The Effect of Plating on Adjacent Segments in Anterior Cervical Discectomy and Fusions in Patients with Degenerative Spine Disease: A Retrospective Cohort Study

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Abstract:

Introduction: Plate distance is correlated with an increased incidence of adjacent segment pathologies (ASP). However, a correct plate-to-disk distance >5 mm is often not achieved. Therefore, this study aimed to quantify the effect of short plate-to-disk distance on the development of ASP using epidemiological measures in patients with cervical degenerative spine disease undergoing single-level anterior cervical discectomy and fusion (ACDFs).

Methods: Medical records of all patients with cervical degeneration undergoing single-level ACDF with plating (between January 2015 and December 2017), and a follow-up of at least 1 year, were reviewed retrospectively. Radiologic and clinical outcomes were assessed preoperatively, postoperatively, and at last follow-up. The plate-to-adjacent disk distance was measured, and epidemiological measures were calculated to quantify the risk on adjacent-level ossification development (ALOD) and adjacent segment degeneration (ASD).

Results: Thirty-eight (47.5%) of the 80 patients developed ALOD, and 12 (15.0%) developed ASD after a 2-year follow-up. The incidence of ALOD was significantly lower if the plate was >5 mm away from the adjacent disk space compared to <5 mm (cranial adjacent segment, 22.5% vs. 51.3% [P=0.010] and caudal, 21.4% vs. 47.8% [P=0.029]). A correct plate-to-disk distance resulted in a relative risk reduction of 57.2% for the cranial segment and 56.0% for the caudal segment, with a number needed to treat of 4. The ASD was only observed in the cranial adjacent segments, and a correct plate-to-disk distance resulted in a relative risk reduction of 32.1% and a number needed to treat of 18.

Conclusions: Only four patients need to be treated with a correct plate-to-disk distance to avoid one case of ALOD. Therefore, it is advisable to keep the plate at a distance >5 mm away from the adjacent disk.

Keywords:

adjacent segment pathology, anterior cervical discectomy and fusion, degenerative cervical spine disease, ACDF, adjacent-level ossification development, adjacent segment degeneration, ALOD, ASD

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Introduction

Anterior cervical discectomy and fusion (ACDF) is considered the gold standard in the surgical treatment of cervical degenerative spine disease, and it is intended to achieve decompression of the neural elements by stabilizing the affected segments and restoring spinal alignment[1)]. Numerous studies have reported that the use of plates during ACDFs is associated with adjacent segment pathologies (ASP), including adjacent-level ossification development (ALOD) and adjacent segment degeneration (ASD)[2-4)]. A major contributor to this effect is a short distance of the plate to the adjacent segments, with a distance <5 mm being too short[4-7)]. We have noticed that a correct plate-to-disk distance is often not achieved. Therefore, the purpose of this study was to evaluate and quantify the effect of a short plate-to-disk distance on adjacent segments pathologies. We aimed to calculate epidemiological measures to help surgeons better understand

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the effect of plate distance and make it useful in clinical practice.

Materials and Methods

This retrospective cohort study was performed following the STROBE guideline to secure proper data reporting and improve the methodological quality of our study[8]. The study was approved by the institutional review board (IRB) of the authors' affiliated institution. Informed patient consent was waived because of the study's retrospective nature.

Patients

All patients who underwent plated single-level ACDF for degenerative cervical spine disease were retrospectively selected. Patients were identified based on the current procedural terminology (CPT) code. We selected all consecutive patients aged >40 years with the CPT codes 22551 or 22552 for anterior interbody fusion with discectomy and decompression between January 1, 2015, and December 31, 2017. Patients were included if the indication of the ACDF was degenerative spine disease for cervical radiculopathy, myelopathy, or facetogenic neck pain. Patients without a 1-year follow-up, those who received multiple ACDFs, and those with previous spine surgery were excluded from the study. Patients with an ACDF on C6-C7 or lower were also excluded due to bony overlap, which precluded adequate visualization of the caudal intervertebral disc at this level. Three neurosurgeons at our institution performed all surgeries. Radiographs were evaluated at three specific time points: preoperative, directly postoperative, and at last follow-up. Patients were divided into two groups for each of the two adjacent disk spaces: one group with a plate-to-disk distance <5 mm and the other one with ≥5 mm.

Definitions and outcomes

The primary outcome was the risk quantification by epidemiological measures of short plate-to-disk distance on the development of radiographic ASP, including ALOD and ASD. The secondary outcomes were the clinical outcome and registration of adverse events, and the analysis of a possible correlation of these outcomes with radiographic ASP. The radiological and clinical outcomes were evaluated 1 day postoperatively and at last follow-up, and they were compared with baseline. The radiographic measurements were performed by two observers (JH and KR) who were not involved in patient care. Both observers were adequately trained to do measurements and did the measurements once. The intraclass correlation coefficient (ICC) was used to calculate inter-observer reliability and to measure the degree of agreement among the two observers. Cicchetti's guideline was used for interpretation[9].

Radiologic outcomes

Routine standing anteroposterior and lateral views were made preoperatively, postoperatively, and at last follow-up. Flexion and extension views were available for patients with a clinical indication. Radiologic outcomes—ALOD and ASD—were evaluated at last follow-up, while the plate-to-disk distance was measured directly postoperatively. The plate-to-disk distance was the distance between the upper and lower edges of the plate and the cranial and caudal disk, respectively. Radiological measurements were measured preoperatively, directly postoperatively, and at last follow-up.

Adjacent segment pathology

Radiological ASP was quantified by measuring ALOD and ASD at the cranial and caudal adjacent disk spaces of the fusion (Fig. 1). ALOD was measured preoperatively and postoperatively, and quantified using the method of Park et al[4]. The severity of ossification was classified as Grade 0, meaning no ossification; Grade 1, ossification extended across <50% of the disk space; Grade 2, ossification extended across ≥50% of the disk space; or Grade 3, complete bony bridging of the adjacent disk space[4].

ASD was defined as an intervertebral disc narrowing of >2 mm on lateral radiographs or as a vertebral slip (anterior or posterior) of >3 mm[10]. The last radiograph at the last follow-up was compared with the radiograph directly postoperatively. The average disk height was used and calculated by measuring the anterior and posterior disk height, and the total was divided by two (Fig. 2a). A vertebral slip was measured by measuring the transverse distance between the lines drawn along the posterior side of the vertebral body at the level of the cranial and caudal vertebra.

Other radiologic outcomes

Several angles were measured on lateral X-ray (Fig. 2b). The fusion rate was defined by two criteria at the last follow-up[11]. Criterion I was the visualization of bridging the trabecular bone between the endplates, and Criterion II was the absence of radiolucency between the graft and endplate. Graft subsidence was defined as a 2 mm decrease of the fused segment height at final follow-up compared with the immediate postoperative radiographs. Plate system migration was defined as a 2 mm change in the plate-to-disk distance between the measurements postoperatively and at final follow-up. Graft retropulsion was defined as placement of the graft past the posterior wall of the vertebral body.

Clinical outcomes

Neck pain and radicular arm pain were evaluated using the Numeric Rating Scale (NRS; 0-10, with 0 reflecting no pain). At the last follow-up, the effect of treatment was evaluated by classifying the patients into the following three categories: improvement, same complaint, or new complaint. Adverse events and reoperation rates were recorded.

Statistical analysis

The SPSS software, version 23.0 (IBM), was used for statistical analysis. Results were reported as mean with SD or as median with range. Differences between the measure-

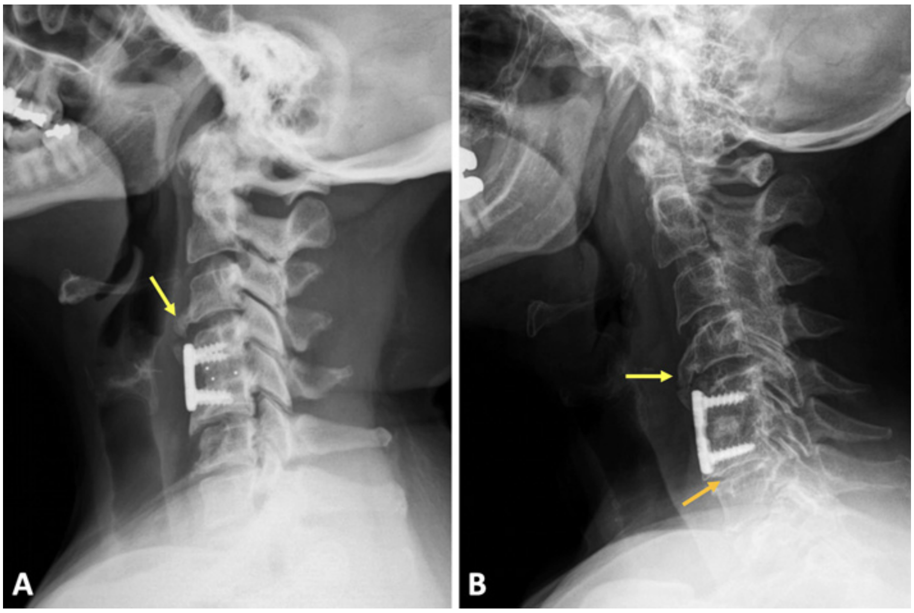

Figure 1. Sagittal films of two patients with findings suggestive of adjacent-level ossification development (ALOD) and adjacent segment disease (ASD).
A: 59-year-old female status post C4–C5 anterior cervical discectomy and fusion (ACDF) due to degenerative C4–C5 disk extrusion. Sagittal film is suggestive of ASD (yellow arrow) 16 months after surgical intervention.
B: 69-year-old female status post C5–C6 anterior cervical discectomy and fusion (ACDF) due to degenerative C5–C6 disc extrusion. Sagittal film is suggestive of ASD (yellow arrow) and ALOD (orange arrow) 30 months after surgical intervention.

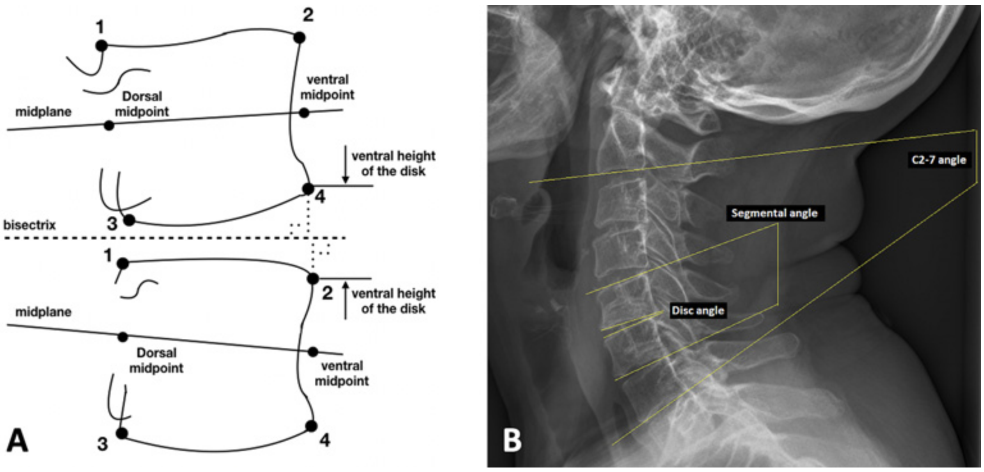

Figure 2. Sagittal Measurements.
A: Method used to measure disc height on plain radiography: (1) determine the four corners of the two adjacent vertebral bodies; (2) draw a straight bisecting line; (3) draw a perpendicular line (the shortest distance) from the bisecting line to all corners of the upper and lower endplates; and (4) calculate the sum of the shortest distances for anterior and posterior.
B: Method used to measure sagittal angles.

ments in time were assessed by paired *t*-test for continuous data and a McNemar for dichotomous data. A chi-squared test was used to compare the clinical outcome by every radiological complication. The ICC was used to calculate inter-observer reliability and measure the agreement between the two observers. The ICC for inter-observer variability was calculated based on a mean-rating (k=2), consistency, and two-way random-effects model. Significance was defined as $P<0.05$ for all analyses.

Results

Patient selection

A total of 102 patients with degenerative cervical spine disease were retrospectively identified using the CPT code. In total, 80 patients were included in the study because 22 patients did not have follow-up x-rays. The ICC for inter-observer variability of the radiographic measurements of the two observers was r=0.76 (95% CI, 0.70-0.82), indicating a moderate to good inter-observer reliability[9].

Descriptive

The mean age of patients at the time of procedure was 59.3 (9.9) years, with a median follow-up of 2.0 (1.0-4.0) years. The main indication for a single ACDF was spondylotic myelopathy, followed by symptomatic degenerative hernia (Table 1). The majority of patients were operated at the level C5-C6 and had an ASA classification of 2. Only static plates were used in all cases. The operation resulted in multiple sagittal changes (Table 2). Of the 80 included patients, 39 (48.8%) had the plate within 5 mm of the cranial adjacent disk, and 23 (28.8%) had the plate within 5 mm of the caudal adjacent disk.

Table 1. Patient Characteristics (N=80).

Characteristic	Data
Age, y, mean (SD)	59.3 (9.9)
Sex, male, No. (%)	46 (57.5)
Degenerative cervical disease, No. (%)	
Spondylotic myelopathy	26 (32.5)
Degenerative hernia	20 (25.0)
Spondylosis	14 (17.5)
Cervical spinal stenosis	12 (15.0)
Foraminal stenosis	7 (8.8)
Degenerative spondylolisthesis	1 (1.3)
Segments, No. (%)	
C3–C4	18 (22.5)
C4–C5	18 (22.5)
C5–C6	44 (55.0)
ASA classification, No. (%)	
1	9 (11.3)
2	58 (72.5)
3	13 (16.3)
Graft, No. (%)	
Allograft	72 (90.0)
PEEK	8 (10.0)
Plate length, mm, mean (SD)	17.5 (3.8)

Abbreviations: ASA, American Society of Anesthesiologists; PEEK, polyetheretherketone

Adjacent segment pathology

At the last follow-up, 38 (47.5%) patients exhibited a significant increase of ossification at the adjacent segments following their procedure. Ossification increased in 29 (36.3%) patients at the cranial adjacent-level (P<0.001) and in 23 (28.7%) at the caudal adjacent-level (P=0.001). The ASD was found in 12 (15.0%) patients at the cranial adjacent segment, but it was not observed in the caudal adjacent segment (Fig. 2). The mean cranial plate-to-disk distance was 5.0 mm (2.9), and the mean caudal plate-to-disk distance was 6.7 mm (3.0).

If the plate was ≥5 mm away from the adjacent disk space, this resulted in an ALOD incidence rate of 22.0% for the cranial segments and 21.1% for the caudal segments, while a plate within <5 mm of the adjacent-level resulted in an incidence rate of 51.3% for the cranial segment and 47.8% for the caudal segment. The incidence rate was significantly different between the two groups for the cranial adjacent disk spaces (51.3% vs. 22.0%; P=0.01) and the caudal adjacent disk spaces (47.8% vs. 21.4%; P=0.029). The increase in severity of ossification was also significantly higher in the <5 mm group (Table 3). The RRR in developing ALOD, by placing the plate 5 mm away from the disk, was 57.2% for the cranial segment and 56.0% for the caudal segments. The number needed to treat (NNT) was 4 in both segments, meaning that four patients needed to be treated with a correct disk-to-plate distance of >5 mm to prevent one case of ALOD during plated ACDFs (Table 4).

The ASD was only observed in the cranial segments (<5

Table 2. Sagittal Changes by Anterior Cervical Discectomy and Fusion.

Radiographic Measurements	Index Height*		Changes by Operation* (post op – pre op)		*P-Value*, Pre vs. Post†		Change at LFU* (LFU – post op)		*P-Value*, Post vs. LFU†	
	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior
Cranial disk, mm	4.9 (1.2)	3.1 (1.2)	−0.2 (1.1)	0.0 (1.1)	0.233	0.927	0.1 (1.2)	−0.2 (0.8)	0.651	.087
Treated disk, mm	4.0 (1.8)	2.1 (1.3)	4.7 (1.9)	4.2 (2.0)	<0.001	<0.001	−1.4 (1.9)	−0.3 (2.0)	0.001	.248
Caudal disk, mm	4.5 (1.8)	2.7 (1.2)	−0.3 (1.0)	0.1 (0.7)	0.024	0.494	0.1 (1)	0.0 (0.8)	0.578	.902
Fused disk angle	3.7° (5.1)		3.5° (7.3)		<.001		−0.8° (5.1)		.199	
Segmental angle	0.9° (6.6)		4.5° (4.7)		<.001		−1.5° (4.2)		.003	
Cervical lordosis	10.4° (14.4)		1.4° (8.3)		.144		0.1° (7.8)		.947	

Abbreviation: LFU, last follow-up

* Reported as mean (SD)

†Paired *t-test*

Table 3. The Severity of ALOD Divided by Plate-to-Disk Distance.

Plate-to-Disk Distance	<5 mm	≥5 mm	*P-Value**
Increased ALOD cranial adjacent disk spaces	n=39	n=41	.029
Not increased, n (%)	19 (48.7)	32 (78.0)	
1 grade, n (%)	15 (38.5)	7 (17.1)	
2 grades, n (%)	5 (12.8)	2 (4.9)	
Increased ALOD caudal adjacent segment	n=23	n=57	.045
Not increased, n (%)	12 (52.2)	45 (78.9)	
1 grade, n (%)	8 (34.8)	11 (19.3)	
2 grades, n (%)	3 (13.0)	1 (1.8)	

Abbreviation: ALOD, adjacent-level ossification development
*χ^2 test

Table 4. Risk of Adjacent Segmental Pathology.

Place-to-Disk Distance	<5 mm	≥5 mm	RR*	RRR*	ARR*	NNT*
Increased ALOD, cranial†	51.3%	22.0%	0.43 (0.22; 0.82)	−57.2% (−77.7; −17.8)	−29.3% (−49.5; −9.2)	3.4 (2.0; 10.9)
Increased ALOD, caudal†	47.8%	21.1%	0.44 (0.23; 0.85)	−56.0% (−77.2; −14.9)	−26.8% (−49.8; −3.8)	3.7 (2.0; 26.5)
ASD cranial	17.9%	12.2%	0.68 (0.24; 1.96)	−32.1% (−96.2; 76.5)	−5.8% (−21.4; 9.9)	17.4 (−10.1; 4.7)

Abbreviations: ALOD, adjacent-level ossification development; ARR, absolute risk reduction; ASD, adjacent segment degeneration; NNT, number needed to treat; RR, relative risk; RRR, relative risk reduction
* Reported with 95% confidence interval
† Significant difference

Table 5. Plate Migration Divided by Plate-to-Disk Distance Postoperatively.

Plate-to-Disk Distance	<5 mm (n=39)	≥5 mm (n=41)	P-Value
Cranial migration	n=9 (23.1%)	n=11 (26.8%)	0.798*
• Mean change	−2.6 mm (0.8)	−3.5 mm (1.5)	0.123†
Plate-to-Disk Distance	<5 mm (n=23)	≥5 mm (n=57)	P-Value
Caudal migration	n=6 (26.1%)	n=14 (24.6%)	0.782*
• Mean change	−2.5 mm (0.7)	−4.0 mm (1.6)	0.043†

* Fisher's exact test
†Unpaired *t*-test

mm, 17.9% vs. ≥5 mm, 12.2%; *P*=0.055) and not observed in the caudal segments. A correct plate distance resulted in a risk reduction of 32.1% on the development of ASD and the NNT was 18, meaning that 18 patients needed to be treated with a plate ≥5 mm away from the adjacent disk space to prevent one case of ASD.

Radiologic outcomes

In 20 patients (25%), a migration of the plate system was observed with a mean change of 3.1 mm on the cranial side and 3.6 mm on the caudal side. When dividing the group by plate-to-disk distance postoperatively (<5 mm vs. ≥5 mm), the frequency of migration did not differ, but the amount of migration was larger in the ≥5 mm group (Table 5). No plate or screw failures were seen. Fusion was seen in 72 (90.0%) patients according to Criteria I and in 63 (78.8%) according to Criteria II. Twenty patients (25.0%) experienced anterior subsidence with a mean (SD) decrease of 4.3 (2.1) mm, and 14 patients (17.5%) experienced posterior subsidence with a mean (SD) decrease of 4.5 (1.6) mm. Six (7.5%) patients had retropulsion of the graft. No correlation was found between the incidence of graft retropulsion and ASP (ALOD and ASD).

Clinical outcomes

At the last follow-up, neck pain improved in 46 patients (57.5%) with an NRS decrease of 4 points. Neurologic deficit improved for 47 patients (58.8%). The adverse event rate was 6.3% (n=5); two patients had recurrent laryngeal nerve palsy, one had postoperative Horner syndrome, one had right-sided forearm weakness, and one had right-sided C5 palsy. Retropulsion was determined in six patients, and only one complained of it. Seven (8.8%) patients were operated on again because of the recurrence of radicular pain at adjacent segments. No statistical association was found between neck pain and radiologic outcomes.

Discussion

Our study confirmed that a short plate-to-disk distance is a critical risk factor for the development of ALOD. The ALOD prevalence was high if the plate was close to the adjacent disk space (51.3% for the cranial disk space and 22.0% for the caudal disk space), while placing the plate at a distance >5 mm away resulted in a significantly lower prevalence (21.2% for the cranial disk space and 22.0% for the caudal disk space). A correct plate distance resulted in a relative risk reduction (RRR) of 56%-57.2% on the development of ALOD with a NNT of four, indicating that one of four patients will benefit from a correct plate-to-disk distance. The ASD was only observed in the cranial adjacent segments and not in the caudal segments. A correct plate-to-disk distance resulted in a RRR of 32.1% and a NNT of 18 on the development of ASD.

In our total cohort, ALOD was observed in 47.5% of the patients. According to a recent study, the prevalence of ALOD in patients with plated ACDFs ranges from 29% to 72%[12]. Several studies evaluated the plate-to-disk distance related to ALOD and identified a short plate-to-disk distance as an important risk factor for the development of ALOD[3,4,6,7,12-15]. The original study of Park et al. demonstrated first in 2005 that a plate-to-disk distance of <5 mm resulted in a statistically significant higher incidence ALOD[4]. Despite these previously published data, 48.8% of the patients in our institute between 2015 and 2017 had a plate-to-disk distance <5 mm. In this study, we presented epidemiological measures to quantify the risk reduction of a longer plate-to-disk distance. These measures may represent a useful tool to estimate the impact of an incorrect plating technique. Patients had a RRR ranging from 56.0% to 57.2% with regard to experiencing ALOD when the plate-to-disk distance was ≥5 mm. The exact mechanism of ALOD development is still unclear, but it is thought to be a type of heterotopic ossification caused by iatrogenic damage of the soft tissue near the disk.

In our study, the prevalence of radiological ASD was 15.0% and was lower than expected. In a meta-analysis of Xia et al., the pooled prevalence of radiographical ASD after cervical spine surgery was 32.8% (95% CI, 17.8%-47.9%)[16]. A possible explanation for the difference is the relatively short follow-up in our study. Bone and disk degeneration usually increase over time, while heterotopic ossification develops within the first 12 months after surgery[6]. Thus, a longer follow-up period will affect the incidence of ASD. Another reason could be the ASD definition used in this study. There are several classification systems for grading of ASD[17]. The classification systems comprise a variety of anatomical, biomechanical, and clinical observations and use different kinds of imaging (plain radiography, computed tomography, and magnetic resonance imaging).

In general, the rate of adjacent segment pathology is higher in the cranial adjacent segments than in caudal segments;[2] this has also been proven in our study. Cranial ALOD increased by 36.3% of the patients, and caudal ALOD increased by 28.7% of the patients. The ASD was only observed in the cranial adjacent segments (15.0%) and not in the caudal adjacent segments. This finding is consistent with a biomechanical study that demonstrated increased forces on the cranial adjacent-level[18]. The exact mechanism is not yet fully understood, but a fusion probably changes the biomechanics of the cervical spine, which results in a stiffer fused segment with more stress on the cranial adjacent segment.

Symptomatic ASP was observed in 12.5% of our cohort. However, radiological ASP findings did not correlate with clinical outcomes at the last follow-up. This finding was in concordance with previously published data[19,20].

Limitations

As with any retrospective study, our study is associated with several limitations inherent to the study design. Although the primary aim was to evaluate the short-term effects of plate distance in plated ACDFs, a follow-up of 2 years is relatively short for the development of ASD. This short follow-up and study design were selected to show the negative effect of incorrect plate-to-disk distance in the short-term. However, the results regarding ASD need to be interpreted with caution, because degeneration typically increases over time, and there is a possibility that radiologic and clinical outcomes worsen the farther one gets from surgery. A study of Park et al. concluded that most cases of ossification of adjacent levels appeared within 12 months postoperatively and that those with no ossification at 12 months were very unlikely to progress to advanced ossification[6]. For this reason, a median follow-up of 2 years should be sufficient to determine an accurate ALOD prevalence.

Finally, it is plausible that adjacent segments degenerate due to natural wear and not solely by the impact of the ACDF. To effectively determine if adjacent segments are genuinely impacted by fusion, one would need to compare the natural wear of degeneration in the general population with an ACDF population. However, the negative effect of a short plate-to-disk distance on accelerated degeneration is evident. Future comparative studies are needed to investigate natural degeneration in patients with degenerative spine disease and compare the ACDF group with a degenerative spine control group.

Implications

This study confirms results of previous studies according to which the plate-to-disc distance was a critical risk factor for the development of ALOD and ASD. A strength of this study is that we calculated several epidemiological measures for quantifying the risk, making it better understandable and clinically relevant for surgeons. Lee et al. presented a modified plating technique to reduce the risk of ALOD by minimizing the dissection of the anterior longitudinal ligament by starting screw holes at the corner of the endplate and angling the screw away from that endplate to allow the shortest possible plate[7]. They compared this technique with the conventional technique, which uses parallel screws, finding a significant decrease in ALOD in both adjacent segments. The incidence of ALOD decreased from 72% to 42% at the cranial segment and from 42% to 20% at the caudal segment. Another possible option to reduce ALOD is to utilize a stand-alone cage. A recent study compared stand-alone ACDFs with plated ACDFs and demonstrated a lower incidence of ALOD for stand-alone ACDFs (29% vs. 2.8%)[12].

Conclusion

A substantial group of patients treated with ACDF and plating developed ALOD short after their treatment. Patients had 56.0%-57.2% less chance of developing ALOD when the plate was correctly placed with a disc-to-plate distance >5 mm. The NNT was four, indicating that one in four patients will benefit from a correct plate-to-disc distance. ASD occurred only in the cranial adjacent segments with a RRR of 32.1% and a NNT of 18.

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Kent R. Richter: (2) data acquisition, (4) drafting of the manuscript, (5) critical revision.

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Tito G. Vivas-Buitrago: (5) critical revision.

Matthew T. Neal: (5) critical revision, (7) administrative support, (8) supervision.

Alfredo Quinones-Hinojosa: (5) critical revision, (7) administrative support, (8) supervision.

Kingsley Abode-Iyamah: (1) conception and design, (5) critical revision, (7) administrative support, (8) supervision.

Ethical Approval: Approval for this study was granted by the Mayo Clinic Institutional Review Board (18-003951). The study is performed according to the Declaration of Helsinki and amendments. Informed consent was obtained by all participants in this study.

Data Availability Statement: The data and materials are available to strengthen the transparency and reliability of the study. The additional data could be requested by sending an e-mail to the corresponding author.

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References

1. Katsuura A, Hukuda S, Saruhashi Y, et al. Kyphotic malalignment after anterior cervical fusion is one of the factors promoting the degenerative process in adjacent intervertebral levels. Eur Spine J. 2001;10(4):320-4.
2. Hilibrand AS, Robbins M. Adjacent segment degeneration and adjacent segment disease: the consequences of spinal fusion? Spine J. 2004;4(6):S190-S4.
3. Yang H, Lu X, He H, et al. Longer plate-to-disc distance prevents adjacent-level ossification development but does not influence adjacent-segment degeneration. Spine. 2015;40(7):E388-93.
4. Park JB, Cho YS, Riew KD. Development of adjacent-level ossification in patients with an anterior cervical plate. J Bone Joint Surg Am. 2005;87(3):558-63.
5. Kim HJ, Kelly MP, Ely CG, et al. The risk of adjacent-level ossification development after surgery in the cervical spine: are there factors that affect the risk? A systematic review. Spine. 2012;37(22 Suppl):S65-74.
6. Park J-B, Watthanaaphisit T, Riew KD. Timing of development of adjacent-level ossification after anterior cervical arthrodesis with plates. Spine J. 2007;7(6):633-6.
7. Lee DH, Lee JS, Yi JS, et al. Anterior cervical plating technique to prevent adjacent-level ossification development. Spine J. 2013;13(7):823-9. eng.
8. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. Int J Surg. 2014;12(12):1495-9.
9. Cicchetti DV. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychol Asses. 1994;6(4):284.
10. Ishihara H, Kanamori M, Kawaguchi Y, et al. Adjacent segment disease after anterior cervical interbody fusion. Spine J. 2004;4(6):624-8.
11. Oshina M, Oshima Y, Tanaka S, et al. Radiological fusion criteria of postoperative anterior cervical discectomy and fusion: a systematic review. Global Spine J. 2018;8(7):739-50.
12. Huang C, Mobbs R, Selby M, et al. Adjacent-level ossification development in single-level standalone anterior cervical discectomy and fusion versus anterior cervical discectomy and fusion with plate. Spine. 2020:2192568220902749.
13. Garrido BJ, Wilhite J, Nakano M, et al. Adjacent-level cervical ossification after Bryan cervical disc arthroplasty compared with anterior cervical discectomy and fusion. J Bone Joint Surg Am. 2011;93(13):1185-9.
14. Jeong E-S, Choi B-Y, Shin C-S. Factors affecting adjacent level ossification development after anterior cervical discectomy and fusion. J Kor Orthop Asso. 2012;47(6):425-31.
15. Park Y, Maeda T, Cho W, et al. Comparison of anterior cervical fusion after two-level discectomy or single-level corpectomy: sagittal alignment, cervical lordosis, graft collapse, and adjacent-level ossification. Spine J. 2010;10(3):193-9. eng.
16. Xia X-P, Chen H-L, Cheng H-B. Prevalence of adjacent segment degeneration after spine surgery: a systematic review and meta-analysis. Spine. 2013;38(7):597-608.
17. Kraemer P, Fehlings MG, Hashimoto R, et al. A systematic review of definitions and classification systems of adjacent segment pathology. Spine. 2012;37(22 Suppl):S31-9.
18. Matsunaga S, Kabayama S, Yamamoto T, et al. Strain on intervertebral discs after anterior cervical decompression and fusion. Spine. 1999;24(7):670-5.
19. Shiban E, Nies M, Kogler J, et al. No correlation between radiological and clinical outcome 1 year following cervical arthrodesis. Acta Neurol. 2018;160(4):845-53.

20. Burkhardt BW, Simgen A, Wagenpfeil G, et al. Is there a difference in the grade of degeneration at the cervical spine following anterior cervical fusion with respect to clinical outcome, diagnosis, and repeat procedure? An MRI study of 102 patients with a mean follow-up of 25 years. J Neurosurg Spine. 2019:1-9.