Neurospine 2022;19(4):927-934.
https://doi.org/10.14245/ns.2244750.375

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

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Received: September 1, 2022
Revised: November 24, 2022
Accepted: November 24, 2022

The Effect of Subsidence on Segmental and Global Lordosis at Long-term Follow-up After Anterior Cervical Discectomy and Fusion

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Objective: Subsidence following anterior cervical discectomy and fusion (ACDF) may lead to disruptions of cervical alignment and lordosis. The purpose of this study was to evaluate the effect of subsidence on segmental, regional, and global lordosis.
Methods: This was a retrospective cohort study performed between 2016–2021 at a single institution. All measurements were performed using lateral cervical radiographs at the immediate postoperative period and at final follow-up greater than 6 months after surgery. Associations between subsidence and segmental lordosis, total fused lordosis, C2–7 lordosis, and cervical sagittal vertical alignment change were determined using Pearson correlation and multivariate logistic regression analyses.
Results: One hundred thirty-one patients and 244 levels were included in the study. There were 41 one-level fusions, 67 two-level fusions, and 23 three-level fusions. The median follow-up time was 366 days (interquartile range, 239–566 days). Segmental subsidence was significantly negatively associated with segmental lordosis change in the Pearson (r = -0.154, p = 0.016) and multivariate analyses (beta = -3.78; 95% confidence interval, -7.15 to -0.42; p = 0.028) but no associations between segmental or total fused subsidence and any other measures of cervical alignment were observed.
Conclusion: We found that subsidence is associated with segmental lordosis loss 6 months following ACDF. Surgeons should minimize subsidence to prevent long-term clinical symptoms associated with poor cervical alignment.

Keywords: Cervical vertebrae, Intervertebral disc, Vertebral body, Spinal fusion, Diskectomy, Lordosis

INTRODUCTION

Anterior cervical discectomy and fusion (ACDF) is a standard operative treatment for degenerative conditions of the cervical spine. Historically, spine surgeons have used allograft or autograft bone to fill the interbody space after discectomy.[1] More recently, synthetic cages have seen wider use with the most common being carbon fiber, titanium, and polyetheretherketone (PEEK). In comparison to autologous bone, synthetic cages have the added benefit of avoiding iliac crest harvesting which increases operative time, patient discomfort, and risk of donor-site morbidity.[2] Synthetic cages may provide a stronger support to help maintain disc height and promote fusion. Despite the use of interbody devices, alterations in spinal geometry, such as subsidence, are still relatively common.

Subsidence is generally defined as a reduction in the anterior or posterior disc height of greater than 2 or 3 mm during the postoperative period following ACDF. According to one systematic review of 35 articles, subsidence is a common occurrence with an incidence of approximately 19.3% to 42.5%.[3] Thus, some loss of disc height may be expected following ACDF, but the amount of subsidence that becomes clinically significant remains unclear. Evidence of adverse clinical outcomes associated with subsidence has been mixed. Some studies suggest no impact on outcomes,[4-7] whereas others have found associations with worse pain and clinical outcomes when subsidence occurs.[8-10] Differing results may be due to heterogeneity in radiographic measurements, interbody cages, and length of follow-up.

Although the clinical impact of subsidence remains equivocal, it can have a substantial impact on cervical sagittal alignment.[11] Normal sagittal alignment of the cervical spine is highly variable in contrast to the lumbar or thoracic regions, and the clinical implications of these alignment variations remains uncertain. Consequently, the optimal sagittal alignment to target after cervical surgery is unclear.[11] Some studies suggest a loss of cervical lordosis to be pathological and advocate for restoration of cervical lordosis,[12-14] although some patients with neutral or kyphotic alignment are entirely asymptomatic.[15-17] To achieve the best ACDF outcomes, it is critical for spine surgeons to better understand the impact of subsidence on sagittal alignment. Therefore, the purpose of this study was to assess the effect of subsidence on segmental and global lordosis following ACDF.

MATERIALS AND METHODS

1. Study Design

This retrospective study was approved the Institutional Review Board of Icahn School of Medicine at Mount Sinai (STUDY-21-01028). Consecutive patients who underwent ACDF between 2016 and 2021 were included. Patients undergoing ACDF were identified using Current Procedural Terminology codes 22551, 22552, and 22554. Exclusion criteria included patients under 18 years of age at the time of surgery, revision surgery, surgery in the setting of trauma, those undergoing cervical fusion via a posterior approach, and those requiring a corpectomy. All data for this study was collected using the electronic medical record at our institution.

Eligibility criteria included patients who had both immediate postoperative and final follow-up radiographs. Final follow-up radiographs were defined as the final radiograph where the intervertebral disc spaces in the fused segments were distinguishable. Patients were excluded from the study if they did not have both an immediate postoperative radiograph within 6 weeks of surgery and a final follow-up radiograph greater than 6 months from the date of surgery. Additionally, radiographs with significant shoulder shadow at C7 or poor image quality were excluded from the study to preserve measurement accuracy.

2. Demographics and Outcome Measurements

Demographic information, including age at the time of surgery, sex, smoking status, and osteopenia were collected from the electronic medical record. Smoking status was confirmed as positive if the patient was a current or former smoker. Osteopenia included both osteopenia and osteoporosis and was identified based on prior diagnosis or dual-energy x-ray absorption bone density scan results. T-scores less than -1.5 were defined as osteopenic.

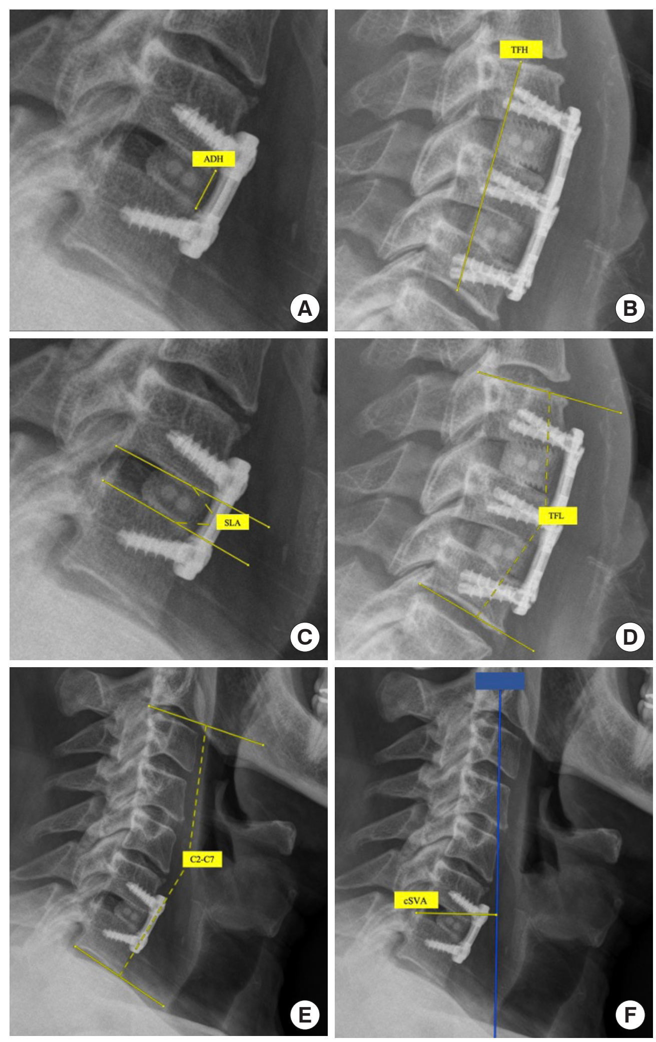

Fig. 1. Measurement of anterior disc height (ADH, A), total fused height (TFH, B), segmental lordosis angle (SLA, C), total fused lordosis (TFL, D), C2–7 lordosis (E), and cervical sagittal vertical alignment (cSVA, F).

https://doi.org/10.14245/ns.2244750.375

Plain radiographs were evaluated for segmental and total subsidence of the intervertebral cage. Segmental subsidence was determined by taking the difference of the anterior disc heights between the final follow-up and immediate postoperative radiographs. Total subsidence was determined by taking the difference of the total height of the fused segments between the final follow-up and immediate postoperative radiographs (Fig. 1). A decrease in disc height or total fused height was defined as positive subsidence. All radiographic measurements were collected by trained researchers and were verified by a senior author with high interobserver reliability.

Intervertebral cage type was determined by assessing the shape and density of the cages on radiographs and by confirming with operative notes when possible. Intervertebral cage types included structural allograft, titanium, PEEK, ceramic, and zero profile. With the exception of patients receiving a zero-profile implant with integrated screws, all patients underwent plating with interbody fusion. The cage-to-vertebral body ratio was also collected by measuring both the intervertebral cage length and vertebral body length below each level of the fusion. The ratio was calculated by dividing the cage length by the vertebral body length for each level. All radiographic measurements were performed on lateral cervical radiographs using the PACS (picture archiving and communications system) imaging software within the electronic record system at our institution.

The outcome variables of this study were radiographic measures of lordosis and vertebral alignment including segmental lordosis, total fused lordosis, C2–7 lordosis, and sagittal cervical vertical alignment. The segmental lordosis was defined as the angle between the inferior and superior end plates of each level of the fusion. The total fused lordosis was defined as the angle between the superior aspect of the superior most vertebrae and the inferior aspect of the inferior most vertebrae. C2–7 lordosis was defined as the angle between the inferior endplate of C2 and the inferior endplate of C7. If the inferior endplate of C7 was not visible, the angle was estimated using the superior endplate of C7 or inferior endplate of C6. Cervical sagittal vertical alignment (cSVA) was defined as the horizontal distance between the superior posterior corner of C7 and a vertical plumb line from the centroid of C2.

3. Statistical Analysis

Continuous data is presented as mean and standard deviation or median and interquartile range. For categorical variables, counts with percentage of the total sample are provided. To determine the relationship between subsidence and lordosis, Pearson correlation coefficients were calculated and are presented in the results section with p-values. The results are divided based on segmental and total fused subsidence correlations.

Multivariate linear regression models were constructed to examine the relationship between subsidence and lordosis while controlling for other variables. The main predictor in the regression models was subsidence. Separate regression models were created with segmental or total fused subsidence as the predictor. The outcome variables of each regression model were various measures of lordosis and cervical alignment as defined previously. The regression models controlled for age, sex, smoking status, osteopenia, cage-to-body ratio, level of fusion, number of fused segments, and cage type. All statistical analyses were performed in Python version 3.8.8. Alpha less than 0.05 was defined as the level of significance for all statistical testing.

RESULTS

In total, 131 patients and 244 fused levels (1.86 ± 0.69 mean levels per patient) were included in the study. The mean age of the patients was 53.6 ± 10.9 years. The median follow-up time for immediate postoperative radiographs was 11 days (interquartile range [IQR], 1–14 days), and median follow-up for final radiographs was 366 days (IQR, 239–566 days). There were 56 males (42.7%) and 75 females (57.3%). Sixty-two patients

Table 1. Demographics and fusion characteristics of patients undergoing ACDF

Variable	Value
Total patients	131
Total levels	244
Age (yr)	53.6 ± 10.9
Male sex	56 (42.7)
Smoking history	62 (47.3)
Osteopenia	27 (20.6)
1-Level fusion	41 (31.3)
2-Level fusion	67 (51.1)
3-Level fusion	23 (17.6)
Structural allograft	68 (51.9)
PEEK cage	27 (20.6)
Titanium cage	22 (16.8)
Ceramic cage	11 (8.4)
Zero-profile cage	3 (2.3)

Values are presented as mean ± standard deviation or number (%).
ACDF, anterior cervical discectomy and fusion; PEEK, polyetheretherketone.

(47.3%) had a history of smoking, and 27 patients (20.6%) had a diagnosis of osteopenia. There were 41 one-level fusions (31.3%), 67 two-level fusions (51.1%), and 23 three-level fusions (17.6%). The majority of fusions (n = 68, 51.9%) were performed with a structural allograft. There were also 27 PEEK cages (20.6%), 22 titanium cages (16.8%), 11 ceramic cages (8.4%), and 3 zero-profile spacers (2.3%; 2 PEEK and 1 allograft) which were considered separately (Table 1, Supplementary Tables 1 and 2).

Pearson correlation testing showed that segmental subsidence was significantly negatively correlated with segmental lordosis change (r = -0.154, p = 0.016) (Fig. 2). Segmental subsidence was also positively correlated with C2–7 lordosis change (r = 0.015, p = 0.811) and cSVA change (r = 0.057, p = 0.376) and negatively correlated with total fused lordosis change (r = -0.055, p = 0.393) but these correlations were not significant. No significant correlations were found between total fused subsidence and C2–7 lordosis change (r = 0.026, p = 0.767) (Fig. 3), cSVA change (r = 0.019, p = 0.832), or total fused lordosis change (r = 0.066, p = 0.456) (Table 2, Supplementary Table 3).

After controlling for characteristics of the patient and fusion, multivariate analysis found that segmental subsidence was significantly negatively associated with segmental lordosis change (beta = -3.78; 95% CI, -7.15 to -0.42; p = 0.028). Although not significant, segmental subsidence was positively associated with cSVA change (beta = 0.45; 95% CI, -0.52 to 1.43; p = 0.358) and C2–7 lordosis change (beta = 0.91; 95% CI, -4.58 to 6.41; p = 0.743) and negatively associated with total fused lordosis change (beta = -3.30; 95% CI, -8.19 to 1.59; p = 0.185). The multivariate model

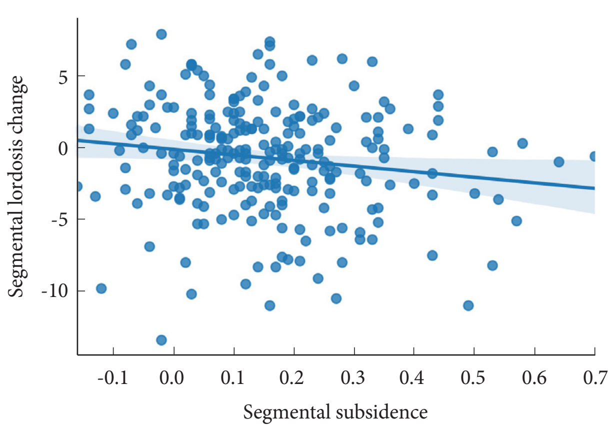

Fig. 2. Scatter plot of segmental subsidence and segmental lordosis change with fitted regression line.

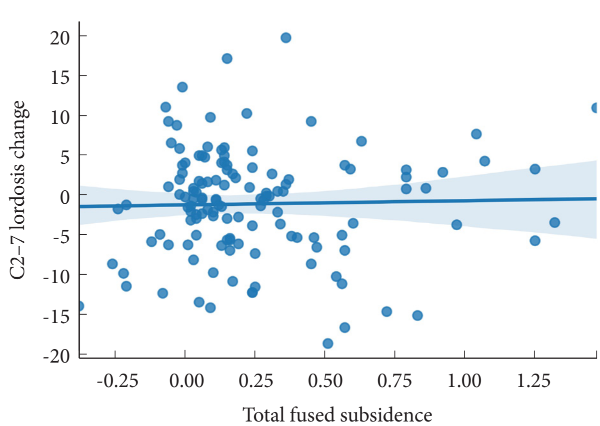

Fig. 3. Scatter plot of fused subsidence and C2–7 lordosis change with fitted regression line.

Table 2. Pearson correlation matrix with segmental and total fused subsidence from immediate postoperative radiograph to final follow-up radiograph

Variable	Pearson r	p-value
Segmental subsidence (n = 244)		
Segmental lordosis change	-0.154	0.016*
C2–7 lordosis change	0.015	0.811
cSVA change	0.057	0.376
Total fused lordosis change	-0.055	0.393
Total fused subsidence (n = 131)		
C2–7 lordosis change	0.026	0.767
cSVA change	0.019	0.832
Total fused lordosis change	-0.066	0.456

cSVA, cervical sagittal vertical alignment.
*p < 0.05, statistically significant differences.

Table 3. Linear regression results with segmental and total fused subsidence as the predictor variables

Variable	Beta	95% CI	p-value
Segmental subsidence (n = 244)			
Segmental lordosis change	-3.78	-7.15 to -0.42	0.028*
C2–7 lordosis change	0.91	-4.58 to 6.41	0.743
cSVA change	0.45	-0.52 to 1.43	0.358
Total fused lordosis change	-3.30	-8.19 to 1.59	0.185
Total fused subsidence (n = 131)			
C2–7 lordosis change	2.99	-0.47 to 6.45	0.089
cSVA change	-0.21	-0.82 to 0.39	0.485
Total fused lordosis change	-0.28	-3.14 to 2.58	0.847

The segmental subsidence model controls for cage-to-body ratio, the level of the fusion, the position of the level with respect to the fusion, cage type, age, sex, smoking, and osteopenia. The total fused subsidence model controls for the number of levels, cage type, sex, age, smoking status, and osteopenia.
CI, confidence interval; cSVA, cervical sagittal vertical alignment.
*p < 0.05, statistically significant differences.

https://doi.org/10.14245/ns.2244750.375

for fused subsidence did not show any significant associations. However, there was a nonsignificant positive association with C2–7 lordosis change (beta = 2.99; 95% CI, -0.47 to 6.45; p = 0.089) and negative association with both cSVA change (beta = -0.21; 95% CI, -0.82 to 0.39; p = 0.485) and total fused lordosis change (beta = -0.28; 95% CI, -3.14 to 2.58; p = 0.847) (Table 3).

DISCUSSION

Subsidence of intervertebral cages in the cervical spine have been associated with increased pain, worse clinical outcomes based on Odom's criteria, and higher nonunion rates in some studies while others show no correlation.[8] However, postoperative cervical sagittal alignment has been shown to lead to worse clinical outcomes after ACDF.[18] One study by Iyer et al.[19] found that preoperative C2–7 cSVA was an independent predictor of preoperative Neck Disability Index (NDI). Poor cervical alignment has also been associated with increased risk for adjacent segment disease.[20] Although the relationship between subsidence and clinical outcomes is unclear, further exploration of the relationship between subsidence and cervical sagittal alignment is necessary. In this study, our aim was to assess the effect of subsidence on cervical sagittal alignment after ACDF using lateral cervical radiographic measurements at the immediate postoperative and final follow-up time periods.

Although segmental lordosis measurements are specific to a single level in the cervical spine, some studies suggest that segmental kyphosis may correlate with cervical disc herniation and worse clinical outcomes.[11,21] Yang et al.[22] in their retrospective study of ACDF with allograft found that decreased segmental height was associated with decreased segmental lordosis. Another retrospective study published by Pinter et al.[23] found that segmental subsidence was associated with greater segmental lordosis loss in ACDF with allograft. Similarly, Lee et al.[4] found in their retrospective analysis of single-level ACDF that segmental kyphosis was greater in levels with significant cage subsidence. Our findings mirror the results of the aforementioned studies as we found that segmental subsidence was significantly correlated with decreased segmental lordosis. Therefore, there is growing evidence that cage subsidence leads to decreased segmental lordosis. While segmental subsidence leads to kyphotic changes at the segmental level, total subsidence may have a larger effect on global cervical alignment, especially for patients undergoing multilevel fusion procedures.

Previous studies have shown conflicting results regarding the impact of subsidence on regional and global lordosis. In their retrospective study, Yang et al.[22] found that segmental subsidence after ACDF was associated with decreased C2–7 lordosis. Segmental lordosis in their study was measured between the upper endplate of the superior vertebrae and lower endplate of the inferior vertebrae. Additionally, measurements were performed using computed tomography scans of the cervical spine. Conversely, Pinter et al.[23] reported that subsidence did not correlate with global cervical alignment as measured by C2–7 lordosis. In our study, neither segmental subsidence nor total subsidence was significantly correlated with any measures of regional or global cervical alignment. Differences between our study and others are likely due to variations in measurement methods, choice of imaging modality, patient population, and surgical technique.

We found a nonsignificant trend of total subsidence being correlated with C2–7 lordosis loss during the postoperative period which suggests that there may be compensatory mechanisms which allow the vertebral segments above and below the subsided levels to counteract segmental kyphotic changes. While such adjustments may maintain global lordosis in the short term, long-term global lordosis maintenance is still unknown. As our sample of segmental subsidence measurements was greater than our sample of total subsidence measurements, a larger sample size may show an association between total fused subsidence and C2–7 lordosis. Overall, our findings generally agree with previously published results that segmental subsidence does not affect total fused lordosis change, cSVA change, or C2–7 lordosis change at short-term follow-up after ACDF.

The effect of subsidence on lordosis may depend on variations of ACDF surgery including but not limited to cervical plating, revision following cervical disc arthroplasty, and multilevel fusion. Recent studies have compared clinical outcomes and subsidence rates between ACDF with and without cervical plating.[24] Lee et al.[25] found that subsidence rates were higher when cervical fusions were performed without plating. In our study, all fusions were performed with plating or with a zero-profile cage with integrated screws. It is important to consider that plating may affect both subsidence and changes to lordosis of the cervical spine. Furthermore, with the increasing use of cervical disc arthroplasty, revision ACDF procedures may show differing subsidence and lordosis restoration outcomes than index procedures.[26] Finally, although multilevel cervical fusion may increase the amount of subsidence, 3-level cervical fusion with plating has been shown to restore cervical lordosis in patients with degenerative spine diseases.[27]

While ACDF generally provides excellent fusion rates and patient outcomes, the effect of subsidence on nonunion and poor clinical outcomes is debated. Nonunion is a known complication of ACDF with a reported rate of about 5 percent.[28,29] A systematic review by Karikari et al.[3] found no significant differences in fusion rates based on cage subsidence. Since subsidence causes a compounding effect in multilevel cervical fusions, it is possible that cage subsidence in multilevel fusions increases the risk of nonunion.[30] However, further research is needed on this topic. Furthermore, while studies have found no correlation between subsidence of intervertebral cages and clinical outcomes,[3,5,7,8] one prospective randomized controlled trial performed by Kast et al.[9] in 2009 concluded that subsidence of PEEK cages significantly correlated with poorer patient outcomes as measured by Odom's criteria.

The current literature may not fully encompass the true effect of subsidence on clinical symptoms due to many studies reporting short-term follow-up less than 2 years. Some research suggests that segmental kyphosis allows for increased posterior disc space and opening of the intervertebral foraminal space which may explain why subsidence has not been correlated with clinical symptoms such as return or persistence of radiculopathy.[4] Since segmental kyphosis may increase stress on musculoskeletal segments adjacent to the fusion, clinical symptoms as a result of this additional stress could take longer to manifest. As more long-term studies are reported, it is possible that a relationship between cage subsidence and clinical symptoms will become clearer.

There are several limitations of this study that the authors would like to acknowledge. This is a retrospective study performed using data from a single institution, and as such there may be variations in patient population and surgical techniques that do not generalize to other populations. Although we attempted to control for variations in patient and surgery characteristics in our multivariate analysis, there may be additional variations in surgical techniques that we were unable to account for. Additionally, radiographic techniques are not standardized across clinics which introduces variability in posture and rotation of the patient with respect to the x-ray detector. Furthermore, there may be some "settling" of the cage immediately following surgery which we were unable to control for in this radiographic study. Finally, our radiographic findings may not extrapolate to clinical outcomes. In spite of these limitations, the strengths of our study examining the effect of subsidence on lordosis include using a large, heterogeneous database of ACDF patients with average follow-up greater than 1 year.

CONCLUSION

Herein we present our results which show a relationship between segmental cage subsidence following ACDF and segmental lordosis of the cervical spine after controlling for patient and surgical characteristics. Neither segmental subsidence nor total fused subsidence was significantly associated with changes in global lordosis or cervical sagittal alignment at a mean follow-up greater than 1 year. Radiographic analysis does provide some strengths in that it allows an objective assessment of alignment and morphological changes in the cervical spine. While a correlation between subsidence and clinical outcomes has not been proven, surgeons should attempt to minimize cage subsidence when possible as changes in segmental lordosis due to subsidence of cervical cages may lead to adjacent segment disease and long-term cervical misalignment.

NOTES

Supplementary Materials: Supplementary Tables 1-3 can be found via https://doi.org/10.14245/ns.2244750.375

Supplementary Table 1. Pearson correlation analysis with segmental and total fused subsidence excluding zero-profile cages

Supplementary Table 2. Pearson correlation analysis with segmental and total fused subsidence for zero profile cages only

Supplementary Table 3. Pearson correlation analysis with cage height and subsidence (n = 244)

Conflict of Interest: SKC: IP royalties from Globus Medical and paid consultant from Stryker: JSK: paid consultant from Stryker. Other authors have nothing to disclose.

Funding/Support: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution: Conceptualization: AD, UNI, JSK, SKC; Data curation: AD, CG, EAG, PJF Jr, AMR, UNI, BZ, JSK, SKC; Formal analysis: AD, CG; Methodology AD, CG, EAG, PJF Jr, AMR, UNI, BZ, PMAA, JM, JSK, SKC; Project administration: UNI, JSK, SKC; Visualization: AD, CG; Writing - original draft: AD, CG, EAG; Writing - review & editing: PJF Jr, AMR, UNI, BZ, PMAA, JM, JSK, SKC.

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REFERENCES

1. Yoon ST, Konopka JA, Wang JC, et al. ACDF graft selection by surgeons: survey of AOSpine members. Global Spine J 2017;7:410-6.
2. Marrache M, Bronheim R, Harris AB, et al. Synthetic cages associated with increased rates of revision surgery and higher costs compared to allograft in ACDF in the nonelderly patient. Neurospine 2020;17:896-901.
3. Karikari IO, Jain D, Owens TR, et al. Impact of subsidence on clinical outcomes and radiographic fusion rates in anterior cervical discectomy and fusion: a systematic review. J Spinal Disord Tech 2014;27:1-10.
4. Lee CH, Kim KJ, Hyun SJ, et al. Subsidence as of 12 months after single-level anterior cervical inter-body fusion. Is it related to clinical outcomes? Acta Neurochir (Wien) 2015;157: 1063-8.
5. Obermueller T, Wagner A, Kogler L, et al. Radiographic measurements of cervical alignment, fusion and subsidence after ACDF surgery and their impact on clinical outcome. Acta Neurochir (Wien) 2020;162:89-99.
6. Wu WJ, Jiang LS, Liang Y, et al. 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 2011;21:1374-82.
7. Milczynska WM, Ahmad A, Ahmed AI, et al. Does titanium cage subsidence affect clinical outcomes in ACDF surgery? A tertiary centre experience. Ann R Coll Surg Engl 2022 Aug 11. https://doi.org/10.1308/rcsann.2022.0050. [Epub].
8. Noordhoek I, Koning MT, Jacobs WCH, et al. Incidence and clinical relevance of cage subsidence in anterior cervical discectomy and fusion: a systematic review. Acta Neurochir (Wien) 2018;160:873-80.
9. Kast E, Derakhshani S, Bothmann M, et al. Subsidence after anterior cervical inter-body fusion. A randomized prospective clinical trial. Neurosurg Rev 2009;32:207-14; discussion 214.
10. Lee YS, Kim YB, Park SW. Risk factors for postoperative subsidence of single-level anterior cervical discectomy and fusion: the significance of the preoperative cervical alignment. Spine (Phila Pa 1976) 2014;39:1280-7
11. Teo AQA, Thomas AC, Hey HWD. Sagittal alignment of the cervical spine: do we know enough for successful surgery? J Spine Surg 2020;6:124-35.
12. Alpayci M, Şenköy E, Delen V, et al. Decreased neck muscle strength in patients with the loss of cervical lordosis. Clin Biomech 2016;33:98-102.
13. Lee SE, Jahng TA, Kim HJ. Correlation between cervical lordosis and adjacent segment pathology after anterior cervical spinal surgery. Eur Spine J 2015;24:2899-909.
14. Gao K, Zhang J, Lai J, et al. Correlation between cervical lordosis and cervical disc herniation in young patients with neck pain. Medicine (Baltimore) 2019;98:e16545.
15. Takeshima T, Omokawa S, Takaoka T, et al. Sagittal alignment of cervical flexion and extension: lateral radiographic analysis. Spine 2002;27:E348.
16. Guo GM, Li J, Diao QX, et al. Cervical lordosis in asymptomatic individuals: a meta-analysis. J Orthop Surg Res 2018; 13:147.
17. Grob D, Frauenfelder H, Mannion AF. The association between cervical spine curvature and neck pain. Eur Spine J 2006;16:669-78.
18. Scheer JK, Tang JA, Smith JS, et al. Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine 2013;19:141-59.
19. Iyer S, Nemani VM, Nguyen J, et al. Impact of cervical sagittal alignment parameters on neck disability. Spine (Phila Pa 1976) 2016;41:371-7.
20. Park MS, Kelly MP, Lee DH, et al. Sagittal alignment as a predictor of clinical adjacent segment pathology requiring surgery after anterior cervical arthrodesis. Spine J 2014;14: 1228-34.
21. Hansen MA, Kim HJ, Van Alstyne EM, et al. Does postsurgical cervical deformity affect the risk of cervical adjacent segment pathology? A systematic review. Spine (Phila Pa 1976) 2012;37(22 Suppl):S75-84.
22. Yang JJ, Park S, Kim HJ, et al. Segmental height decrease adversely affects foraminal height and cervical lordosis, but not clinical outcome after anterior cervical discectomy and fusion using allografts. World Neurosurg 2021;154:e555-65.
23. Pinter ZW, Mikula A, Shirley M, et al. Allograft subsidence decreases postoperative segmental lordosis with minimal

effect on global alignment following ACDF. Global Spine J 2022;12:1723-30.
24. Lynch CP, Cha EDK, Patel MR, et al. Effects of anterior plating on achieving clinically meaningful improvement following single-level anterior cervical discectomy and fusion. Neurospine 2022;19:315-22.
25. Lee CH, Hyun SJ, Kim MJ, et al. Comparative analysis of 3 different construct systems for single-level anterior cervical discectomy and fusion: stand-alone cage, iliac graft plus plate augmentation, and cage plus plating. J Spinal Disord Tech 2013;26:112-8.
26. Joaquim AF, Lee NJ, Riew KD. Revision surgeries at the index level after cervical disc arthroplasty - a systematic review. Neurospine 2021;18:34-44.
27. Louie PK, Sexton AC, Bohl DD, et al. Rigid-plating and cortico-cancellous allograft are effective for 3-level anterior cervical discectomy and fusion: radiographic and clinical outcomes. Neurospine 2020;17:146-55.
28. Pirkle S, Kaskovich S, Cook DJ, et al. Cages in ACDF are associated with a higher nonunion rate than allograft: a stratified comparative analysis of 6130 patients. Spine (Phila Pa 1976) 2019;44:384-8.
29. Ren B, Gao W, An J, et al. Risk factors of cage nonunion after anterior cervical discectomy and fusion. Medicine (Baltimore) 2020;99:e19550.
30. Yang JJ, Yu CH, Chang BS, et al. Subsidence and nonunion after anterior cervical interbody fusion using a stand-alone polyetheretherketone (PEEK) cage. Clin Orthop Surg 2011;3:16-23.

 https://doi.org/10.14245/ns.2244750.375

Supplementary Table 1. Pearson correlation analysis with segmental and total fused subsidence excluding zero-profile cages

Variable	Pearson r	p-value
Segmental subsidence (n = 239)		
Segmental lordosis change	-0.158	0.015*
C2–7 lordosis change	0.011	0.864
cSVA change	0.059	0.364
Total fused lordosis change	-0.052	0.428
Total fused subsidence (n = 128)		
C2–7 lordosis change	0.002	0.982
cSVA change	0.016	0.862
Total fused lordosis change	-0.068	0.448

cSVA, cervical sagittal vertical alignment.
*$p < 0.05$, statistically significant differences.

Supplementary Table 2. Pearson correlation analysis with segmental and total fused subsidence for zero profile cages only

Variable	Pearson r	p-value
Segmental subsidence (n = 5)		
Segmental lordosis change	0.573	0.311
C2–7 lordosis change	0.142	0.820
cSVA change	-0.279	0.650
Total fused lordosis change	0.327	0.591
Total fused subsidence (n = 3)		
C2–7 lordosis change	0.999	0.033
cSVA change	0.374	0.756
Total fused lordosis change	0.149	0.905

cSVA, cervical sagittal vertical alignment.

https://doi.org/10.14245/ns.2244750.375

Supplementary Table 3. Pearson correlation analysis with cage height and subsidence (n = 244)

	Pearson r	p-value
Cage height × segmental subsidence	0.329	< 0.001*