computed tomography with a minimum 2-year follow-up: Clinical article. **J Neurosurg Spine** 16:601–609, 2012
 34. Upadhyaya CD, Wu JC, Trost G, Haid RW, Traynelis VC, Tay B, et al: Analysis of the three United States Food and Drug Administration investigational device exemption cervical arthroplasty trials. **J Neurosurg Spine** 16:216–228, 2012
 35. Vaccaro A, Beutler W, Peppelman W, Marzluff JM, Highsmith J, Mugglin A, et al: Clinical outcomes with selectively constrained SECURE-C cervical disc arthroplasty: two-year results from a prospective, randomized, controlled, multicenter investigational device exemption study. **Spine (Phila Pa 1976)** 38:2227–2239, 2013
 36. Villavicencio AT, Babuska JM, Ashton A, Busch E, Roeca C, Nelson EL, et al: Prospective, randomized, double-blind clinical study evaluating the correlation of clinical outcomes and cervical sagittal alignment. **Neurosurgery** 68:1309–1316, 2011
 37. Wu JC, Hsieh PC, Mummaneni PV, Wang MY: Spinal motion preservation surgery. **BioMed Res Int** 2015:372502, 2015
 38. Wu JC, Huang WC, Tsai HW, Ko CC, Fay LY, Tu TH, et al: Differences between 1- and 2-level cervical arthroplasty: more heterotopic ossification in 2-level disc replacement: Clinical article. **J Neurosurg Spine** 16:594–600, 2012
 39. Wu JC, Huang WC, Tsai TY, Fay LY, Ko CC, Tu TH, et al: Multilevel arthroplasty for cervical spondylosis: more heterotopic ossification at 3 years of follow-up. **Spine (Phila Pa 1976)** 37:E1251–E1259, 2012
 40. Wu JC, Huang WC, Tu TH, Tsai HW, Ko CC, Wu CL, et al: Differences between soft-disc herniation and spondylosis in cervical arthroplasty: CT-documented heterotopic ossification with minimum 2 years of follow-up. **J Neurosurg Spine** 16:163–171, 2012
 41. Yi S, Shin DA, Kim KN, Choi G, Shin HC, Kim KS, et al: The predisposing factors for the heterotopic ossification after cervical artificial disc replacement. **Spine J** 13:1048–1054, 2013

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: JC Wu, HK Chang, CC Chang, Tu, Huang, Fay, PY Chang, CL Wu. Acquisition of data: JC Wu, HK Chang, CC Chang, Tu, Huang. Analysis and interpretation of data: JC Wu, HK Chang, CC Chang, Tu, Huang. Drafting the article: JC Wu, HK Chang, CC Chang, Tu, Huang, Fay, PY Chang, CL Wu. Critically revising the article: JC Wu, HK Chang, Huang, Cheng.

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