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ORIGINAL ARTICLE

Multi- versus single-level anterior cervical discectomy and fusion: comparing sagittal alignment, early adjacent segment degeneration, and clinical outcomes

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Abstract

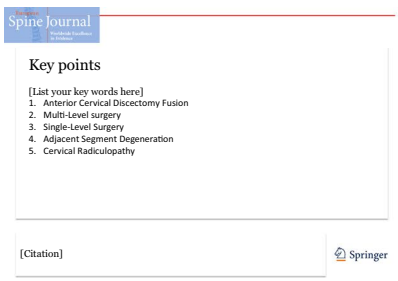
Purpose The purpose of this study was to compare the rates of adjacent segment degeneration (ASD), sagittal alignment parameters, and patient-reported outcomes in patients who underwent multi-level versus single-level anterior cervical discectomy and fusion (ACDF).

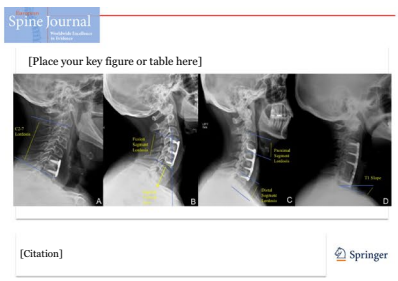
Methods A retrospective cohort analysis was performed on consecutive patients who underwent an ACDF. Pre- and post-operative radiographic assessment included ASD, change in C2–C7 lordosis, T1 angle, levels fused, sagittal vertical axis (SVA), fusion mass lordosis, proximal and distal adjacent segment lordosis. Patient-reported outcomes were obtained.

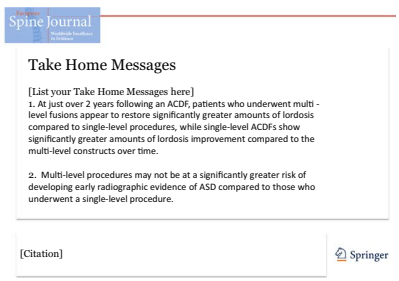
Results Of the 404 that underwent an ACDF with a minimum of 6 months of follow-up (average 28 months), there was no significant difference in the rate of radiographic ASD overall ($p = 0.479$) or in the proximal or distal adjacent segments on multivariate analysis. Secondarily, the multi-level fusions appear to restore significantly greater amounts of lordosis compared to single-level procedures ($p < 0.001$) and are able to maintain the corrected cervical lordosis and fusion segment lordosis over time. From the immediate post-operative period to final follow-up, the single-level ACDFs show continuing lordosis improvement ($p = 0.005$) that is significantly greater than that of the multi-level constructs. There were no significant differences between pre-operative, post-operative, or change in patient-reported outcomes.

Conclusions Two years following an ACDF, patients who underwent multi-level fusions appear to restore significantly greater amounts of lordosis compared to single-level procedures, while single-level ACDFs show significantly greater amounts of lordosis improvement over time. Multi-level procedures may not be at a significantly greater risk of developing early radiographic evidence of ASD compared to single-level procedure.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.







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Extended author information available on the last page of the article

Keywords Anterior cervical discectomy fusion · Multi-level surgery · Single-level surgery · Adjacent segment degeneration · Radiculopathy

Introduction

Anterior cervical discectomy and fusion (ACDF) is a well-established and successful treatment for cervical spondylotic myelopathy (CSM) and radiculopathy [1, 2]. Cervical spondylosis is a progressive and kyphogenic process that involves the bulging of disks, hypertrophy of the facet joint, thickening of soft tissues, and joint laxity [3]. It often results in compression of the ventral aspect of the spinal cord and nerve roots. As such, an anterior approach is commonly used to allow for direct visualization and decompression of the spinal cord while also restoring cervical lordosis.

While the anterior approach for treatment of single- and two-level cervical disease has been well described and multiple studies have illustrated favorable outcomes, multi-level cervical pathology still poses a clinical challenge [4, 5]. As the number of fused and decompressed levels increases, operation complexity and risks significantly elevate [6]. Multi-level ACDF has been associated with high morbidity of non-union due to multiple graft-host interfaces [5, 7]. Furthermore, some have proposed that fusion of cervical spinal segments leads to excessive stress on the unfused adjacent levels. This can instigate or exacerbate the pathologic process of adjacent segment degeneration (ASD), potentially necessitating surgical intervention [8–10]. Many factors have been assessed for contribution to the development of symptomatic ASD following ACDF, particularly the number of levels included in the fusion construct [11–16]. The thought is that there is compensation for lost cervical range of motion of fused segments by adjacent unfused segments, and as the number of fused levels increases, more motion is being translated through fewer unfused segments. There is also a concern that limited sagittal correction can be achieved over the long vertical segment in multi-level ACDF.

However, there is a lack of evidence in the literature that directly compares multi-level versus single- or two-level ACDF procedures. The present study was therefore designed to compare the rates of radiographic ASD, sagittal alignment parameters, and patient-reported outcomes in patients who underwent multi-level versus single- and two-level ACDF.

Materials and methods

Study design

Following institutional review board (IRB) approval, we retrospectively reviewed the records of consecutive patients who underwent ACDF between January 2008 and December 2015. All surgeries were performed by one of two senior orthopedic spine surgeons (HSA, EG) at a single quaternary referral medical center. Surgery indications included: radiculopathy, myelopathy, or myeloradiculopathy upon failure of conservative treatments. Patients were excluded from analysis if they were under 18 years of age at the time of surgery, had undergone a previous cervical fusion or concomitant posterior surgery, had postoperative follow-up less than 6 months, or had ACDF for cervical spine fracture or infection. Of the 467 patients originally identified, 404 were found to fulfill the above criteria (Fig. 1). For analysis, patients were divided into three groups based on the number of levels included in the fusion (one level, two levels, and three or four levels).

Surgical technique and postoperative follow-up

The surgical technique used by both surgeons was as follows. After the induction of general endotracheal anesthesia, the patients were placed in a supine position on a radiolucent OR table. A bump was placed between the scapulae, and Gardner–Wells tongs were placed with 15 lb of traction. A left-sided approach was utilized for all primary ACDF. A standard Smith–Robinson approach to the anterior cervical spine was performed. Discectomy was performed in a standard fashion. A laminar spreader was placed in the disk space to allow for distraction necessary to perform for aminotomies and place an interbody graft. Holes were burred

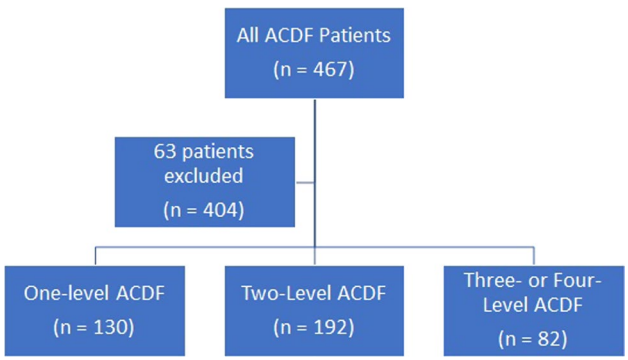

Fig. 1 Patient flowchart

into the endplates to allow for bleeding and the graft/endplate junction. After implants were trialed in the standard fashion, a fresh-frozen VG2 cortico-cancellous allograft was placed in the disk space and traction was removed. A rigid or semirigid plate was applied to the anterior cervical spine, and screws were then placed. Standard lordosis designed into each plate was used; no adaptation to plate lordosis was made. Closure of the platysma layer and sub-cutaneous tissue was performed with 3-0 Vicryl suture, and the skin was closed with 4-0 vicryl suture and Dermabond. Patients were then extubated at the conclusion of the procedure.

Postoperatively all patients were placed into a soft cervical collar and discharged home once they cleared physical and occupational therapy. AP and lateral cervical spine radiographs were taken at each postoperative visit.

Demographic and radiographic measurement analysis

Demographic information was collected for all patients that included: age, sex, body mass index, diabetes, smoking status, America society of Anesthesiologists (ASA) class, and type of plating (rigid vs. semirigid).

Several radiographic parameters were measured preoperatively, immediately postoperatively, and at the last follow-up (Fig. 2): C2–C7 lordosis, T1 angle, sagittal vertical axis (SVA), fusion mass lordosis, proximal and distal adjacent segment lordosis, height of the fusion mass, adjacent segment degeneration (ASD), and fusion. C2–C7 lordosis was measured using the Cobb angle between the inferior endplate of C2 to the inferior endplate of C7. Similarly, lordosis of the fusion mass was the Cobb angle between the inferior endplate of the superior vertebral body and the inferior endplate of caudal vertebral body encompassed into the fusion. The T1 slope is the angle created from a line tangential to the superior endplate of T1 and a horizontal line. The SVA was obtained through measuring the distance from the posterior–superior corner of C7 to a vertical line that bisected the C2 centroid. Proximal adjacent segment lordosis was the angle between the superior endplate of the vertebral body cephalad to the fusion mass (or proposed fusion mass) and the inferior endplate of the most cephalad vertebral body of the fusion mass. Similarly, distal adjacent segment lordosis was the angle between the inferior endplate of the vertebral body caudal to the fusion mass (or proposed fusion mass) and the superior endplate of the most caudal vertebral body of the fusion mass.

For this study, the primary outcome was radiographic ASD, which was determined by the presence of disk space narrowing > 50%, new or enlarged osteophytes, endplate sclerosis, and/or increased calcification of the anterior longitudinal ligament (ALL) as presented by previous published studies [17–19]. Fusion was deemed present if anterior and posterior bone bridging was present on plain radiographs, as is standard at our institution. Subsidence was measured by a decrease in intervertebral disk height of ≥ 2 mm from immediate postoperative radiographs to final follow-up radiographs.

Clinical outcome assessment

Evidence of clinical adjacent segment disease, defined as the radiographic signs of ASD with associated clinical symptoms such as radiculopathy or myelopathy attributable to the adjacent level, was collected as an outcome. Patient-reported outcomes were obtained in the form of Neck Disability Index (NDI) scores and Visual Analog Scale (VAS) scores for the neck and arm preoperatively

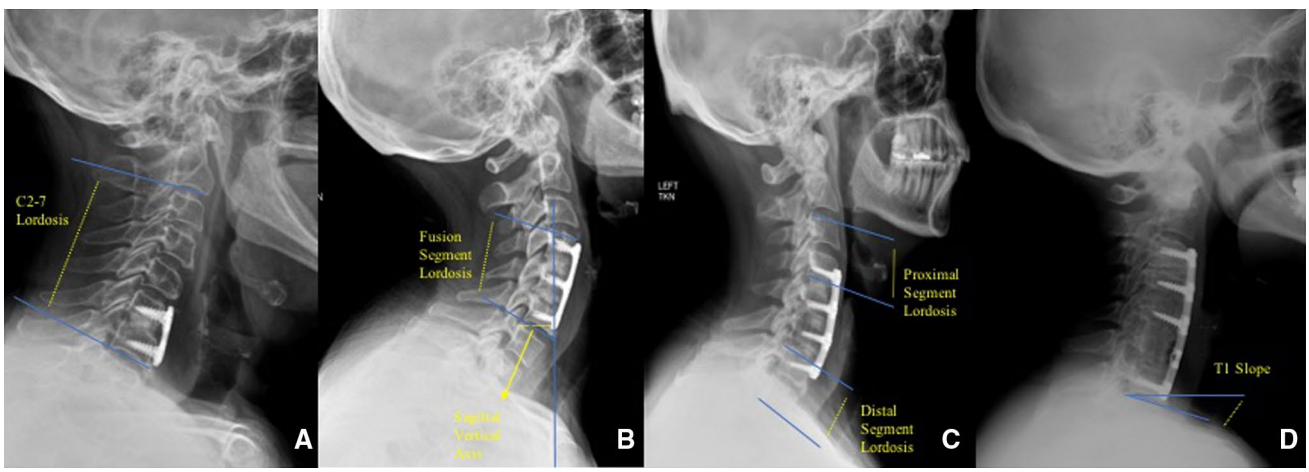

Fig. 2 Postoperative radiographs of C2–C7 lordosis in a one-level ACDF (**a**), fusion segment lordosis and sagittal vertical axis measurements in a two-level ACDF (**b**), proximal and distal segment lordosis measurements in a three-level ACDF (**c**), and T1 slope angle measured on a four-level ACDF (**d**)

and at the most recent follow-up. Charts were also reviewed for evidence of symptomatic pseudarthrosis and any reoperations in the cervical spine.

Statistical analysis

Analysis was conducted using Stata version 13.1 (StataCorp LP, College Station, TX). The level of significance was set at $p < 0.05$. Radiographic measurements were taken by two independent observers. Baseline patient characteristics were compared using Chi-squared analysis and independent sample t tests for categorical and continuous data, respectively. Bivariate and multivariate regressions were subsequently used to compare clinical outcomes between procedure groups. Multivariate analyses controlled for differences in baseline patient characteristics.

Results

A total of 404 patients that underwent ACDF with a minimum of 6-month follow-up (average 28 months) were included in this study. A total of 167 patients (41.4%) had at least 2 years of follow-up. Among all patients, 130 (32.2%) underwent a single-level procedure, 192 (47.5%) underwent a 2-level procedure, and 82 (20.3%) underwent a 3- or 4-level surgery (Table 1). Significant differences in age were found for each number of level category, with older patients generally having undergone ACDF at more levels ($p < 0.001$). Additionally, there was a higher rate of rigid plating for 3–4-level procedures compared to one and two levels ($p = 0.003$). No differences were found for patient sex, BMI, smoking, diabetes, or ASA class.

Multivariate analysis was subsequently performed to assess the association between number of levels and outcomes while controlling for differences in baseline

Table 1 Demographics

	One level	Two levels	3–4 Levels	All patients	*p* value
Overall	130	192	82	404	
Age	46.6 ± 11.9	50.2 ± 10.0	54.5 ± 10.2	49.9 ± 11.1	**< 0.001**
Female sex	47.3%	49.5%	53.7%	49.6%	0.665
BMI	28.4 ± 6.0	28.2 ± 6.1	30.5 ± 6.7	28.7 ± 6.3	0.014
Smoking	20.8%	20.8%	13.4%	19.3%	0.318
Diabetes	12.3%	10.9%	12.3%	11.7%	0.911
ASA ≥ 3	14.6%	19.3%	26.8%	19.3%	0.090
Rigid plating (vs. semirigid)	36.9%	29.7%	51.2%	36.4%	**0.003**

Bold represents statistical significance as designated by a *p* value < 0.05

ASA American Society of Anesthesiologists Physical Status Classification

Table 2 Comparison of ASD, reoperations, fusion, and subsidence (one-level ACDF used as reference)

	One level (%)	Two levels (%)	3–4 Levels (%)	All patients (%)	Two levels*		3–4 Levels[a]	
					OR[b]	*p* value	OR[b]	*p* value
Any ASD (%)	16.15	24.08	20.73	20.84	1.70	0.077	1.31	0.479
Proximal (%)	10.77	17.80	17.07	15.38	1.93	0.060	1.78	0.177
Distal (%)	6.92	11.52	10.98	9.93	1.77	0.179	1.39	0.522
Proximal and distal (%)	1.54	5.24	7.32	4.47	3.87	0.089	4.64	0.073
Clinically symptomatic (%)	10.0	5.8	12.2	8.4	0.6	0.240	1.3	0.536
Reoperations (%)	4.59	4.24	6.12	4.48	1.13	0.898	1.24	0.757
Fusion (%)	99.23	96.34	96.34	97.27	0.18	0.115	0.21	0.203
Subsidence (%)	4.62	6.28	9.76	6.45	1.34	0.578	2.58	0.124

Subsidence as measured by a decrease in intervertebral disk height of ≥ 2 mm from immediate postoperative radiographs to final follow-up radiographs

ASD radiographic evidence of adjacent segment degeneration

[a]One-level ACDF used as reference

[b]Odds ratio represents odds of ASD per one-unit increase in each sagittal parameter

demographics. No significant differences were found for development of radiographic ASD based on the number of levels fused (single-level 16.2%; 2-levels 24.1% $p=0.077$; 3–4 levels 20.73%, $p=0.479$, Table 2). Among patients who demonstrated radiographic evidence of ASD, 40.5% had clinical symptoms at the corresponding adjacent level. Clinical adjacent segment disease was not associated with the number of fusion levels on multivariate analysis. Reoperation rates were low in all groups (single-level 4.6%; 2-levels 4.2% $p=0.898$; 3–4 levels 6.1%, $p=0.757$) with no significant differences observed.

Multi-level fusions appeared to restore significantly greater amounts of lordosis compared to single-level procedures (single-level 1.2° ± 8.4°; 2-levels 2.9° ± 7.2° $p=0.025$; 3–4 levels 6.4 ± 8.5; $p<0.001$) and are able to maintain the corrected cervical lordosis and fusion segment lordosis over time (Table 3). Additionally, from the immediate postoperative period to final follow-up, the single-level ACDFs show continuing lordosis improvement (single-level 2.8° ± 5.0°; 2-levels 2.4° ± 5.5° $p=0.025$; 3–4 levels − 0.1 ± 5.1; $p=0.005$) that is significantly greater than that of the multi-level constructs (Table 4).

No significant differences were found between postoperative outcomes or changes in patient-reported outcomes among the three groups ($p>0.05$ for all, Table 5).

Discussion

Anterior cervical discectomy and fusion (ACDF) allows for direction decompression and resection of the entity causing pressure on the spinal cord. While multi-level cervical surgery presents a unique surgical challenge, this present study sought to use a large patient sample to illustrate comparable rates of radiographic ASD, sagittal alignment parameters, pseudarthrosis, and patient-reported outcomes in patients who underwent multi-level versus single- and two-level ACDF. We found that at an average of 2 years following ACDF, patients who underwent multi-level procedures may not be at a significantly greater risk of developing radiographic or clinical evidence of ASD compared to those who underwent a single-level procedure. Additionally, multi-level fusions appear to restore significantly greater amounts of lordosis compared to single-level procedures.

Table 3 Multivariate analysis for differences in sagittal parameters preoperatively and postoperatively

	One level	Two levels	3–4 Levels	All patients	Two levels[a]		3–4 Levels[a]	
					Beta	*p* value	Beta	*p* value
Preoperative								
Lordosis (°)	5.6 ± 12.3	4.3 ± 11.0	2.8 ± 11.2	4.4 ± 11.5	**− 3.1**	**0.021**	**− 5.5**	**0.001**
SVA (mm)	28.5 ± 10.9	26.2 ± 11.6	28.6 ± 10.8	27.4 ± 11.2	− 3.0	0.020	− 1.2	0.454
Fusion segment lordosis (°)	− 0.4 ± 5.5	0.3 ± 7.2	0.1 ± 9.6	0.0 ± 7.3	− 0.2	0.850	− 0.6	0.588
T1 slope (°)	27.3 ± 8.5	25.5 ± 8.0	23.9 ± 8.8	25.9 ± 8.4	**− 2.7**	**0.040**	**− 4.4**	**0.010**
Proximal lordosis (°)	1.7 ± 7.8	0.1 ± 6.4	5.3 ± 10.3	1.7 ± 8.0	**− 2.4**	**0.007**	1.9	0.093
Distal lordosis (°)	3.6 ± 4.8	3.8 ± 4.6	3.8 ± 3.5	3.7 ± 4.5	0.4	0.593	0.8	0.383
Immediate postoperative								
Lordosis (°)	7.1 ± 11.3	7.1 ± 9.5	8.9 ± 9.0	7.5 ± 10.0	− 1.1	0.344	− 0.4	0.767
SVA (mm)	30.1 ± 11.2	28.9 ± 10.4	31.2 ± 10.2	29.7 ± 10.7	− 1.4	0.227	0.0	0.992
Fusion segment lordosis (°)	3.9 ± 4.5	6.9 ± 5.9	9.2 ± 5.8	6.4 ± 5.8	**2.8**	**< 0.001**	**4.8**	**< 0.001**
T1 slope (°)	27.6 ± 8.1	28.5 ± 7.5	27.2 ± 6.4	27.9 ± 7.6	0.6	0.616	− 1.3	0.388
Proximal lordosis (°)	1.4 ± 8.3	− 0.1 ± 7.0	4.0 ± 11.3	1.2 ± 8.6	**− 2.4**	**0.010**	0.8	0.513
Distal lordosis (°)	2.5 ± 4.8	2.9 ± 5.2	1.6 ± 3.0	2.5 ± 4.8	− 0.4	0.503	− 0.4	0.672
Final								
Lordosis (°)	9.9 ± 11.2	8.6 ± 10.1	9.1 ± 8.0	9.1 ± 10.1	− 2.5	0.033	− 2.4	0.099
SVA (mm)	28.0 ± 11.3	25.9 ± 10.0	29.6 ± 10.1	27.3 ± 10.5	− 2.9	**0.008**	− 0.8	0.710
Fusion segment lordosis (°)	3.7 ± 4.9	6.3 ± 5.9	8.2 ± 6.0	5.9 ± 5.8	**2.6**	**< 0.001**	**4.5**	**< 0.001**
T1 slope (°)	29.3 ± 8.5	28.1 ± 7.1	28.7 ± 7.9	28.6 ± 7.7	− 2.1	0.061	− 2.0	0.181
Proximal lordosis (°)	2.0 ± 7.9	1.1 ± 6.9	4.9 ± 10.9	2.2 ± 8.3	− 1.6	0.076	1.5	0.206
Distal lordosis (°)	4.0 ± 4.6	3.8 ± 5.5	1.5 ± 4.7	1.5 ± 4.7	0.0	0.990	− 1.8	0.062

Bold represents statistical significance as designated by a *p* value < 0.05

SVA sagittal vertical axis

[a]One-level ACDF used as reference

Table 4 Multivariate analysis for change in parameters at different time points

	One level	Two levels	3–4 Levels	All patients	Two levels[a]		3–4 Levels[a]	
					Beta	*p* value	Beta	*p* value
Change preoperative to postoperative								
Lordosis (°)	1.2 ± 8.4	2.9 ± 7.2	6.4 ± 8.5	3.1 ± 8.1	**2.2**	**0.025**	**5.4**	**< 0.001**
SVA (mm)	1.5 ± 7.0	2.8 ± 7.4	3.0 ± 9.6	2.4 ± 7.8	1.2	0.212	0.9	0.485
Fusion segment lordosis (°)	4.3 ± 4.9	6.6 ± 6.2	9.2 ± 8.1	6.4 ± 6.5	**3.0**	**< 0.001**	**5.6**	**< 0.001**
T1 slope (°)	0.3 ± 4.8	2.7 ± 5.2	4.6 ± 6.4	2.2 ± 5.5	**2.5**	**0.006**	**4.0**	**0.001**
Proximal lordosis (°)	− 0.5 ± 3.7	− 0.2 ± 4.0	− 0.8 ± 4.2	− 0.4 ± 4.0	0.1	0.816	− 0.6	0.327
Distal lordosis (°)	− 1.3 ± 3.8	− 0.8 ± 5.0	− 2.1 ± 2.9	− 1.2 ± 4.3	0.3	0.621	− 1.1	0.207
Change postoperative to final								
Lordosis (°)	2.8 ± 5.9	1.4 ± 5.5	− 0.1 ± 5.1	1.5 ± 5.6	**− 1.5**	**0.025**	**− 2.3**	**0.005**
SVA (mm)	− 2.2 ± 7.5	− 3.6 ± 7.4	− 2.0 ± 6.3	− 2.8 ± 7.3	− 1.6	0.051	− 0.7	0.546
Fusion segment lordosis (°)	− 0.3 ± 3.6	− 0.6 ± 3.5	− 0.9 ± 4.3	− 0.6 ± 3.7	− 0.2	0.693	− 0.3	0.630
T1 slope (°)	1.5 ± 4.2	− 1.2 ± 6.6	− 0.2 ± 4.8	− 0.1 ± 5.7	**− 2.6**	**0.006**	− 1.6	0.200
Proximal lordosis (°)	0.5 ± 4.1	1.3 ± 3.7	0.9 ± 3.3	1.0 ± 3.8	**0.9**	**0.039**	0.7	0.192
Distal lordosis (°)	1.3 ± 4.2	1.2 ± 3.7	− 0.1 ± 3.5	1.0 ± 3.9	− 0.1	0.921	− 1.3	0.098
Change preoperative to final								
Lordosis (°)	3.9 ± 8.0	4.4 ± 7.6	6.4 ± 7.8	4.7 ± 7.8	1.0	0.292	**3.6**	**0.003**
SVA (mm)	− 0.3 ± 7.7	− 0.6 ± 7.9	0.5 ± 8.7	− 0.3 ± 8.0	− 0.7	0.486	− 0.7	0.549
Fusion segment lordosis (°)	4.1 ± 5.4	6.0 ± 6.3	8.2 ± 8.5	5.8 ± 6.7	**2.8**	**< 0.001**	**5.4**	**< 0.001**
T1 slope (°)	2.3 ± 4.5	1.8 ± 7.6	3.2 ± 7.9	2.2 ± 6.8	− 0.8	0.507	0.7	0.674
Proximal lordosis (°)	0.2 ± 4.7	1.2 ± 4.3	0.0 ± 4.8	0.6 ± 4.6	1.0	0.076	0.0	0.950
Distal lordosis (°)	0.2 ± 4.1	− 0.1 ± 4.5	− 2.2 ± 4.5	− 0.3 ± 4.4	− 0.4	0.526	**− 2.6**	**0.003**

Bold represents statistical significance as designated by a p value < 0.05

SVA sagittal vertical axis

[a]One-level ACDF used as reference

Table 5 Multivariate analysis comparing clinical outcomes

	One level	Two levels	3–4 Levels	All patients	Two levels[a]		Three levels[a]	
					Beta	*p* value	Beta	*p* value
Preoperative								
VAS neck	7.1 ± 2.7	6.8 ± 3.6	7.4 ± 3.1	7.1 ± 3.2	− 0.3	0.748	0.3	0.773
VAS arm	4.9 ± 3.6	6.1 ± 3.8	5.4 ± 4.0	5.6 ± 3.8	**1.9**	**0.045**	1.1	0.294
NDI	43.2 ± 19.7	45.3 ± 20.3	51.6 ± 20.6	46.4 ± 20.3	4.1	0.393	**11.1**	**0.044**
Final follow-up								
VAS neck	2.3 ± 2.4	1.7 ± 2.3	2.5 ± 2.4	2.1 ± 2.4	− 0.6	0.321	0.1	0.914
VAS arm	1.1 ± 2.0	2.0 ± 3.0	1.8 ± 2.8	1.7 ± 2.7	0.8	0.205	0.8	0.279
NDI	21.7 ± 21.7	17.5 ± 17.5	25.3 ± 23.5	20.9 ± 20.6	− 3.3	0.488	4.0	0.458
Change preoperative to final								
VAS neck	4.9 ± 3.9	5.3 ± 3.8	5.1 ± 3.8	5.1 ± 3.8	0.5	0.623	0.1	0.915
VAS arm	4.1 ± 3.7	4.3 ± 3.9	3.7 ± 3.8	4.1 ± 3.8	1.0	0.289	− 0.1	0.926
NDI	24.6 ± 29.2	26.9 ± 23.1	28.6 ± 20.5	26.7 ± 24.2	3.5	0.546	5.5	0.411

Bold represents statistical significance as designated by a p value < 0.05

VAS Visual Analog Scale score, *NDI* Neck Disability Index score

[a]One-level ACDF used as reference

No statistically significant difference in the rate of ASD was found between one-level, two-level, and three- or four-level ACDF procedures. These results are similar to those by van Eck et al. [19], who assessed 672 consecutive ACDF patients and found that the number of levels included in the fusion segment was not associated with development

of ASD and need for reoperation. However, that study had only 35 patients with a 3-level ACDF and none with a four-level procedure, and was therefore under-powered for assessing ASD rates in that group. The present study included 83 patients with 3–4 level procedures and had greater power (80% power for a 15% difference in ASD) for assessing these radiographic differences. Bydon et al. [15] assessed 888 ACDF patients for development of ASD and also found no association between the number of levels fused and the development of clinical or radiographic ASD. However, this analysis may have been limited in that single-level procedures were compared with all other procedures involving two or more levels instead of separating procedures into multiple categories, as was done in the present study. We believe that grouping two-level and four-level procedures together may not be appropriate due to clinical and surgical differences. It should be mentioned that ASD is a time-dependent process and a study with longer follow-up would better delineate the true effect of fusion number on ASD development.

To our knowledge, the present study is the first in the literature to assess the effect of the number of ACDF levels on sagittal parameters. In the present study, multi-level fusions appeared to restore significantly greater amounts of lordosis compared to single-level procedures. Overall cervical lordosis remained stable following multi-level ACDF; however, cervical lordosis increased slightly from postoperative to final follow-up after single-level procedures. With longer fusions, postoperative lordosis changes are likely lessened due to less mobile sections. With one-level fusions, the improvement in global lordosis may be due to better posture and overall cervical alignment. The lordotic compensation in single-level ACDF patients suggests that multi-level fusion is not necessary based on preoperative sagittal alignment alone and that the level of surgery should be mainly dependent on patient symptoms and compressive pathology seen on MR imaging.

Patient-reported outcomes did not significantly differ based on the number of levels fused, which is similar to what is reported in the literature. Fusion rates and reoperations also did not differ based on the number of operative levels. These findings are similar to what has recently been reported in the literature [20]. Studies have demonstrated that ACDF with anterior plate fixation in multi-level procedures can result in high fusion rates and satisfactory clinical outcomes [7, 21–25]. Although some studies evaluating multi-level ACDF have described concerning failure rates (up to 23%), pseudarthrosis (up to 53%) due to the increased number of interfaces requiring fusion, and increased rates of dysphagia, this was not found to translate into worse clinical outcomes in the present investigation [26–29]. Our low pseudarthrosis rate can possibly be attributed to precise grafting bed preparation, as burring the endplates with exposure of the subchondral bone has previously been reported to cause a 4.4% decrease in the pseudarthrosis rate per level [30].

The present study does have several limitations. As a retrospective study, selection bias may potentially affect the results of the study. While this is a concern, it would not be feasible to randomize patients to varying levels of fusion in order to minimize selection bias. Additionally, in an effort to reduce selection bias, multivariate analyses controlled for baseline demographics between groups. Another potential weakness of the present study is length of follow-up. While average postoperative follow-up was approximately 2 years, minimum follow-up was 6 months, and this may not have been enough time for some patients to develop ASD. However, in order to maintain sufficient power for analysis, 6 months of follow-up was used. An additional weakness is possible inter-observer variability in radiographic measurements. To guard against this, all radiographic measurements were taken by multiple authors at varying time points. Another factor to take into account is the presence of preexisting degeneration at non-fused levels. While the surgical levels were symptomatic, there were many patients who had mild degenerative disk disease at the adjacent levels preoperatively; however, this was difficult to stratify in a clinically meaningful way. It is the authors' belief that surgery should be done at the symptomatic levels only as there are many asymptomatic degenerated segments with aging and spondylosis in both single-level and multi-level cases.

Conclusion

Overall, the present study found that patients who underwent multi-level ACDF may not be at a significantly greater risk of developing early radiographic evidence ASD compared to those who underwent a single-level procedure. Additionally, multi-level fusions appear to restore significantly greater amounts of lordosis compared to single-level procedures. Clinical outcomes, pseudarthrosis rates, and reoperation rates were similar between single- and multi-level ACDF patients. The results of this study are important for surgical decision-making and may challenge one potential rationale for using motion-sparing implants or hybrid constructs when addressing multi-level cervical disease.

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