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Clinical Studies

Early radiographic outcomes after anterior cervical discectomy and fusion with anatomic versus lordotic cages

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ABSTRACT

Background: Anterior cervical discectomy and fusion (ACDF) interbody implants are shaped anatomically, with a convex superior aspect, or lordotically, with an angle and flat surfaces. However, the effect of implant shape on cervical sagittal balance (CSB) is not well described.

Methods: Of the 192 cases reviewed from 2018 to 2019, 118 were included with matching pre- and postoperative imaging. Cases were categorized by interbody implant type (anatomic or lordotic) and number of levels fused (1-level, 2-level, etc.). SurgiMap was used to measure cervical lordosis (CL), C2–C7 sagittal vertical axis (cSVA), T1 slope (T1S), and T1S minus CL (T1S-CL) on pre- and postoperative imaging. Pre- and postoperative parameters were compared within and between each cohort. Change in CL (ΔCL), cSVA (ΔcSVA), and T1S-CL (ΔT1S-CL) were calculated as the difference between pre- and postoperative values and were compared accordingly (1) anatomic versus lordotic and (2) 1-level versus 2-level versus 3-level fusion.

Results: Thirty-nine (33.1%), 57 (48.3%), and 22 (18.6%) cases comprised the anatomic, lordotic, and mixed (anatomic and lordotic) groups, respectively. ACDFs improved CL and T1S-CL by 5.71° ($p<.001$) and 3.32° ($p<.01$), respectively. CL was improved in the lordotic (5.27°; $p<.01$) and anatomic (4.57°; $p<.01$) groups, while only the lordotic group demonstrated improvement in T1S-CL (3.4°; $p=.02$). There were no differences in ΔCL ($p=.70$), ΔcSVA ($p=.89$), or ΔT1S-CL ($p=.1$) between the groups. Two- and 3-level fusions improved CL by 7.48° ($p<.01$) and 9.62° ($p<.01$), and T1S-CL by 4.43° ($p<.01$) and 5.96° ($p<.01$), respectively.

Conclusions: Overall, ACDFs significantly improved CL and T1S-CL however, there were no differences in CSB correction between the anatomic and lordotic groups. Two- and 3-level fusions more effectively improved CL (vs. single-level) and T1S-CL (vs. 3-level). These results suggest that implants should continue to be personalized to the patient's anatomy, however, future research is needed to validate these findings and incorporate the effects of preoperative deformities.

Introduction

Anterior cervical discectomy and fusion (ACDF) is a procedure to treat cervical spine pathologies by anterior decompression of the disc space and interbody grafting and fusion [1]. Interbody implants are anatomic or lordotic in shape. Anatomic implants possess a convex superior aspect that aligns with the anatomy of the inferior cervical vertebral end plates [2]. Lordotic implants are angled and have flat surfaces.

Certain cervical spine parameters are becoming of increasing interest for the measurement of cervical spine curvature and balance. Cervical sagittal vertical axis (cSVA) represents the translation of the cervical spine in the sagittal plane. This parameter is measured by plumbline from the C2 centroid to the superior posterior portion of C7 [3]. Cervical lordosis (CL) describes the curvature of the cervical spine, and it supports important functions including eye movement, shock absorption with movement, and breathing. Cervical lordosis can be measured from C2 to C7 using Cobb's method, from spinal line summation using Ishihara's index, from C2 to C7 posteriorly using Harrison's method, and from the area under the curve [4]. T1 slope (T1S) dictates the amount of subaxial lordosis needed for the center of gravity of head to be balanced. This factor is a predictor of sagittal balance and physiological alignment [5]. T1S minus CL (T1S-CL) can be used as a marker of cervical deformity and as a target for correction.[6] These parameters have been well-studied with regard to number of levels [2,7–12], however,

FDA device/drug status: Not applicable.

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Table 1
Descriptive statistics of patient population and sub-groups.

	Lordotic	Anatomic	Mixed	Total	p-value
N **(%)**	57 (48.3)	39 (33.1)	22 (18.6)	118	
Age (years)*	61.1 (9.02)	56.6 (11)	58.4 (9.2)	59.1 (9.9)	.09
BMI (kg/m^2)*	30.4 (5.4)	30.4 (6.3)	31.1 (5.4)	30.5 (5.7)	.87
Female, n (%)	32 (56.1)	27 (69.2)	14 (63.6)	73 (61.9)	.42
Prior spine surgery, n (%)					
Cervical	26 (45.6)	11 (28.2)	2 (9.1)	39 (33.1)	***<.01***
Noncervical	20 (35.1)	12 (30.8)	5 (22.7)	37 (31.4)	.57
Preoperative, n (%)					
Loss of cervical lordosis	12 (21.4)	9 (23.1)	3 (13.6)	24 (20.5)	.66
Spondylolisthesis	24 (42.1)	22 (56.4)	9 (40.9)	55 (46.6)	.32
No. of levels fused, n (%)					**<.01**
1	25 (43.9)	19 (48.7)	-	44 (37.3)	
2	22 (38.6)	16 (41.0)	9 (40.9)	47 (39.8)	
3	10 (17.5)	4 (10.3)	12 (54.6)	26 (22.0)	
4	-	-	1 (4.6)	44 (37.3)	
Imaging modality, n (%)					.75
X-Ray	49 (86.0)	33 (84.6)	19 (86.4)	101 (85.6)	
MRI	5 (8.8)	5 (12.8)	3 (13.6)	13 (11.0)	
CT	3 (5.3)	1 (2.6)	-	4 (3.4)	
Months between imaging and operation†					
Preoperative	1.6 (1.2, 3.7)	2.3 (1.3, 4.2)	2.3 (0.9, 5.7)	2 (1.2, 4.2)	
Postoperative	2.7 (2.5, 4. 8)	2.8 (5.6, 2.3)	2.5 (2.4, 2.9)	2.6 (2.4, 3.7)	

CT, computer topography; MRI, magnetic resonance imaging.
* Mean (SD).
† Median (I.Q.R.).

the effects of anatomic or lordotic implants on these parameters is not well defined.

Few studies have demonstrated that while implant shape may not have a significant impact on regional cervical alignment [2,13], improper fitment maybe implicated in perioperative complications or worsening of deformity [14–16]. Therefore, research on the impact of different cage shapes on global cervical alignment is needed to provide evidence for surgical decision making. This study aimed to determine the effect of interbody shape on the correction of cervical spine parameters and whether there are any differences between anatomic and lordotic implants and the number of levels fused.

Materials and methods

Patient population

We performed a retrospective cohort study of all adult patients (greater than 18 years of age) who underwent an ACDF surgery between January 1st, 2018, to December 31st, 2019, by a single neurosurgeon, MCO. Case logs were used to identify eligible cases. Approval by the institutional review board was obtained prior to patient enrollment and performing study procedures.

Initially, 192 consecutive cases were considered eligible. MCO confirmed preoperative diagnoses, comorbid deformities, and surgeries performed on each patient. Hospital records were reviewed for pre- and postoperative lateral plain radiographs (X-ray), computer-topography (CT), or magnetic-resonance imaging (MRI) of the cervical spine. Patients without matching pre- and postoperative imaging modalities or adequate visualization of the vertebrae of interest were immediately excluded (n=74). These data were missing at random due to loss to follow up, inability to download imaging files from medical records for analyses, or inadequate visualization of the patients first thoracic vertebral body. A total of 118 cases with matching pre- and postoperative imaging of any modality were included in the final study group. Of these, 101 cases with pre- and postoperative X-rays were included in the cervical spine parameter analyses.

For the included patients, hospital records were further reviewed for age in years, sex, body mass index (BMI) kg/m^2, previous spine surgeries, and revision surgeries. Further, each operative report was reviewed for the number of levels fused, implant brand, implant size, and implant type (anatomic or lordotic), plate and screw sizes, and any complications associated with the operation. Detailed data of the patient population and cohort groups are in Table 1.

Surgical technique

The surgical indication for each operation, number of levels fused, and type of cage to be implanted was at the sole discretion of MCO, which involved the individualized evaluation of presenting symptoms and perioperative imaging. The presence of myelopathy and/or radiculopathy were the primary indications for surgery and while, patients may have presented with a cervical spine deformity, no deformity classifications were made at preoperative evaluation as the necessary parameters were measured retrospectively. However, obvious deformity (ie, hyper-kyphosis) associated with neck pain and/or radiculopathy/myelopathy was considered sufficient indication.

Regarding implant choice, if the inferior endplate of the superior level being fused maintained a normal physiological concave curvature, an anatomic implant with a convex superior aspect was used, as seen in Fig. 1A before surgery, and Fig. 1B, following surgery. If the endplates of the levels being fused were not amenable to the curvature of the anatomic interbody implant, a lordotic implant was used, as seen in Fig. 1C, before surgery, and Fig. 1D, following surgery. An example of both PEEK interbody implants (Castle-Loc-C, Aegis Spine, Englewood, CO) implant can be found in Supplementary Fig. 1.

Data collection and radiographic parameters

For each case, pre- and postoperative imaging was uploaded to SurgiMap software (2.3.2.1, Nemaris; New York, NY) for the measurement of CL, cervical-sagittal vertical axis (cSVA), T1 slope (T1S) and T1S minus cervical lordosis (T1S-CL). Cervical lordosis was measured using the C2–C7 Cobb angle; cSVA was measured via a plumbline from the center of C2 to the posterior superior endplate of C7; T1S was measured as the angle between a horizontal line and the superior endplate of T1; T1S minus CL was calculated by subtracting CL from T1S. Measurements were performed by MCO, who was nonblinded. SurgiMap was used to improve reproducibility and standardization of measurements obtained. A sample of the methods used for these measurements are demonstrated in Fig. 2. Change in CL (ΔCL), cSVA (ΔcSVA), and T1S-CL (ΔT1S-CL)

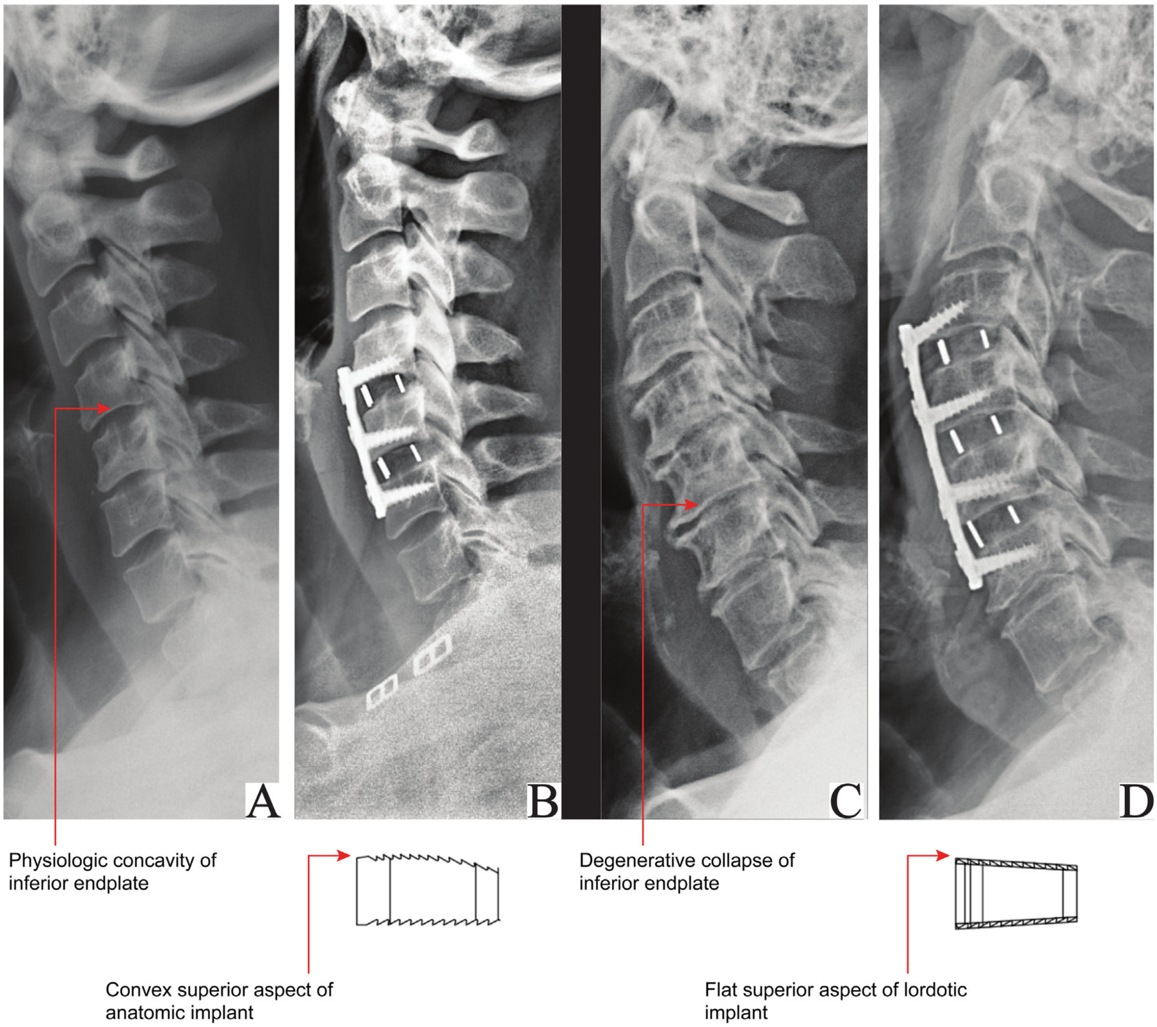

Fig. 1. Plain radiographs of sample patients demonstrating the different morphologies of the vertebral body that determined the interbody shape utilized for the ACDF operation. (A) Preoperative plain radiograph demonstrating the physiological convexity of the inferior endplates, C4 and C5, best suited for an Anatomic cage. (B) Postoperative plain radiograph in the same patient in (A) following a 2-level ACDF with Anatomic cages. (C) Preoperative plain radiograph demonstrating the collapse of the inferior endplates of C3, C4, and C5, best suited for a Lordotic cage. (D) Postoperative plain radiograph in the same patient in (C) following a 3-level ACDF with Lordotic cages.

were calculated as the postoperative values minus the preoperative values.

The normal degree of cervical lordosis is not well-defined and variable in literature with differences seen in asymptomatic individuals based on age and method of measurement [4,5,17,17–20]. For example, Guo et al. [4] performed a meta-analysis on studies reporting cervical lordosis in asymptomatic individuals and reported a mean of 12.57° (95% CI 6.59, 18.84). Generally, negative values represent a lordosis and positive values, kyphosis. Therefore, we defined loss of cervical lordosis as a CL>0°.

Statistical analysis

Statistical analysis was performed using Stata 17.0 (StataCorp, College Station, TX) by a blinded third-party statistician. Significance cutoff was defined as $p<.05$ for all tests. We initially analyzed the pre- and postoperative data for the entire cohort using paired *t* test for parametric and Wilcoxon ranked-sum test for nonparametric continuous data. Subsequently, we evaluated the individual cohorts: anatomic-only fusions, lordotic-only fusions, 1-level fusions, 2-level fusions, and 3-level fusions. Within the entire cohort and each sub-cohort, we evaluated the differences between pre- and postoperative parameters. Following, the pre- and postoperative parameters as well as the change in each of the parameters were compared accordingly, (1) anatomic versus lordotic and (2) 1-level versus 2-level versus 3-level fusions. The between group differences of parametric data were analyzed using independent samples *t* test or 1-way ANOVA for more than 2 groups. Wilcoxon test and Kruskal–Wallis were used for nonparametric data. Tukey's honestly significant differences (HSD) post-hoc test was used to evaluate the specific pairwise comparisons, if the initial test was significant. Categorical data was analyzed using chi-square analysis.

In addition, we constructed univariate and multivariable linear regression models to identify any potential confounding variables associated with the effects seen in the multilevel to single-level fusion comparisons. First, a univariate analysis was used to evaluate the effect of number of levels on ΔCL, followed by 2 multivariate models with plate length and their interaction. Interaction terms were considered significant if their coefficient demonstrated statistical significance and the *R-squared* value of the model increased with their addition.

Categorical data is reported as Number and percentage (%). All continuous data are reported using mean and standard deviation (SD), if parametric, or median and interquartile range (IQR), if

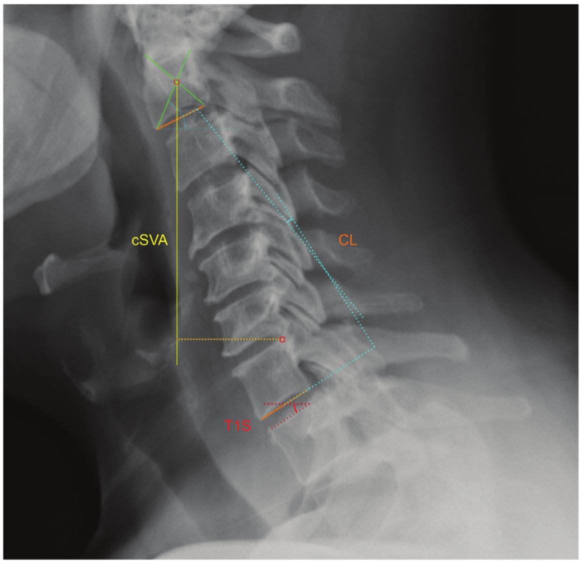

Fig. 2. Lateral view plain radiograph of cervical spine demonstrating method of measurements taken. Cervical Lordosis (CL) measured using the Cobb method (blue line). Cervical sagittal vertical axis (cSVA) measured using a plumbline from the center of C2 to the posterior superior endplate of C7 (yellow line). Slope of T1 (T1S) measured as the angle between a horizontal line and the super endplate of T1 (red line).

nonparametric, unless otherwise stated. The focus of these analyses was to evaluate the changes in these radiographic parameters following the ACDF operations and to compare these differences based on type of interbody implant used and number of levels fused.

Results

Patient population

A total of 118 cases (mean [SD] age, 59.11 [9.86] years; 73 [61.9%] female; mean [SD] BMI, 30.54 [5.67] kg/m^2) met the inclusion criteria. 101 (85.6%) cases used plain radiographs, 13 (11%) used MRI, and 4 (3.4%) used CT imaging. The median duration from preoperative imaging to surgery was 2.04 (IQR, 0.03, 34.27) months. The median duration from surgery to postoperative imaging was 2.63 (IQR, 0.46, 29.44) months. 39 (33.1%) cases of the entire cohort had a history of prior cervical spine surgery and 37 (31.4%) had a history of noncervical spine surgery. Preoperative loss of cervical lordosis, defined as a CL > 0°, was noted in 24 (20.5%) cases and spondylolisthesis in 55 (46.6%) cases (Table 1).

In the Lordotic group (n=57, 48.3%), there were 25 (43.9%) single-level fusions, 22 (38.6%) 2-level fusions, and 10 (17.5%) 3-level fusions. In the Anatomic group (n=39, 33.1%), there were 19 (48.7%) single-level fusions, 16 (41%) 2-level fusions, and 4 (10.3%) 3-level fusions. In the Mixed group (n=22, 18.6%), which involved multilevel operations using a mixture of anatomic and lordotic interbody implants, there were 9 (40.9%) 2-level fusions, 12 (54.6%) 3-level fusions, and 1 (4.6%) 4-level fusion. Table 1 details the descriptive statistics of the entire cohort and subgroups by interbody shape. For consistency with current literature and standard of care, the remainder of the study results and statistical analyses are reported on the cases involving only the usage of plain radiograph imaging (n=101, 85.6%).

Baseline and postoperative cervical spine parameters

Mean preoperative (Pr-OP) measurements of cSVA, CL, T1S, and T1S-CL, were as follows: 33.51±15.64 mm, −9.57°±13°, 30.10°±9.26°, and 20.65°±9.89°, respectively. Mean postoperative (P-OP) measures

Table 2
Within group differences of pre- and postoperative cervical spine parameters of entire cohort and sub-cohorts.

Parameter	Preop*	PostOp*	p-value†
Total			
cSVA, mm	33.51 (15.64)	33.34 (14.18)	.90
CL, degrees	-9.57 (13.60)	-15.27 (12.07)	<.01
T1S, degrees	30.0 (9.26)	32.63 (7.58)	***<.01***
T1S-CL, degrees	20.65 (9.89)	17.33 (8.28)	***<.01***
Lordotic			
cSVA, mm	34.48 (17.91)	33.99 (16.06)	.70
CL, degrees	-9.90 (13.50)	-15.17 (12.47)	***<.01***
T1S, degrees	30.43 (9.30)	32.92 (7.73)	***.01***
T1S-CL, degrees	20.34 (10.39)	16.94 (9.87)	***.02***
Anatomic			
cSVA, mm	32.75 (14.62)	33.32 (11.98)	.80
CL, degrees	-9.38 (15.46)	-13.94 (12.80)	***.01***
T1S, degrees	31.40 (9.92)	31.38 (8.39)	.91
T1S-CL, degrees	20.80 (9.80)	17.76 (5.92)	.08
One-Level			
cSVA, mm	35.43 (18.06)	35.62 (15.32)	.89
CL, degrees	-10.97 (15.03)	-12.43 (12.50)	.25
T1S, degrees	32.35 (8.37)	32.47 (6.94)	.92
T1S-CL, degrees	18.31 (10.88)	17.77 (9.74)	.70
Two-Levels			
cSVA, mm	31.10 (14.11)	28.56 (13.06)	.13
CL, degrees	-8.79 (12.26)	-16.27 (11.35)	***<.01***
T1S, degrees	27.93 (10.77)	31.28 (8.93)	***<.01***
T1S-CL, degrees	21.55 (9.83)	17.12 (7.13)	***<.01***
Three-Levels			
cSVA, mm	33.96 (14.14)	37.53 (12.56)	.03
CL, degrees	-8.65 (13.95)	-18.26 (12.29)	***<.01***
T1S, degrees	30.74 (8.43)	35.30 (6.22)	***<.01***
T1S-CL, degrees	25.09 (16.75)	16.75 (7.70)	***<.01***

* Mean (SD).
† Paired *t* test.

of cSVA, CL, T1S, and T1S-CL, were as follows: 33.34±14.18 mm, −15.27°±12.07°, 32.63°±7.58°, and 17.33°±8.28° (Table 2).

Overall effect of ACDF on cervical spine parameters

Overall, CL significantly improved by 5.71°±8.68° (p<.01). T1S-CL mismatch improved by 3.32°±7.13° (p<.01). Cervical sagittal vertical axis changed by −0.17±9.08 mm, however this was not a statistically significant change (p=.90) (Fig. 3).

Effect of interbody shape on cervical spine parameters

Lordotic

Within the lordotic group (n=49, 48.5%), significant improvement was seen in CL and T1S-CL mismatch by a mean of 5.27°±8.84° (p<.01) and 3.40°±7.69° (p=.02), respectively. Cervical sagittal vertical axis decreased by a mean of 0.49±8.71 mm, but there was no difference between Pr-OP and P-OP values (p=.70) (Table 2, Fig. 4).

Anatomic

Within the anatomic group (n=33, 32.7%), CL significantly improved by a mean of 4.57°±9.45° (p=.01). However, the decrease in T1-CL mismatch by 3.04°±7.50°, was not statistically significant (p=.08) (Table 2, Fig. 4).

Between anatomic and lordotic groups

Overall, Pr-OP values of cSVA (p=.65), CL (p=.88), and T1S-CL (p=.87) were not significantly different between the anatomic and lor-

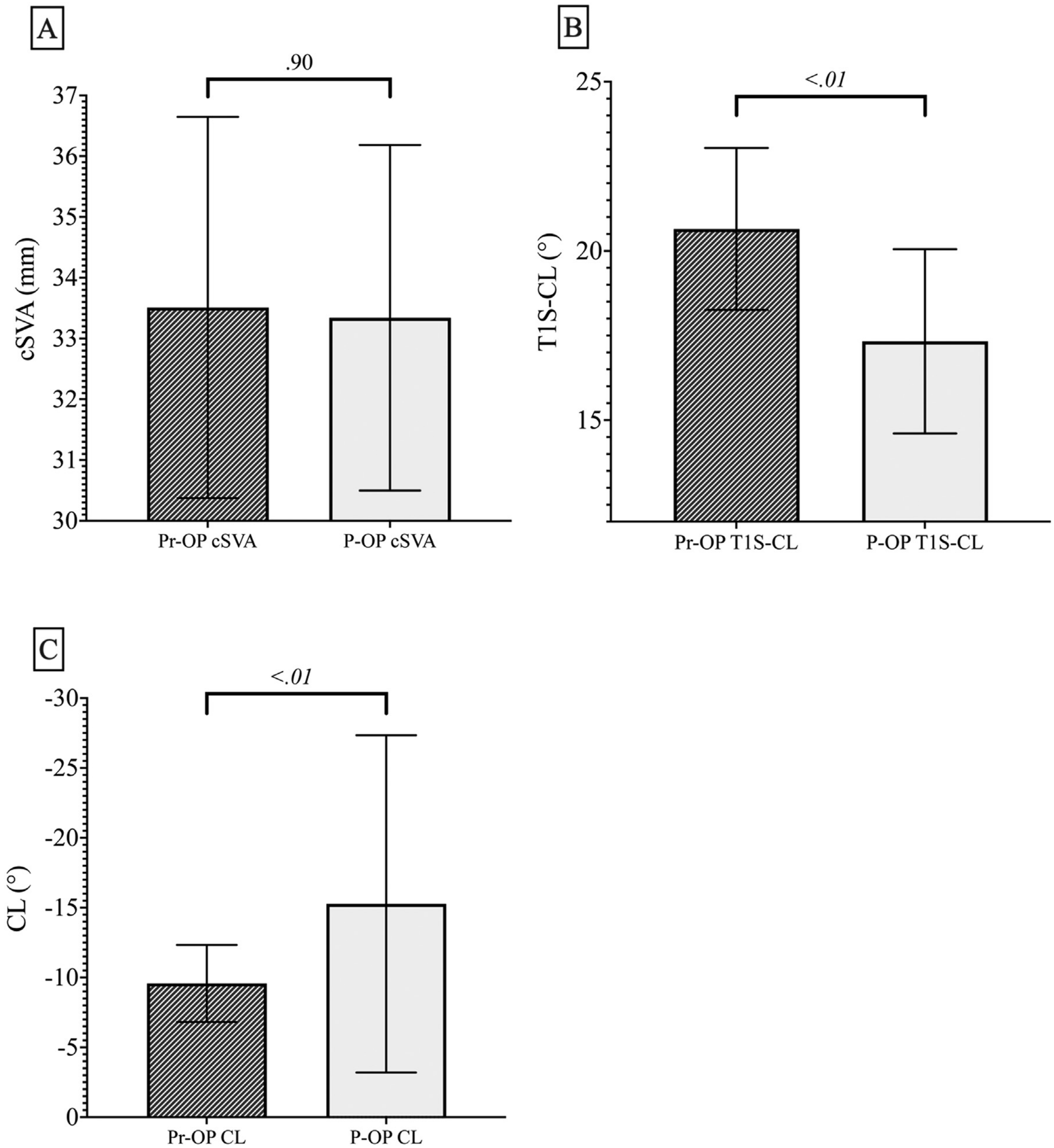

Fig. 3. Pre- and postoperative comparisons of cSVA (A), CL (B), and T1S-CL (C) in the entire cohort.

dotic groups. Similarly, P-OP cSVA (p=.85), CL (p=.67), T1S-CL (p=.73) were no different between the 2 groups and there was no significance noted between the groups in mean ΔcSVA (p=.66), ΔCL (p=.74), or ΔT1S-CL (p=.87) (Supplementary Table 1, Fig. 5).

Effect of number of levels fused on cervical spine parameters

Single level

In 1-level fusions (n=37, 36.6%) cSVA increased by 0.19±8.40 mm (p=.89), CL improved by 1.46°±7.40° (p=.25), and T1S-CL mismatch decreased by 0.53°±7.01° (*P*=.70). However, these changes were not statistically significant (Table 2).

Two levels

Overall, in cases with two-level fusions (n=40, 39.6%), statistically significant improvements were noted in CL by a mean of 7.48°±8.04° (p<.01) and T1S-CL mismatch by a mean of 5.96°±7.97° (p<.01). A reduction in cSVA by a mean of 2.54±9.91 mm was seen but lacked significance (p=.13) (Table 2).

Three levels

Overall, in cases with 3-level fusions (n=23, 22.8%), the group experienced a significant increase in mean cSVA of 3.57±7.50 mm (p<.03). Significant improvements were seen in mean CL by 9.62°±9.00 (p<.01) and T1S-CL improved by 5.96°±7.97° (p<.01), both of which were significant findings (Table 2).

Between groups

Mean ΔcSVA (p=.04), ΔCL (p<.01), and ΔT1S-CL (p=.03) were significantly different across all groups (Supplementary Table 2). Compared to 2-level fusions (−2.54±9.91 mm), 3 levels fusions demonstrated a significantly larger increase in cSVA (3.57±7.50 mm; p=.03)

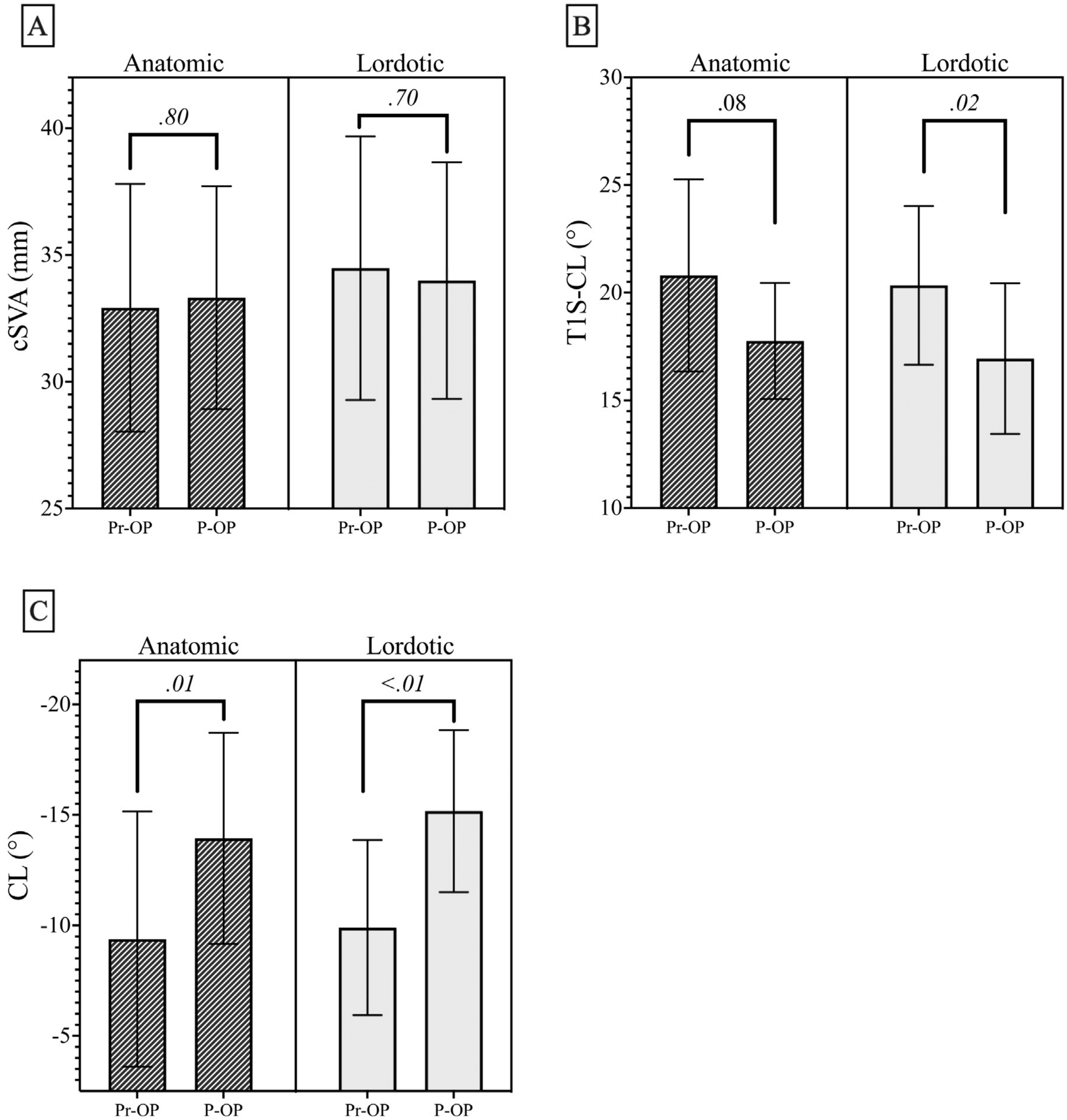

Fig. 4. Pre- and postoperative within-group comparisons of cSVA (A), CL (B), and T1S-CL (C) by Interbody Shape.

(Fig. 6). Additionally, compared to 1-level fusions (1.46°±7.40°), CL was improved more significantly by both 2-level (−7.48°±8.04; p<.01) and 3-level (9.62°±9°; p<.01) fusions (Fig. 6). Compared to 1-level fusions (−0.53°±7.01°), changes in T1S-CL were more significant in 3-level fusions (−5.96°±7.97; p=.04) (Fig. 6).

In an analysis of ΔCL, plate length was evaluated as a potential explanatory variable for these between group differences. In a univariate linear regression model with level of fusion alone (Supplementary Table 3, Model 1), both 2-level (*B* −5.92; 95% CI −10.1, −1.71; p<.01) and 3-level (*B* −8.40; 95% CI −14.0, −2.78; p<.01) fusions were associated with significant improvements in CL compared to 1-level fusions.

In a multivariate analysis with plate length and number of levels, neither variable was significantly associated with ΔCL (p>.05) (Supplementary Table 3, Model 2) In the final model, the interaction of plate length and number of levels was not significantly associated with the outcome (p>.05) (Supplementary Table 3, Model 3). Additionally, the models' *R-squared* values decreased approximately 3% to 5% with the addition of the plate length to the model (Supplementary Table 3.). Finally, stratified by level of fusion, plate length had no significant effect on ΔCL (p>.05) (Supplementary Table 4).

Discussion

ACDF implant shape on cervical spine parameters and outcomes

The evaluation of different types of implants in ACDF surgeries is an area of major research [21,22]. The impact of the implant shape on cervical spine curvature correction is uncertain. This study's main findings demonstrate an equivocal improvement in CL and T1S-CL mismatch between anatomic and lordotic implants.

To our knowledge, only two other clinical studies have evaluated the differences in regional balance as a function of implant shape [2,13]. Similar to our cages and results, Kim et al. [2] reported that while both cage types improved disc height and segmental angles, there was no significant difference in segmental angle correction, between curved and wedge-shaped cages in single-level ACDFs. Importantly, they noted that the degree of subsidence in the wedge-shaped group (2.43 mm)

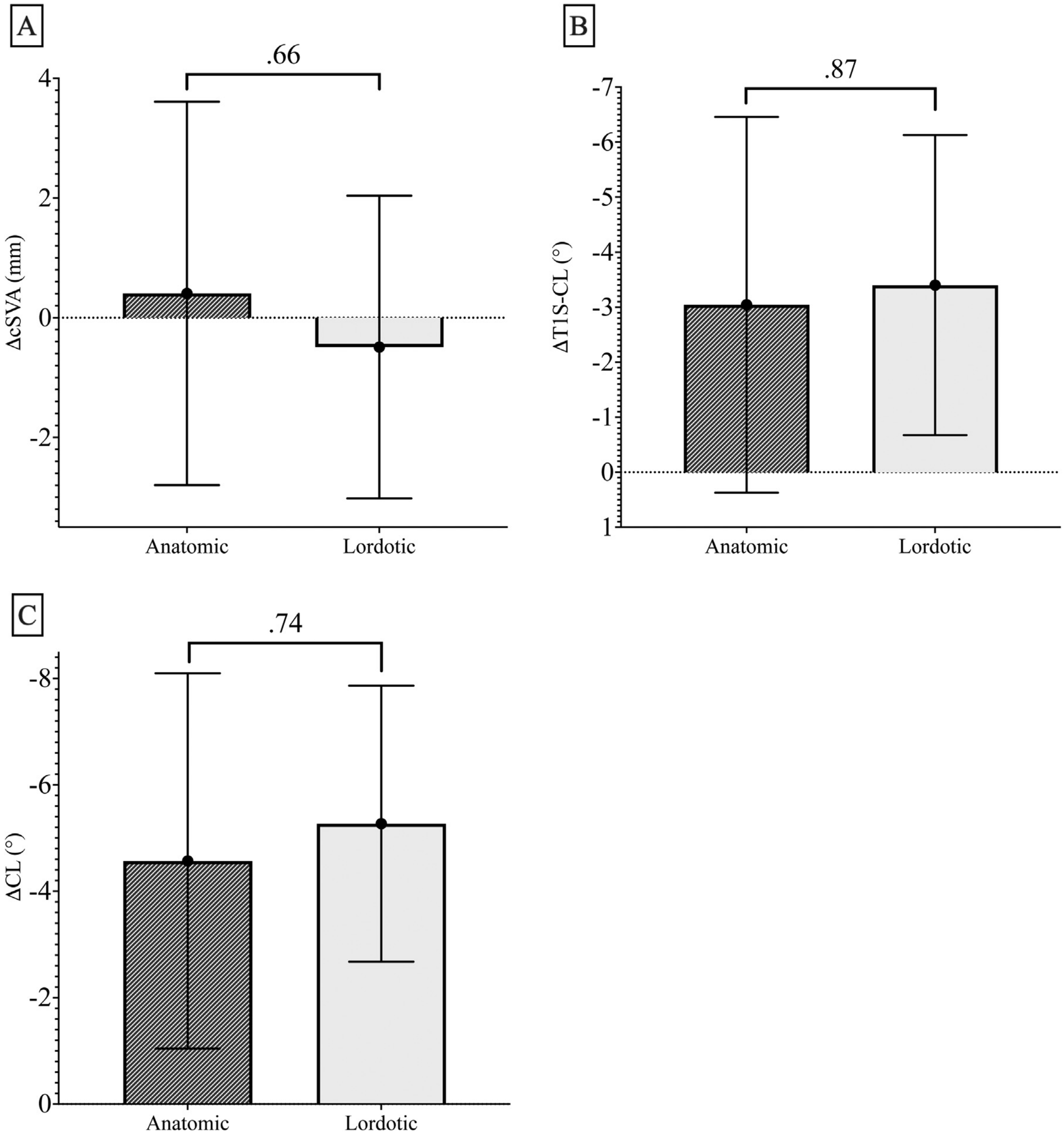

Fig. 5. Between-group comparisons of the mean values of ΔcSVA (A), ΔCL (B), and ΔT1S-CL (C) of the anatomic and lordotic groups.

was significantly greater than in the curved cage group (1.68 mm; p=.04) [2].

Villavicencio et al. [13] compared the effects of lordotic versus parallel cages on cervical and segmental sagittal alignment (CSA, SSA), as well as the Health-related Quality of Life measures (HRQOLs), Short Form-36 (SF-36), Neck Disability Index (NDI), and Visual Analogue Scale (VAS) for pain scores. They reported equivocal increases in CSA and SSA, improvements in quality of life, and that maintenance or correction of SSA was more important overall [13]. Similarly, we found that CL was increased overall in both groups however, only 2- and 3-level fusions demonstrated a significantly greater improvement when compared to 1-level fusions [13]. As such, individualized placement of implants may be most important in optimal outcomes.

Studies report that cage geometry and fitment may be implicated in complications such as subsidence [14,15], adjacent segment disease [16], and associated with worsening cervical deformity. Barsa et al. [14] found that an increased distance from the anterior rim of the superior endplate and a decreased implant surface area to upper-endplate surface area ratio were significantly associated with subsidence of the graft. They also reported a loss of segmental lordosis in all subsided cases with a mean change of 9°, highlighting the importance of appropriate graft utilization and placement [14]. In a cadaveric study by Zhang et al. [16], they found that cages conformed to the endplate, likened to our “anatomic” group, caused significantly less stress on both endplates and in all planes of motion, with a predilection for reduction at the inferior endplate involved. The stress produced was more uniformly distributed in comparison to the anterior predominance seen in the nonconformed group [16]. In addition, their model showed that, conformed cages, compared to wedge-shaped cages, were more stable in flexion-extension and, in axial rotation, equivocal to the control [16]. In fact, a recent fine-element analysis demonstrated that custom-fitted cages were associated with nearly half as much stress as standard commercial implants [23]. While custom fitted cages may not be financially feasible, this study highlights the importance of proper fitment. Thus, it appears that with

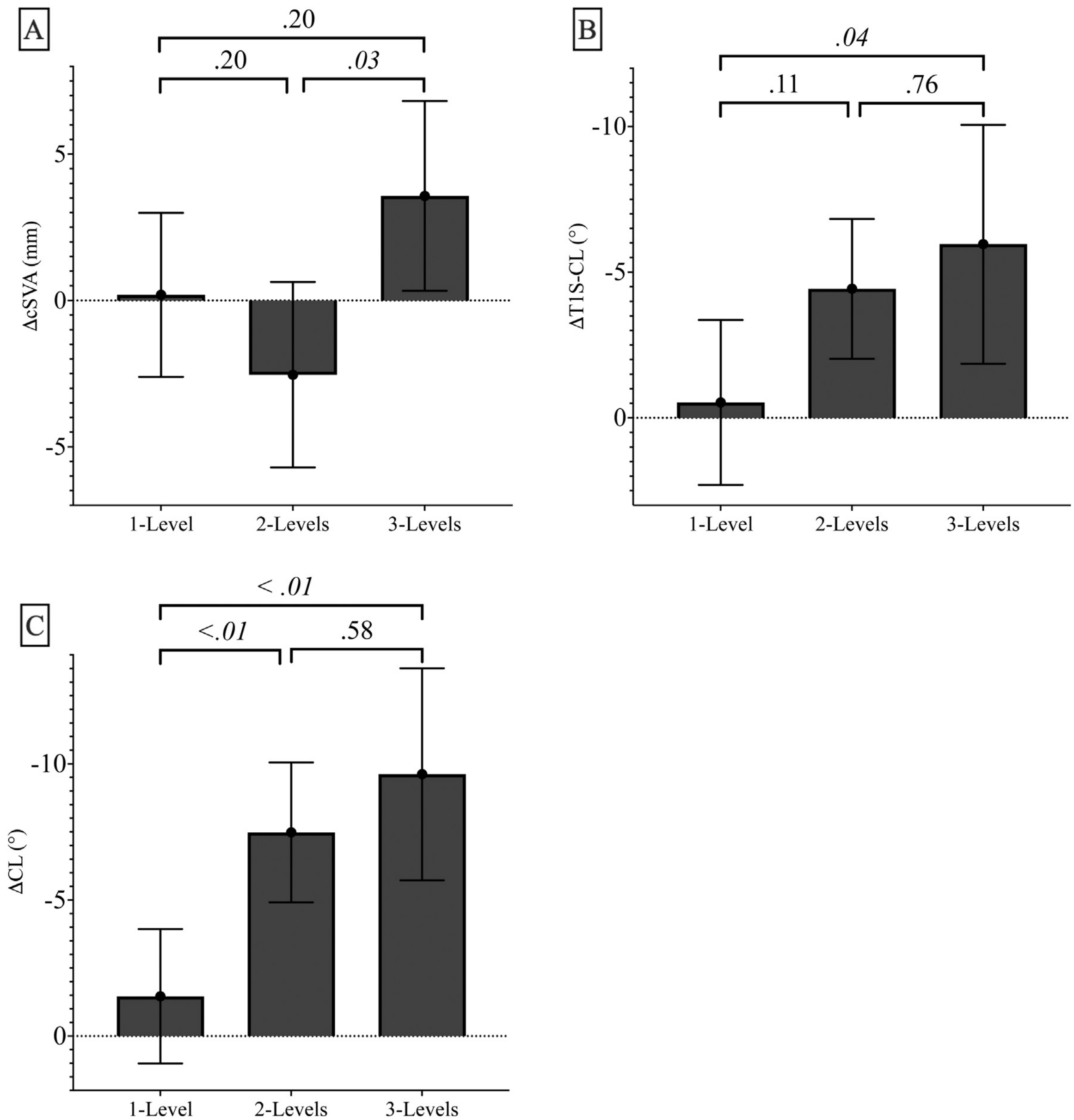

Fig. 6. Between-group comparisons of the mean values of ΔcSVA (A), ΔCL (B), and ΔT1S-CL (C) of the 1-level, 2-level, and 3-level fusion groups.

the most suitable fitment, cage-shape may be irrelevant in regard to the changes in these parameters [2,13].

Cervical spine parameters and outcomes

Cervical sagittal vertical axis has an uncertain correlation with postoperative quality of life and may vary based on which measure is used [24,25,25,26]. However, at extremes such as, 40.8 mm and 70.6 mm, it is significantly associated with moderate and severe disability on the NDI, respectively [25]. In our study cohort we did not see a significant change in cSVA over the entire cohort, nor were there any differences between the anatomic and lordotic groups. However, we found that 3-level fusions increased cSVA, which was significantly different from the decrease seen in 2-level fusions. Guo et al. [9] reported that the 2- and 3- level fusions demonstrated significant increases immediately following surgery, which later decreased at final follow-up [9] and did not differ between 1-, 2-, and 3-level fusions. Compared to ours, their cohort demonstrated greater lordosis and sagittal balance preoperatively [9], which may impact postoperative correction [27]. When we stratified our cohort by preoperative cSVA quartiles, ΔcSVA was significantly different across all groups ($p<.01$) and between all pairs ($p<.05$), except the 25th versus 50th percentile groups. Taken together, cSVA appears to lack a consistent pattern in the postoperative period and may not be clinically relevant except at extreme values. Moreover, complete correction of cSVA may not be necessary for clinical benefit as patients with residual imbalance following surgery still experience improvements in their neurological symptoms [27].

CL has demonstrated similar controversy with respect to HRQOLs. Studies have shown that this parameter has no correlation with changes in NDI, JOA, and VAS scores [28,29]. On the other hand, a “normal” preoperative CL, defined as all dorsal aspects of C3-6 anterior to a line connecting the C2 and C7 vertebral bodies, is associated with improvements in JOA scores [30], while the presence of cervical pain was highly associated with a CL of > 0° (OR 18, $p<.001$) [31]. In our cohort, CL was improved in the anatomic, lordotic, 2-level, and 3-level fusion groups as well as, in the entire cohort. We additionally identified that 2- and 3-level fusions corrected CL more significantly than 1-level fusions, similar to that seen in other studies [8]. In addition, our regression analyses involving the interaction of number of levels fused and plate length did not support plate length as a significant confounding variable on the differences seen in CL between the fusion level groups, which has not been demonstrated elsewhere.

We identified a significant increase in T1S in the lordotic, 2-level, and 3-level fusion groups, as well as in our entire cohort. Studies [32–34] have demonstrated that T1S is positively correlated with NDI scores following surgery, while others have reported no significant correlation with HRQOLs [25]. Therefore, it is unsure if an increase or decrease in this parameter results in favorable outcomes measured by HRQOLs, but an increase may be more protective from complications [35]. Passfall et al. [36] reported superior outcomes and decreased rates of distal junctional kyphosis and failure when T1S was below 45.5° and even more so, below 26° therefore, this value should be corrected to a certain degree.

T1S [34,37], CL [34,37], cervical tilt (CT) [34], and cSVA have been shown to be significantly lower in patients who develop adjacent-level ossification following surgery. While a high preoperative T1S is associated with greater lordotic alignment, these patients may experience greater kyphotic change following surgery [38,39]. Knott et al. [39] found that when T1S was greater than 25°, all participants had at least +10 cm of sagittal imbalance. Similarly, Alas et al. [40] reported that hyperkyphotic patients (mean preoperative CL 41.7°) who experienced significant postoperative reductions in their CL also had significant increases in T1S and thoracic kyphosis (TK) improvement, postoperatively. However, baseline hyperlordosis (mean preoperative CL −25.8°) without postoperative improvement, precluded T1 and TK improvements [40]. These patients also demonstrated persistent malalignment and a higher rate of proximal junctional kyphosis[40]. Clearly then, T1S is not only closely connected with CL but the thoracic and lumbar curvatures, as well.

Muzutani et al. [41] described 2 subsets of patients undergoing cervical kyphosis correction, head-balanced and trunk-balanced. The former, with a negative SVA_{C7}, hyperlordotic lumbar (LL>PI), and low T1S, experienced significant anterior movement of the C7PL and T1S with increases in thoracic curvature and decreases in LL [41]. The later, with a positive SVA_{C7}, normal PI–LL, normal T1S, and hyperlordotic cervical curvature, experienced decreases in SVA_{COG} and cSVA without changes in thoracic or lumbar curvature [41,42]. In our cohort, patients identified as hyperkyphotic, saw greater improvements in CL (−11.46° vs. 0.067) and T1S (3.98 vs. −1.08) compared to the hyperlordotic group. In this specific cohort, lordotic cages were more effective than anatomic cages at increasing T1S overall (5.75 vs. −0.62) and in 1-level fusions alone, whereas in the HL group, there was no difference between the cage shapes. Overall, hyperkyphotic patients may be more amenable to surgical intervention and sensitive to variations in surgical technique or cage shape. In addition, it appears that T1S and, subsequently, the operated segments may be restricted by the portion of the spine that is not being operated on.

Similar to findings elsewhere [32,43], T1S-CL mismatch was significantly reduced, overall and in almost all subgroups. As such, we found T1S-CL mismatch to be of increasing interest as a comprehensive assessment of overall alignment. T1S-CL mismatch has been shown to be positively correlated with cSVA [25,32,33] and NDI scores [25,32,33], as well as negatively correlated with CL [33]. A T1S-CL mismatch of 17°[6, 33] has been shown to correspond with a cSVA of 40mm, representing cervical deformity, and may help identify patients at risk for postoperative worsening of sagittal balance [44,45].

Consequently, it appears that preoperative deformities and sagittal balance influence the ability of an operation to alter sagittal balance. It should also be noted that several samples had a history of previous cervical surgery, which may limit the corrective ability of any future operations due to potential reductions in segmental mobility at those levels. Therefore, understanding a patient's global alignment and corrective potential is critical in predicting operative success and may aid in preoperative planning. Due to the uncertain correlation between these parameters and HRQOLs, this is especially important in those who are not obviously deformed nor experiencing apparent dysfunction. T1S and T1S-CL may be particularly useful in this regard as they have been demonstrated to correlate with global alignment and compensation. Therefore, in patients at the extremes of these parameters, we believe that further work up may be indicated.

From our study cohort, it appears that cage variation may be more impactful and applicable for this patient population, as the presence of thoracolumbar deformity or imbalance in conjunction with cervical deformities or malalignment, may dictate postoperative balance. In contrast, it is likely that cage shape does not affect these parameters, as supported by our findings, and that interbody type utilization should continue to be determined individually. However, further research is needed to solidify these relationships. Future research should focus on investigating the effect of interbody shape on various sub-groups based on preoperative balance.

This study is limited by its retrospective nature, lack of randomization, and single observer for the radiographic parameters measured. To mitigate bias in parameter measurements, we used SurgiMap for standardization of the techniques. While there appears to be significant debate regarding their correlation with HRQOLs, we could not correlate the radiographic findings with validated patient reported outcome measures. In addition, there may be confounding factors surrounding these parameters, which we did not include in our primary analyses. Regarding cervical lordosis, some may argue that the anterior plates used in ACDF operations may dictate postoperative curvature, particularly when increasing the number of levels fused. However, we believe we statistically corrected for these potential effects with a relatively balanced cohort, in terms of number of levels fused, the lack of statistical difference between the groups' pre- and postoperative measures, and the insignificant effect of plate length when included in the regression models for change in CL.

Moreover, a small subset of patients in this cohort received a combination of anatomic and lordotic implants, which we did not include in the primary analyses. As such, our results may not be applicable to similar patients. Future studies may improve upon this aspect by evaluating the effect of implant type on the segmental correction within the same patient, which would require a larger sample than in the current study.

Lastly, the surgical indication and implant shape were at the sole discretion of a single surgeon. Despite these limitations, the findings from this study are useful in that it is the first of its kind to evaluate the relationship between cage shape and global cervical spine curvature. Additional prospective, randomized trials with multiple surgeons are needed to validate these findings and mitigate the biases present in the current study. In addition, future studies should include patient reported outcomes as secondary measures, limit any confounding factors by excluding patients with prior spine surgery, and restrict statistical comparisons to homogenous cohorts (ie, those with the same number of levels and/or same levels fused).

Conclusions

This study aimed to evaluate the early postoperative changes in CL, cSVA, T1S, and T1S-CL mismatch as a function of interbody shape and the number of levels fused. In our study cohort, there were statistically significant improvements in CL and T1S-CL, while cSVA did not significantly change postoperatively. In addition, the anatomic and lordotic implant types both effectively restored CL and T1S-CL however, there was no significant difference between the 2 groups. Lastly, our results demonstrated that, as expected, 2- and 3-level fusions more effectively improved CL when compared to single-level fusions, whereas only 3-level fusions demonstrated more effective improvements in T1S-CL. In conclusion, the patient's vertebral body anatomy should dictate the type of implant used, rather than goals determined by these parameters, to minimize complications associated with improper fitment within the disc space.

Declarations of Competing Interest

One or more authors declare potential competing financial interests or personal relationships as specified on required ICMJE-NASSJ Disclosure Forms.

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Supplementary materials

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References

[1] Rhee JM, Ju KL. Anterior cervical discectomy and fusion. JBJS Essent Surg Tech 2016;6:e37.
[2] Kim HS, Song JS, Heo W, Cha JH, Rhee DY. Comparative study between a curved and a wedge PEEK cage for single-level anterior cervical discectomy and interbody fusion. Korean J Spine 2012;9:181–6.
[3] Scheer JK, Lau D, Smith JS, et al. Alignment, classification, clinical evaluation, and surgical treatment for adult cervical deformity: a complete guide. Neurosurgery 2021;88:864–83.
[4] Guo G-M, Li J, Diao Q-X, et al. Cervical lordosis in asymptomatic individuals: a meta-analysis. J Orthop Surg Res 2018;13:147.
[5] Ames CP, Blondel B, Scheer JK, et al. Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. Spine 2013;38:S149–60.
[6] Staub BN, Lafage R, Kim HJ, et al. Cervical mismatch: the normative value of T1 slope minus cervical lordosis and its ability to predict ideal cervical lordosis. J Neurosurg Spine 2018;30:31–7.
[7] Veeravagu A, Cole T, Jiang B, Ratliff JK. Revision rates and complication incidence in single- and multilevel anterior cervical discectomy and fusion procedures: an administrative database study. Spine J 2014;14:1125–31.
[8] Basques BA, Louie PK, Mormol J, et al. Multi- versus single-level anterior cervical discectomy and fusion: comparing sagittal alignment, early adjacent segment degeneration, and clinical outcomes. Eur Spine J 2018;27:2745–53.
[9] Guo S, Lu S, Kong C, Li X, Liu C. Comparison of clinical outcomes and sagittal alignment after different levels of anterior cervical discectomy and fusion in patients with cervical spondylotic myelopathy: from one-level to three-level. Spine (Phila Pa 1976) 2021;46:E153–60.
[10] Hyun S-J, Kim K-J, Jahng T-A, Kim H-J. Relationship Between T1 Slope and Cervical Alignment Following Multilevel Posterior Cervical Fusion Surgery. SPINE 2016;41:E396–402.
[11] Jeon S-I, Hyun S-J, Han S, et al. Relationship between cervical sagittal alignment and patient outcomes after anterior cervical fusion surgery involving 3 or more levels. World Neurosurgery 2018;113:e548–54.
[12] Shin JJ. Comparison of adjacent segment degeneration, cervical alignment, and clinical outcomes after one- and multilevel anterior cervical discectomy and fusion. Neurospine 2019;16:589–600.
[13] Villavicencio AT, Babuska JM, Ashton A, et al. Prospective, randomized, double-blind clinical study evaluating the correlation of clinical outcomes and cervical sagittal alignment. Neurosurgery 2011;68:1309–16.
[14] Barsa P, Suchomel P. Factors affecting sagittal malalignment due to cage subsidence in standalone cage assisted anterior cervical fusion. Eur Spine J 2007;16:1395–400.
[15] Wang Y, Lu T, He X, et al. Effect of dome-shaped titanium mesh cages on cervical endplate under cyclic loading: an in vitro biomechanics study. Med Sci Monit 2019;25:142–9.
[16] Zhang F, Xu HC, Yin B, et al. Can an endplate-conformed cervical cage provide a better biomechanical environment than a typical non-conformed cage?: A finite element model and cadaver study. Orthop Surg 2016;8:367–76.
[17] Tan LA, Riew KD, Traynelis VC. Cervical spine deformity-part 1: biomechanics, radiographic parameters, and classification. Neurosurgery 2017;81:197–203.
[18] Patel PD, Arutyunyan G, Plusch K, Vaccaro A, Vaccaro AR. A review of cervical spine alignment in the normal and degenerative spine. J Spine Surg 2020;6:106–23.
[19] Tang Y, Zhao W, Liu X, Yu M. Normative values of cervical sagittal alignment according to global spine balance: based on 126 asymptomatic Chinese young adults. Eur Spine J 2021;30:2427–33.
[20] Nasreddine MA, Pratali RDR, Barsotti CEG, Santos FPED, Oliveira CEASD. Radiographic alignment of cervical spine on a sample of asymptomatic subjects. Coluna/Columna 2017;16:13–16.
[21] Chong E, Pelletier MH, Mobbs RJ, Walsh WR. The design evolution of interbody cages in anterior cervical discectomy and fusion: a systematic review. BMC Musculoskelet Disord 2015;16:99.
[22] Huang H, Liu J, Wang L, Fan Y. A critical review on the biomechanical study of cervical interbody fusion cage. Med Novel Technol Devices 2021;11:100070.
[23] Sun B, Han Q, Sui F, et al. Biomechanical analysis of customized cage conforming to the endplate morphology in anterior cervical discectomy fusion: A finite element analysis. Heliyon 2023;9:e12923.
[24] Roguski M, Benzel EC, Curran JN, et al. Postoperative cervical sagittal imbalance negatively affects outcomes following surgery for cervical spondylotic myelopathy. Spine 2014;39:2070.
[25] Hyun SJ, Han S, Kim KJ, Jahng TA, Kim HJ. Assessment of T1 slope minus cervical lordosis and C2-7 sagittal vertical axis criteria of a cervical spine deformity classification system using long-term follow-up data after multilevel posterior cervical fusion surgery. Oper Neurosurg (Hagerstown) 2019;16:20–6.
[26] Tang JA, Scheer JK, Smith JS, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery 2012;71:662–9 discussion 669.
[27] Karamian BA, Mao JZ, Viola A, et al. Patients with preoperative cervical deformity experience similar clinical outcomes to those without deformity following 1–3 level anterior cervical decompression and fusion. Clin Spine Surg 2022;35:E466–72.
[28] Liang Y, Xu S, Yu G, Zhu Z, Liu H. Cervical spine alignment and clinical outcomes after multilevel anterior cervical decompression and fusion with or without plate. Medicine 2021;100:e26126.
[29] 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 Neurochirurgica 2020;162:89–99.
[30] Naderi S, Ozgen S, Pamir MN, Ozek MM, Erzen C. Cervical spondylotic myelopathy: surgical results and factors affecting prognosis. Neurosurgery 1998;43:43–50.
[31] McAviney J, Schulz D, Bock R, Harrison DE, Holland B. Determining the relationship between cervical lordosis and neck complaints. J Manipulative Physiol Ther 2005;28:187–93.
[32] Xu Y, Liu S, Wang F, Wu X. Cervical sagittal parameters were closely related to Neck Disability Index score after anterior cervical decompression and fusion. J Orthop Surg Res 2020;15:325.
[33] Lan Z, Huang Y, Xu W. Relationship between T1 slope minus C2-7 lordosis and cervical alignment parameters after adjacent 2-level anterior cervical diskectomy and fusion of lower cervical spine. World Neurosurg 2019;122:e1195–201.
[34] Liu W, Rong Y, Chen J, et al. Cervical sagittal alignment as a predictor of adjacent-level ossification development. J Pain Res 2018;11:1359–66.
[35] Suk K-S, Jimenez KA, Jo JH, et al. Anterior plate-screws and lower postoperative T1 slope affect cervical allospacer failures in multi-level ACDF surgery: anterior versus posterior fixation. Global Spine J 2023;13:89–96.
[36] Passfall L, Williamson TK, Krol O, et al. Do the newly proposed realignment targets for C2 and T1 slope bridge the gap between radiographic and clinical success in corrective surgery for adult cervical deformity. J Neurosurg 2022;37:368–75.
[37] Park MS, Kelly MP, Lee DH, Min WK, Rahman RK, Riew KD. Sagittal alignment as a predictor of clinical adjacent segment pathology requiring surgery after anterior cervical arthrodesis. Spine J 2014;14:1228–34.
[38] Kim T-H, Lee SY, Kim YC, Park MS, Kim SW. T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy. Spine 2013;38:E992–7.
[39] Knott PT, Mardjetko SM, Techy F. The use of the T1 sagittal angle in predicting overall sagittal balance of the spine. The Spine Journal 2010;10:994–8.
[40] Alas H, Passias PG, Diebo BG, et al. Cervical deformity patients with baseline hyperlordosis or hyperkyphosis differ in surgical treatment and radiographic outcomes. J Craniovertebr Junction Spine 2021;12:279–86.
[41] Mizutani J, Strom R, Abumi K, et al. How cervical reconstruction surgery affects global spinal alignment. Neurosurgery 2019;84:898–907.
[42] Kim CW, Hyun SJ, Kim KJ. Surgical impact on global sagittal alignment and health-related quality of life following cervical kyphosis correction surgery: systematic review. Neurospine 2020;17:497–504.
[43] Lee HJ, You ST, Sung JH, Kim IS, Hong JT. Analyzing the significance of T1 slope minus cervical lordosis in patients with anterior cervical discectomy and fusion surgery. J Korean Neurosurg Soc 2021;64:913–21.
[44] Protopsaltis T, Terran J, Soroceanu A, et al. T1 slope minus cervical lordosis (TS-CL), the cervical answer to PI-LL, defines cervical sagittal deformity in patients undergoing thoracolumbar osteotomy. Int J Spine Surg 2018;12:362–70.
[45] Alam I, Sharma R, Borkar SA, Goda R, Katiyar V, Kale SS. Factors predicting loss of cervical lordosis following cervical laminoplasty: a critical review. J Craniovertebr Junction Spine 2020;11:163–8.