

# Allograft Subsidence Decreases Postoperative Segmental Lordosis With Minimal Effect on Global Alignment Following ACDF

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## Abstract

**Study Design:** Retrospective cohort study.

**Objective:** Studies investigating the impact of interbody subsidence in ACDF suggest a correlation between subsidence and worse radiographic and patient-reported outcomes. The purpose of this study was to assess whether allograft subsidence assessed on CT is associated with worse cervical alignment.

**Methods:** We performed a retrospective review of a prospective cohort of patients undergoing 1 to 3 level ACDF. Cervical alignment was assessed on standing radiographs performed preoperatively, less than 2 months postoperatively, and greater than 6 months postoperatively. Allograft subsidence was assessed on CT scan performed at least 6 months postoperatively. Patients with at least 1 level demonstrating greater than 4mm of cage subsidence were classified as severe subsidence. Student's t-test was used to compare all means between groups.

**Results:** We identified 66 patients for inclusion, including 56 patients with non-severe subsidence and 10 patients with severe subsidence. For the entire cohort, there was a significant increase in C2-7 Lordosis ( $p = 0.005$ ) and Segmental Lordosis ( $p < 0.00001$ ) from preoperative to early postoperative. On comparison of severely and non-severely subsided levels, severely subsided levels demonstrated a significantly greater loss of segmental lordosis from early to mid-term follow-up than non-severely subsided levels (-4.89 versus -2.59 degrees,  $p < 0.0001$ ), manifesting as a significantly lower segmental lordosis at >6 months postoperative (0.54 versus 3.82 degrees,  $p < 0.00001$ ). There were no significant differences in global cervical alignment parameters between patients with severe and non-severe subsidence.

**Conclusions:** Severe subsidence is associated with a significant increase in loss of segmental lordosis, but has minimal effect on global cervical alignment parameters.

## Keywords

subsidence, cervical alignment, segmental lordosis, interbody, allograft

## Introduction

Interbody subsidence is defined as settling of the interbody into the adjacent vertebral bodies and is a well-documented complication of interbody utilization throughout the cervical and thoracolumbar spine.<sup>1-4</sup> Following anterior cervical discectomy and fusion (ACDF), reported rates of subsidence are between 19.3-42.5% with the use of a variety of different interbody devices.<sup>5-17</sup> Not only is subsidence highly prevalent, but it

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is also very clinically relevant, as multiple studies have demonstrated that interbody subsidence is associated with increased rates of pseudarthrosis and recurrence of preoperative symptoms.<sup>3,4,7,14</sup> To date, very few studies have investigated the impact of interbody subsidence on local and global cervical alignment following ACDF.

Multiple studies have demonstrated that insertion of an interbody device during ACDF leads to intervertebral distraction intraoperatively<sup>1,18-20</sup>; however, the literature pertaining to the impact of subsequent interbody subsidence on cervical alignment is fraught with contradictory evidence. Some studies have reported that subsidence has no effect on local or global cervical alignment,<sup>8,17</sup> while others have found subsidence to be associated with a significant decrease in segmental lordosis.<sup>5,14,21,22</sup> These differing results are likely attributable to variability in the methods used to measure subsidence.

Currently available studies have utilized lateral x-rays to assess subsidence indirectly based on measurement of disc space loss, vertebral height loss, or decreased segmental lordosis. Furthermore, plain radiographs have been shown to be insufficient when measuring variables of small magnitude like subsidence due to variability in magnification and rotation.<sup>23</sup> Due to these methodological flaws, the relationship between subsidence and postoperative cervical alignment remains unclear.

The purpose of the present study was to assess the relationship between interbody subsidence assessed directly on computed tomography (CT) scan and postoperative cervical alignment following ACDF. This is the first study to investigate this relationship using advanced imaging to precisely characterize graft subsidence. The secondary aim of this study was to determine whether preoperative or immediate postoperative cervical alignment plays a role in the development of severe subsidence.

**Table 1.** Demographics.

Variable	No-Moderate Subsidence (n = 56)	Severe Subsidence (n = 10)	P value
Age	54.6	57.4	0.423
Sex (Female)	25 (44.6%)	4 (40%)	0.533
Smoking	13 (23.2%)	3 (30%)	0.386
Diabetes	9 (7.1%)	1 (10%)	0.586
Chronic kidney disease	0 (0%)	0 (0%)	-
Chronic steroid use	1 (1.8%)	0 (0%)	0.394
Inflammatory Arthritis	2 (3.6%)	0 (0%)	0.349
Levels			
One Level	32 (57.1%)	3 (30%)	
Two Level	21 (37.5%)	4 (40%)	
Three Level	3 (5.4%)	3 (30%)	

## Methods

We performed a retrospective review of prospectively maintained medical records and imaging for patients undergoing 1 to 3 level ACDF with an allograft interbody and anterior plating at a single institution between the years 2011-2017. Patient demographics, pertinent comorbidities, and number of instrumented levels were determined and recorded (Table 1). We characterized subsidence of each inserted interbody by recording the magnitude and direction of interbody settling. Subsidence was determined by direct measurement of the distance from the end of the graft to the adjacent endplate on both sagittal (Figure 1A) and coronal (Figure 1B) cuts of a CT scan performed at least 6 months postoperatively. Previous studies have demonstrated that the majority of subsidence occurs



**Figure 1.** (A) Sagittal and (B) Coronal CT cuts demonstrating subsidence measurements in a representative patient.

within the first few months after surgery.<sup>1,14,24</sup> We then classified the subsidence of each interbody into the superior and inferior endplates individually, using the following previously established thresholds<sup>2</sup>: non-severely subsided if less than 4mm and severely subsided if greater than 4mm either superiorly or inferiorly.

Global cervical alignment parameters including C2 sagittal vertical axis (SVA), C2 slope, C2-7 lordosis, C1 to occiput distance, and T1 slope were assessed on lateral radiographs

performed preoperatively, within 2 months postoperatively, and at greater than 6 months postoperatively for the entire cohort (Table 2). Segmental lordosis was also assessed at each level of interbody insertion on lateral radiographs at these same time points. Statistical analysis was performed comparing preoperative and early postoperative (<2 months) cervical alignment parameters between patients who developed severe subsidence (>4mm) and those patients with non-severe subsidence (<4mm)(Table 3). Further analysis was then performed

**Table 2.** Global and Local Cervical Alignment Parameters for the Entire Cohort (N = 66).

Variable	Preoperative	Immediate Postop	>6 months Postop	Preop to Imm Postop P-value	Preop to >6mo Postop P-value
<b>C2 SVA</b>	31.3 (5-70)	33.3 (6.3-67.6)	32.18 (2.5-62.8)	0.405	0.701
<b>C2 Slope</b>	17.3 (-3.5-40.4)	16.7 (1.9-43.7)	15.81 (0-33.9)	0.665	0.271
<b>C2-7 Lordosis</b>	<b>11.4 (-10.6-32.8)</b>	<b>16.5 (-4.7-39.2)</b>	<b>14.09 (-1.5-33.9)</b>	<b>0.005</b>	<b>0.102</b>
<b>C1-Occiput Distance</b>	6.9 (0-15.4)	7.1 (0-14.1)	6.67 (0-19.3)	0.726	0.784
<b>T1 Slope</b>	29.9 (10.1-52.8)	32.3 (12.4-57)	29.64 (5-48.5)	0.202	0.901
<b>Segmental Lordosis</b>	1.7 (-5.7-14.7)	6.3 (1.4-14.4)	3.5 (-4.2-11.4)	P < 0.00001	P < 0.00001

**Table 3.** Global and Local Cervical Alignment Parameters Based on Subsidence (n = 66).

Variable	Non-severe Subsidence (n = 56)	Severe Subsidence (n = 10)	P value
<b>Average Subsidence</b>	1.8	3.28	0.006
<b>C2 SVA</b>			
Preoperative	31.8 (5-70)	28.5 (14.5-47.6)	0.378
<2mo Postoperative	33.95 (6.3-67.6)	29.63 (10.2-47)	0.312
Δ Preoperative to <2mo Postoperative	2.12 (-27-24.3)	1.18 (-10.5-18.4)	0.753
>6mo Postop	33.12 (8.1-62.8)	27.19 (2.5-48.1)	0.213
Δ <2mo to >6mo Postoperative	-0.83 (-22.3-31.6)	-2.44 (-18.6-13.6)	0.658
Δ Preoperative to >6mo Postoperative	1.29 (-19.3-17.2)	-1.26 (-12-13.3)	0.449
<b>C2 Slope</b>			
Preoperative	17.6 (-3.5-40.4)	15.5 (0-25.8)	0.405
<2mo Postoperative	17.1 (2.9-43.7)	14.39 (1.9-31.1)	0.336
Δ Preoperative to <2mo Postoperative	-0.53 (-15.2-14.8)	-1.08 (-9.9-15.5)	0.816
>6mo Postoperative	16.39 (0-33.9)	12.75 (0-20.9)	0.123
Δ <2mo to >6mo Postoperative	-0.73 (-15.5-19.9)	-1.64 (-14.6-6.9)	0.713
Δ Preoperative to >6mo Postoperative	-1.26 (-15.5-15.1)	-2.72 (-8.3-8.8)	0.484
<b>C2-7 Lordosis</b>			
Preoperative	11.72 (-10.6-32.8)	9.59 (-0.7-27.0)	0.565
<2mo Postoperative	16.7 (-4.7-39.2)	15.4 (4.1-25.4)	0.652
Δ Preoperative to <2mo Postoperative	4.95 (-12-23.8)	5.78 (-1.6-17.4)	0.712
>6mo Postoperative	14.33 (-1.5-33.9)	12.86 (4.7-31.4)	0.632
Δ <2mo to >6mo Postoperative	-2.34 (-18-18)	-2.51 (-9.3-6.2)	0.918
Δ Preoperative to >6mo Postoperative	2.61 (-13.1-18.6)	3.27 (-7-13.7)	0.762
<b>C1-Occiput</b>			
Preoperative	6.72 (0-15.4)	7.58 (4.3-10)	0.305
<2mo Postoperative	6.84 (0-14.1)	8.30 (5-12.4)	0.101
Δ Preoperative to <2mo Postoperative	0.12 (-4-7.6)	0.72 (-2.1-6.3)	0.482
>6mo Postoperative	6.46 (0-19.3)	7.83 (3.3-12.5)	0.21
Δ <2mo to >6mo Postoperative	-0.38 (-6.7-8.8)	-0.47 (-4.1-1.5)	0.889
Δ Preoperative to >6mo Postoperative	-0.27 (-5.4-7.4)	0.25 (-3.6-4.7)	0.529
<b>T1 Slope</b>			
Preoperative	30.25 (10.1-52.8)	27.82 (17.8-39.7)	0.373
<2mo Postoperative	32.89 (12.4-57)	29.83 (15.8-52.5)	0.432
Δ Preoperative to <2mo Postoperative	2.95 (-18.7-17.4)	2.01 (-8.1-12.8)	0.728
>6mo Postoperative	30.73 (12.6-48.5)	23.7 (5-34.7)	0.068
Δ <2mo to >6mo Postoperative	0.964 (-18.4-29.3)	-3.3 (-10.8-5.9)	0.095
Δ Preoperative to >6mo Postoperative	0.93 (-14.6-17.7)	-2.64 (-12.8-6.2)	0.261
<b>Segmental Lordosis (n = 103)</b>			
Preoperative	1.80 (-5-14.7)	0.78 (-5.7-5.9)	0.401
<2mo Postoperative	6.40 (1.4-14.4)	5.43 (2.8-8.0)	0.12
Δ Preoperative to <2mo Postoperative	4.60 (-5.4-15.1)	4.65 (-0.1-8.9)	0.965
>6mo Postoperative	3.82 (-4.2-10.8)	0.54 (-1.4-4.7)	<.00001
Δ <2mo to >6mo Postoperative	-2.59 (-9.4-0.6)	-4.89 (-6.4- -2.8)	<.0001
Δ Preoperative to >6mo Postoperative	2.02 (-7.8-10.8)	-0.24 (-5.4-4.3)	0.065

**Table 4.** Global and Local Cervical Alignment Parameters for Severely Subsided Patients (n = 10).

Variable	Preoperative	<2 months Postop	>6 months Postop	Preop to Immediate Postop P-value	Preop to >6mo Postop P-value
<b>C2 SVA</b>	28.45 (14.5-47.6)	29.63 (10.2-47)	27.19 (2.5-48.1)	0.812	0.814
<b>C2 Slope</b>	15.47 (0-25.8)	14.39 (1.9-31.1)	12.75 (0-20.9)	0.753	0.38
<b>C2-7 Lordosis</b>	9.59 (-0.7-27)	15.37 (4.1-25.4)	12.86 (4.7-31.4)	0.18	0.46
<b>C1-Occiput Distance</b>	7.58 (4.3-10)	8.3 (5-12.4)	7.83 (3.3-12.5)	0.46	0.822
<b>T1 Slope</b>	27.82 (17.8-39.7)	29.83 (15.8-52.5)	23.7 (5-34.7)	0.627	0.305
<b>Segmental Lordosis</b>	<b>0.78 (-5.7-5.9)</b>	<b>5.43 (1.6-8)</b>	<b>0.54 (-1.4-11.4)</b>	<b>0.002</b>	<b>0.85</b>

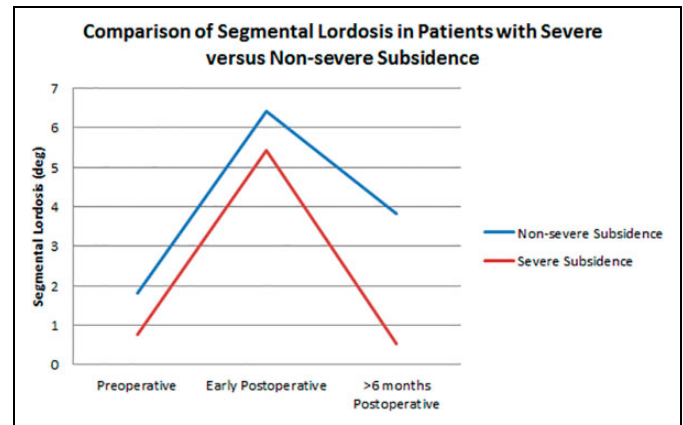
comparing early and mid-term (>6 months) cervical alignment parameters in patients with severe subsidence to those with non-severe subsidence to determine whether the development of severe subsidence led to worsening cervical alignment. Global and local cervical alignment parameters were then compared on preoperative, early postoperative, and mid-term postoperative x-rays for patients with severe subsidence (Table 4). Student's t-test was used to compare means between all groups, with a p-value < 0.05 used to determine statistical significance. Linear regression analysis was performed to assess for correlation between subsidence and C2 SVA and C2-7 lordosis.

## Results

We identified 66 patients (103 levels) for inclusion in this study. The cohort was 43.9% male. Of the 66 patients in the cohort, 56 patients (83 total operative levels) demonstrated non-severe subsidence, while 10 patients (20 total operative levels) demonstrated severe subsidence. These 10 patients each demonstrated 1 level of severe subsidence, for a total of 10 severely subsided allografts. There were no significant differences in demographic variables between patients with severe subsidence and those with non-severe subsidence. The average subsidence was 1.80mm in the non-severe subsidence group when considering all operative levels and 3.28mm in the severe subsidence group when considering all operative levels, including both the severely subsided and non-severely subsided levels (p = 0.006).

### Local Cervical Alignment

In the entire cohort, mean segmental lordosis at the index levels increased from 1.7 degrees (range -5.7-14.7) preoperatively to 6.3 degrees (range 1.4-14.4) in the early postoperative period (p < 0.00001), followed by a decrease to 3.5 degrees (range -4.2-11.4) at >6 months postoperative follow-up (p < 0.00001). In patients with severe subsidence, the segmental lordosis increased from 0.78 degrees (range -5.7-5.9) preoperatively to 5.43 degrees (range 2.8-8.0) postoperatively (p = 0.002); however, radiographic assessment at >6 months postoperatively demonstrated a significant reduction in segmental lordosis by 4.89 degrees (range -6.4 - -2.8) to a mean of 0.54 degrees (range -1.4-4.7) (p < 0.0001). There was no statistically significant difference between preoperative and mid-term segmental lordosis in patients with severe subsidence (p > 0.05).



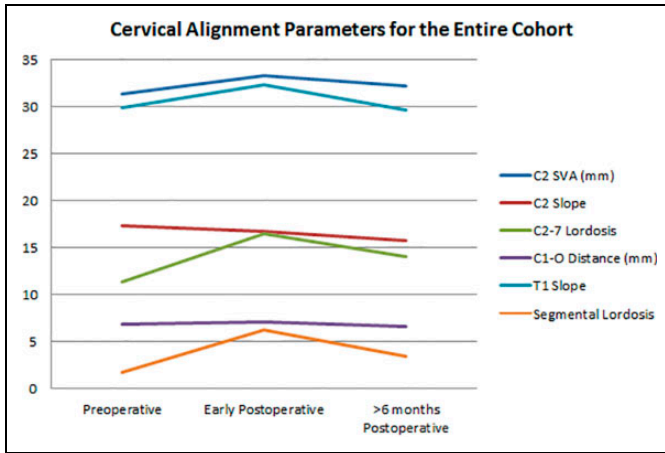
**Figure 2.** Graph demonstrating differences in segmental lordosis in patients with severe and non-severe subsidence at various time points.

In patients with non-severe subsidence, segmental lordosis increased from 1.80 degrees (range -5-14.7) preoperatively to 6.40 degrees (range 1.4-14.4) in the early postoperative period (p < 0.00001), with a subsequent decrease of 2.59 degrees (range -9.4 to 0.6) to 3.82 degrees (range -4.2-10.8) at >6 months postoperatively (p > 0.05), representing a statistically significant improvement from preoperative to >6 months postoperative (p < 0.00001).

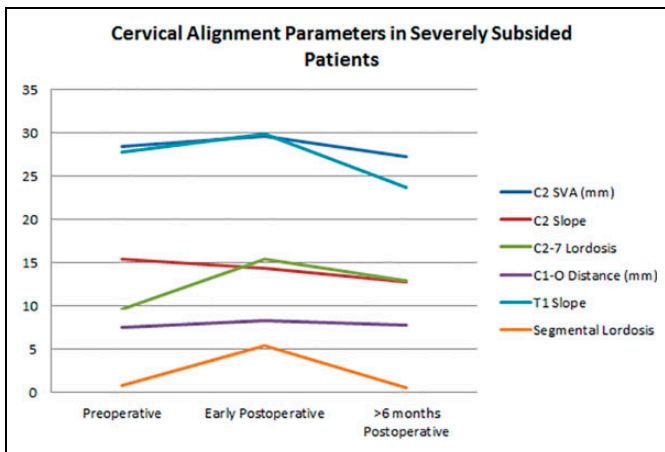
Analysis comparing levels with non-severe subsidence to levels with severe subsidence demonstrated no difference in preoperative segmental lordosis, <2 month postoperative segmental lordosis, or total increase in segmental lordosis from preoperative to early postoperative (p > 0.05). However, this analysis revealed a significant difference in loss of segmental lordosis between the non-severe and severe subsidence subgroups from early postoperative to mid-term postoperative follow-up (-2.59 versus -4.89 degrees, respectively) with an associated difference in segmental lordosis at >6 months postoperative (3.82 versus 0.54 degrees, respectively)(p < 0.0001); there was also a trend toward significantly worse segmental lordosis from preoperative to >6 months postoperative in the severe subsidence subgroup (p = 0.065)(Figure 2).

### Global Cervical Alignment

For the entire cohort, there was no significant difference in C2 SVA, C2 Slope, C1 to Occiput Distance, or T1 Slope at the



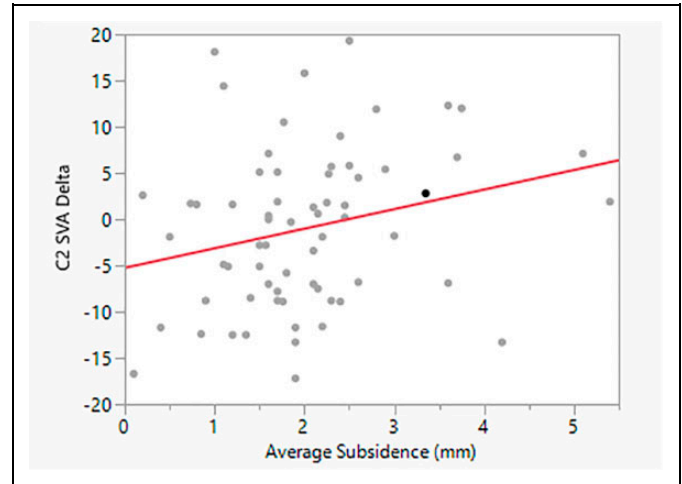
**Figure 3.** Graph demonstrating differences in global cervical alignment parameters in the entire cohort at various time points.



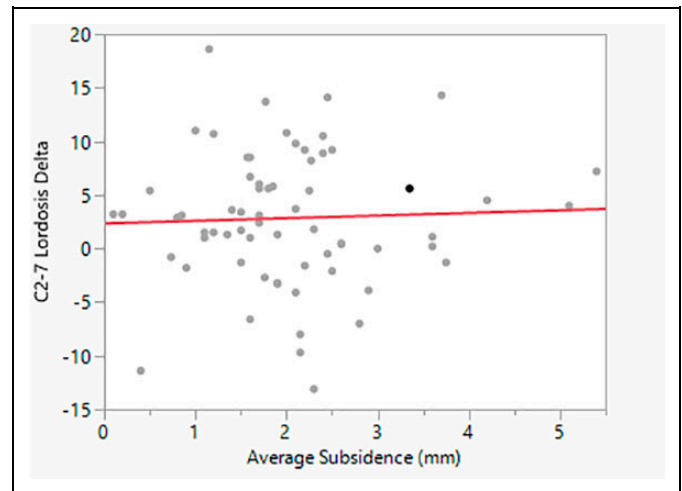
**Figure 4.** Graph demonstrating differences in global cervical alignment parameters in severely subsided patients at various time points.

preoperative, early postoperative, or mid-term postoperative time points ( $p > 0.05$ )(Figure 3). Allograft insertion resulted in a significant improvement in C2-7 Lordosis from a mean of 11.4 degrees (range -10.6-32.8) preoperative to a mean of 16.5 degrees (range -4.7-39.2) at <2 months postoperative ( $p = 0.005$ ). However, the mean C2-7 Lordosis decreased to 14.09 degrees (range -1.5-33.9) at mid-term follow-up, resulting in no significant difference in cervical lordosis from preoperative to >6 months postoperative ( $p = 0.102$ ). Of the 66 patients included in this study, 47 (74.6%) demonstrated a loss of C2-7 Lordosis from early to mid-term follow-up including 8 of 10 patients (80%) with severe subsidence.

On analysis comparing patients with non-severe to severe subsidence, there was no significant difference in C2 SVA, C2 Slope, C2-7 Lordosis, C1 to Occiput Distance, or T1 Slope at any time point based upon degree of subsidence ( $p > 0.05$ ). Changes in these parameters between time points were also not significantly different based upon degree of subsidence ( $p > 0.05$ ). Further subgroup analysis of only patients with severe



**Figure 5.** Linear regression analysis demonstrating poor correlation between subsidence and C2 SVA.



**Figure 6.** Linear regression analysis demonstrating poor correlation between subsidence and C2-7 Lordosis.

subsidence revealed no significant difference in any of these global cervical alignment parameters from preoperative to early postoperative or from preoperative to final assessment at >6 months postoperative ( $p > 0.05$ )(Figure 4). Linear regression analysis demonstrated no significant correlation between magnitude of subsidence and C2 SVA (Correlation coefficient 0.251,  $R^2$  0.063)(Figure 5) or C2-7 Lordosis (Correlation coefficient 0.040,  $R^2$  0.001)(Figure 6) at mid-term follow-up.

## Discussion

Sagittal cervical alignment has been shown to be significantly correlated with patient-reported outcomes and the development of adjacent segment disease. In a retrospective cross-sectional study of 90 patients preparing to undergo a variety of cervical spine operations, Iyer et al. found that increasing C2-7 SVA

and T1 Slope minus Cervical Lordosis (TS-CL) were independent predictors of high preoperative neck disability index (NDI) scores.<sup>25</sup> Gum et al. retrospectively reviewed 101 patients undergoing ACDF and found that postoperative cervical lordosis greater than 6 degrees was predictive of achievement of a minimally clinically important difference (MCID) in NDI.<sup>26</sup> Tang et al. investigated the relationship between sagittal cervical alignment parameters and patient-reported outcomes in 113 patients undergoing multilevel posterior cervical fusions, demonstrating a significant correlation between C2 SVA and NDI scores, with especially strong correlation when C2 SVA exceeded 40mm.<sup>27</sup> In a retrospective review of 102 ankylosing spondylitis patients, Lee et al. demonstrated a significant correlation between both loss of C2-7 lordosis and C2 SVA and worsening visual analog scores (VAS), NDI, and neck pain and disability (NPAD) scale scores.<sup>28</sup> Multiple studies of patients undergoing ACDF for various cervical spine disorders have demonstrated that postoperative segmental kyphotic alignment at the index level is associated with a significant increase in adjacent segment disease requiring surgery.<sup>29-31</sup> Considered together, these studies highlight the importance of maintaining improvements in sagittal cervical balance that are typically achieved during ACDF in order to prevent worsening patient-reported outcomes and the development of adjacent segment disease.

Though some interbody subsidence is anticipated following ACDF, its impact on cervical alignment has yet to be thoroughly investigated. In the earliest study investigating the relationship between subsidence and alignment, Bishop et al. reported a mean loss of segmental lordosis of 1.4 degrees following autograft insertion in ACDF, but did not investigate whether this loss was related to subsidence.<sup>21</sup> Yue et al. retrospectively reviewed 71 patients who underwent ACDF with allograft and anterior plating and found a significant increase in segmental lordosis from 0.6 degrees to 10.9 degrees in the early postoperative period followed by a decrease to 8.7 degrees at final review; however, the authors did not investigate whether loss of segmental lordosis was related to degree of subsidence.<sup>17</sup> Barsa et al. prospectively evaluated 100 patients (144 levels) undergoing ACDF with a single stand-alone titanium interbody, demonstrating that the 18 patients (19 levels) with subsidence experienced a mean loss of 8.7 degrees of segmental lordosis.<sup>5</sup> In their retrospective review of 73 patients who underwent ACDF with autologous iliac crest bone graft, Ghahreman et al. reported a mean loss of 2.7 degrees of segmental lordosis in the first 6 months after surgery and demonstrated that loss of segmental lordosis was significantly related to degree of subsidence.<sup>22</sup> In their retrospective review of 47 patients (63 levels) undergoing ACDF with titanium cages, Yamagata et al. reported that the change in segmental lordosis was significantly worse in the subsidence group (-4.1 degrees preoperative, -8.6 degrees at 1 year postoperative) than in the non-subsidence group (-4.8 degrees preoperative, -0.4 degrees at 1 year postoperative). As a result, C2-7 lordosis was also significantly worse in the subsidence group (9.6 preoperative, 5.1 at 1 year postoperative) than in the non-subsidence group

(7.6 preoperative, 9.4 at 1 year postoperative), and only patients in the non-subsidence group experienced improvement in local and global cervical alignment from preoperative to 1-year postoperative.<sup>14</sup> These studies seem to suggest that subsidence leads to loss of segmental lordosis, which may influence global cervical alignment; however, firm conclusions cannot be drawn due to the assessment of subsidence on lateral x-rays, which are inadequate for characterizing a variable of such small magnitude.

In the present study, subsidence was measured directly on CT scans to ensure accuracy, allowing for more reliable assessment of the relationship between subsidence and cervical alignment. Assessment of segmental lordosis in the entire cohort revealed a significant increase from 1.7 degrees preoperative to 6.3 degrees in the early postoperative period, demonstrating the efficacy of ACDF in producing desired changes in intervertebral lordosis ( $p < 0.00001$ ). However, much of this segmental lordosis was lost by 6 month follow-up with a mean segmental lordosis of 3.5 degrees on x-rays performed at greater than 6 months postoperatively ( $p < 0.00001$ ). Upon subgroup analysis, there was no significant difference in the preoperative or early postoperative segmental lordosis between the subsidence and non-subsidence groups, as both groups gained approximately 4.6 degrees of lordosis at the index level ( $p > 0.05$ ). From early postoperative (<2 months) to final review at >6 months postoperative, the severe subsidence group experienced significantly greater loss of segmental lordosis (-4.89 degrees) than the non-severe subsidence group (-2.59 degrees) ( $p < 0.0001$ ), resulting in significantly worse final alignment in the subsidence group (0.54 degrees) than the non-severe subsidence group (3.82 degrees) ( $p < 0.00001$ ). These results suggest that insertion of allograft interbodies will achieve approximately 4.6 degrees of lordotic correction intraoperatively with subsequent loss of 2.6 degrees of lordosis in patients without severe subsidence and complete loss of correction in patients with severe subsidence.

In our study, the impact of subsidence on global cervical alignment was minimal. For the entire cohort, there was no significant difference in C2 SVA, C2 Slope, C1 to Occiput Distance, or T1 Slope when compared on preoperative, early postoperative, and >6 months postoperative radiographs. Further analysis of these same parameters between the severe and non-severe subsidence subgroups revealed no significant differences at any time point. C2-7 Lordosis improved significantly from 11.38 degrees preoperatively to 16.46 degrees in the early postoperative period ( $p = 0.005$ ), followed by a decrease to 14.09 degrees at >6 months postoperatively. Given the nearly identical changes in segmental and C2-7 lordosis between preoperative to early postoperative and early postoperative to >6 months postoperative, the initial increase in global cervical lordosis was likely driven by the increase in segmental lordosis at the index level, while the subsequent loss of C2-7 lordosis was likely driven by loss of segmental lordosis at the index level. As a result, there was no significant difference in C2-7 lordosis when compared at the preoperative and >6 months postoperative time points ( $p = 0.102$ ). Our study

did not reveal a significant difference in C2-7 Lordosis at any time point between patients with severe and non-severe subsidence; further studies with larger cohorts of patients may be able to further characterize this relationship.

This study has several limitations. First, this study is retrospective in nature. Second, this study included only 66 patients and 103 levels. Third, our study measured subsidence on CT scans performed at least 6 months postoperatively, which means the timing of subsidence and the progression of subsidence cannot be determined. Likewise, if subsidence is a process that progresses beyond 6 months, our assessment of cervical alignment may underestimate the degree to which subsidence impacts cervical alignment. However, the time from surgery to the CT scan measured for analysis averaged 2.07 years for those with severe subsidence versus 2.11 years for those without severe subsidence ( $p > 0.05$ ). Prior work corroborates the assumption that the majority of subsidence occurs within the first few months after surgery.<sup>1,14,24</sup> Finally, while our study did not demonstrate a significant relationship between preoperative or early postoperative cervical alignment and the development of graft subsidence, conclusions regarding this relationship must be qualified due to the limited number of patients with significant cervical deformity. Further studies including patients with more severe cervical deformity should be performed to better characterize the effect of alignment on subsidence.

## Conclusions

Though multiple studies have demonstrated the influence of cervical alignment on patient-reported outcomes, very few studies have investigated the impact of interbody subsidence on cervical alignment. The few studies that have investigated this relationship did so utilizing unreliable subsidence measurements obtained from lateral x-rays. This is the first study to measure subsidence on CT scans and then compare the magnitude of subsidence to changes in cervical alignment in the perioperative period. Based upon this study, insertion of an allograft interbody results in approximately 4.6 degrees of segmental lordotic correction intraoperatively, followed by 50% loss of correction in patients with non-severe subsidence and 100% loss of correction in patients with severe subsidence. As a result, significant improvement in C2-7 Lordosis obtained intraoperatively is commonly lost at long-term follow up. Furthermore, neither preoperative nor early postoperative cervical alignment impacted the magnitude of subsidence, suggesting that worse cervical alignment may not be a risk factor for development of subsidence. Surgeons should consider addressing patient and intraoperative modifiable risk factors for subsidence in an effort to limit the deleterious effects of graft subsidence on local segmental lordosis and mitigate the ensuing increased risk of adjacent segment disease.


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## IRB

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## Informed Consent

Consent was obtained from all study participants prior to inclusion in this study.

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