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Radiographic Characteristics of Caudal Segment in Multilevel Anterior Cervical Discectomy and Fusion: The Bony Buttress Formation

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Objective: Anterior cervical discectomy and fusion (ACDF) with anterior plating is a commonly performed procedure for cervical disc diseases. While the clinical outcomes of most reported multilevel ACDF cases are excellent, symptomatic pseudarthrosis remains a challenge, often requiring revision surgeries. This study aims to present the radiological characteristics of multilevel ACDF constructs, which can be considered during intraoperative management to prevent pseudarthrosis.
Methods: This retrospective cohort study included patients who underwent multilevel (3 or 4 levels) ACDF with anterior plating between June 2010 and August 2022. Patients were regularly followed at 4 months, 12 months, and then annually postoperation. Fusion rates and characteristic radiological patterns, such as the formation of bony buttresses underneath the anterior plate, were graded and evaluated.
Results: A total of 163 patients were included in the study. Overall fusion rates were 26.38%, 64.34%, and 81.58% at 4-month, 1-year, and the final follow-up, respectively. Nonunions at 4-month follow-up with tightly engaged anterior plate with bony buttress formation were more likely to fuse in the later period (Buttress grade 0 vs. 1; $p = 0.01$, odds ratio [OR], 5.70, Buttress grade 1 vs. > 2; $p < 0.01$, OR, 12.00).
Conclusion: This study emphasizes the significance of pseudarthrosis following multilevel ACDF. Pseudarthrosis predominantly occurs in the caudal-most segment of the construct, particularly when it terminates at C7. Constructs that are not tightly engaged and lack bony buttress formation in the caudal part of multilevel ACDF are more likely to develop pseudarthrosis.

Keywords: Multilevel anterior cervical discectomy and fusion, Fusion rate, Pseudarthrosis, Bony buttress

INTRODUCTION

Since the introduction of the anterior approach cervical fusion by Robinson and Smith,[1] it has been widely accepted as an effective treatment for cervical intervertebral disc diseases.[2] In cases of cervical spondylosis, the anterior approach is preferred over the posterior approach due to the predominant compression of the anterior aspect of the spinal cord and cervical roots, allowing for safer and more direct decompression of the pathology.[3] Anterior cervical discectomy and fusion (ACDF) not only provides decompression of neural structures but also stabilizes affected motion segments.[4,5] Consequently, the success of this surgical procedure heavily relies on the development of a solid and stable arthrodesis.[6,7] The utilization of ACDF has become common in the surgical treatment of cervical degenerative disc diseases, encompassing both short segments and multilevel fusion.[8-10]

The fusion rate of multilevel ACDF exhibits significant variability in current literature.[7-16] However, the criteria used to determine fusion are often arbitrary, leading to lower fusion rates in studies with stricter criteria.[16] While pseudarthrosis does not always correlate with poor clinical outcomes,[17,18] the long-term implications of pseudarthrosis remain uncertain, and the need for revision surgery to address symptomatic pseudarthrosis is frequently a concern.[19] As a result, pseudarthrosis in ACDF imposes a substantial burden on both patients and healthcare systems, highlighting the importance of efforts to reduce pseudarthrosis.[20]

Numerous risk factors contributing to pseudarthrosis in ACDF are patient-dependent, including smoking, diabetes mellitus, obesity, malnutrition, and chronic steroid use.[2] However, the fusion rate can also be influenced by surgical skillset and technique.[21] The introduction of anterior cervical plates has improved the fusion rate in long-level ACDF,[11] making precise placement a crucial consideration. Notably, the caudal segments tend to fuse slower and exhibit a higher pseudarthrosis rate compared to other segments.[22] Therefore, this study aims to analyze the formation of bony spurs, known as 'bony buttresses,' in the caudal part of the anterior plate after multilevel ACDF. Additionally, the study seeks to explore the correlation between the presence of these bony buttresses and the outcome of arthrodesis in the multilevel ACDF construct.

MATERIALS AND METHODS

1. Study Design and Data Collection

This retrospective cohort study included patients who underwent multilevel (3 or 4 levels) ACDF with anterior plating between June 2010 and August 2022. Clinical data was collected from electronic medical records, while radiologic data was obtained from the PACS (picture archiving and communication system) used at the hospital. The study was conducted after receiving approval from the Institutional Review Board (IRB) of Korea University Guro Hospital (IRB No. 2023GR0105), with a waiver for informed consent.

2. Surgical Indications and Exclusion Criteria

The surgical indications for treatment included (1) a diagnosis of cervical spondylosis with or without segmental instability, (2) corresponding symptoms such as myelopathy, radiculopathy, radiculomyelopathy, or axial neck pain, and (3) failure of conservative treatment. Patients who received additional posterior support or underwent early revision surgery were excluded from the study. The follow-up of the patients occurred at the outpatient clinic at 4 months postoperation and subsequently on an annual basis (Fig. 1).

3. Surgical Approach and Operative Technique

The modified Robinson technique[2,4] was employed for ACDF. Discectomy was performed until the level of the uncovertebral joints and the posterior longitudinal ligament (PLL). In cases where ossification or ruptured disc material dorsal to the ligament was observed, the PLL was excised. Both the upper and lower endplates were thoroughly decorticated to create a well-

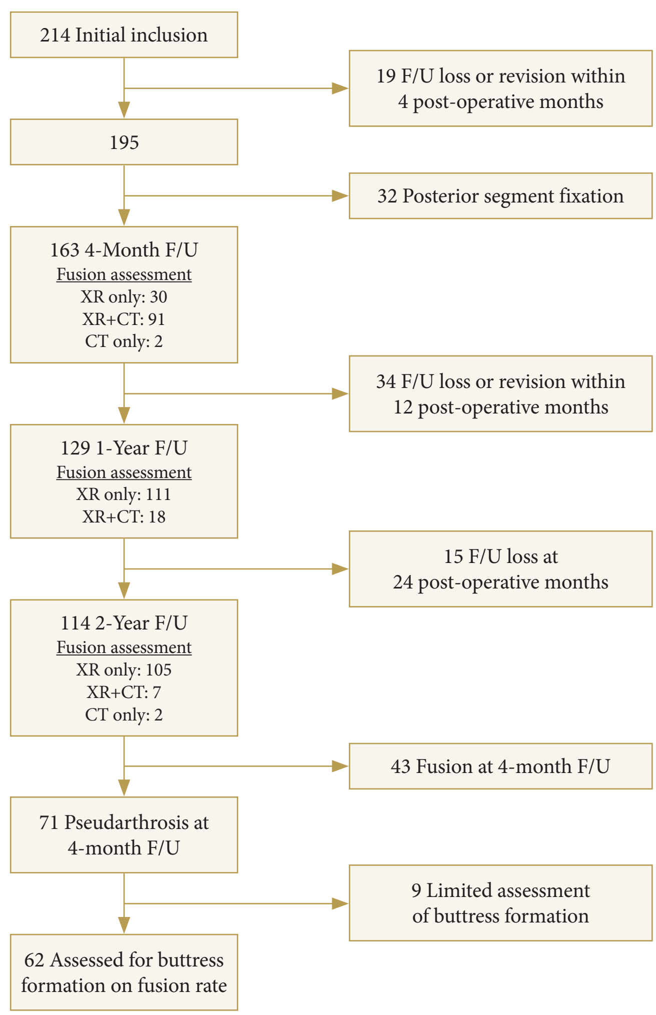

Fig. 1. Flowchart of exclusion criteria. F/U, follow-up; XR, x-ray; CT, computed tomography.

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vascularized fusion bed and facilitate the removal of posterior osteophytes. Complete decompression was achieved, covering the entire compromised portion of the spinal cord. Interbody material consisted of autogenous tricortical iliac bone grafts harvested from the anterior iliac crest, commercial fibular allogenic bone grafts, or commercial polyetheretherketone (PEEK) or ceramic cages. The choice of interbody height (6–9 mm) was determined using preoperative computed tomography (CT) or magnetic resonance imaging scans. Anterior internal plate fixation was achieved using a titanium plate with fixed or variable angle locks, providing anterior stabilization. Segmental screw fixation was applied at each cervical vertebral body spanned by the plate. A drainage catheter was placed in the prevertebral space for 48-hour postsurgery. After the procedure, all patients were instructed to wear a soft cervical collar brace for 4–6 weeks to immobilize their neck.

4. Radiological Outcomes Assessment

Radiological evaluations were conducted using x-rays and CT scans at preoperation, 4-month postoperation, and during annual follow-ups. The fusion state and intersegmental motion were determined by 3 board-certified neurosurgeons by consensus, in which an initial measurement of a fellowship trained neurosurgeon was scrutinized by 2 other neurosurgeons for an

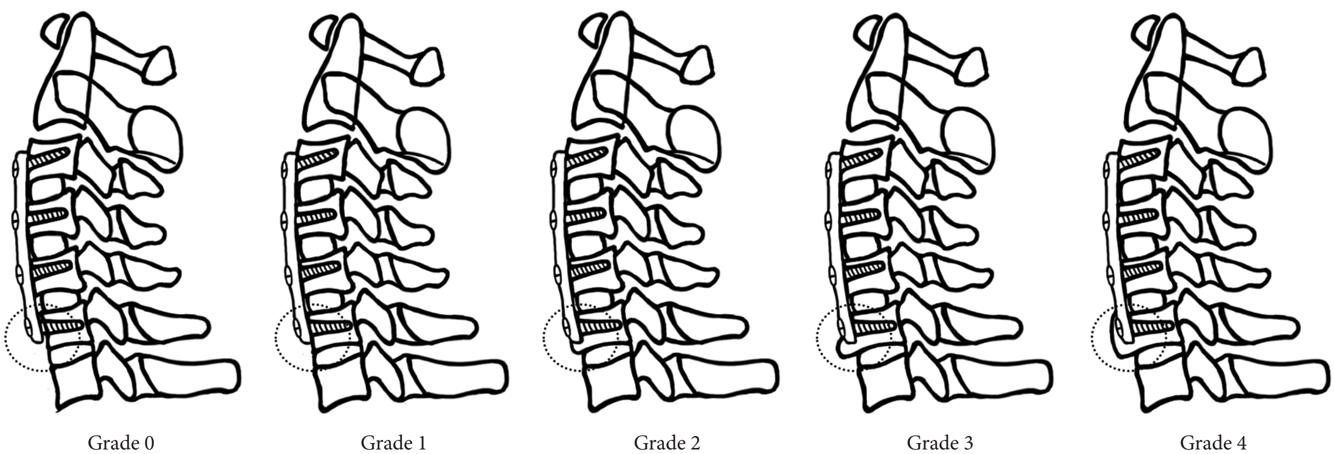

Fig. 2. Illustration of bony buttress grading. Grade 0, the plate does not touch the vertebral body; grade 1, the bony spur extends within the lower margin of the plate; grade 2, the bony spur extends beyond the lower margin of the plate but does not migrate upwards; grade 3, the bony spur migrates upwards anterior to plate but does not reach the screw head; grade 4, the bony spur covers the caudal screws heads.

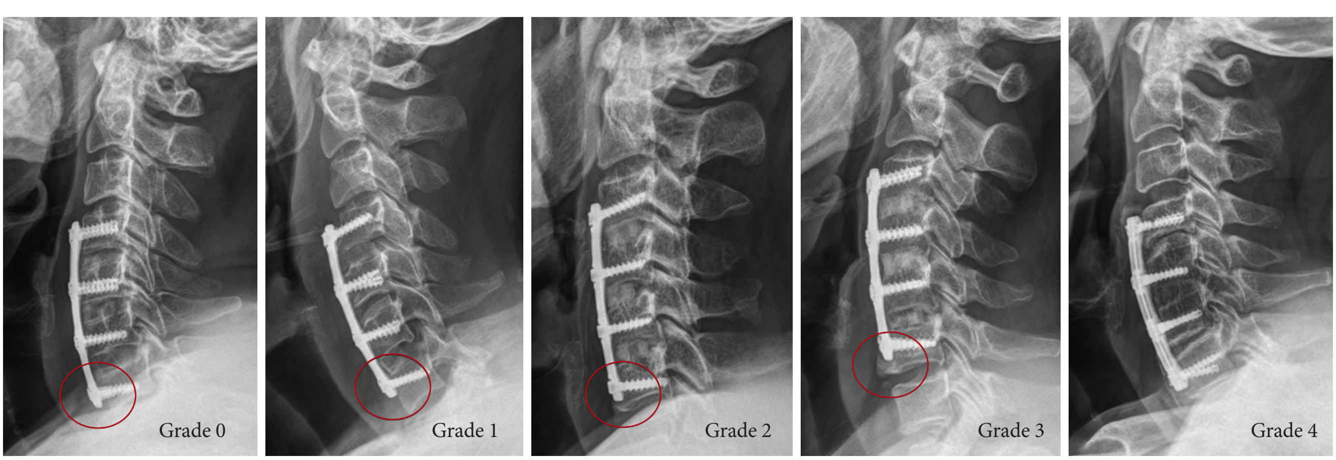

Fig. 3. Examples of buttress grading. Grade 0, the plate does not touch the vertebral body; grade 1, the bony spur extends within the lower margin of the plate; grade 2, the bony spur extends beyond the lower margin of the plate but does not migrate upwards; grade 3, the bony spur migrates upwards anterior to plate but does not reach the screw head; grade 4, the bony spur covers the caudal screws heads.

agreement. The assessment was done on postoperative x-ray flexion-extension views by measuring the interspinous distance at 150% magnified images.[23] In cases where the x-ray provided ambiguous results, cervical CT scans were utilized for confirmation. The fusion criteria included: (1) absence of motion greater than 1 mm between the tips of spinous processes on flexion/extension lateral radiographs, (2) absence of a radiolucent gap between the graft and the endplate, and (3) presence of continuous bridging trabeculae at the graft and endplate junction. Fusion assessment was performed for each operated intersegment.

Bony buttress formation in the caudal aspect of the plate was evaluated on cervical x-ray lateral view, as the caudal segments are at higher risk of pseudarthrosis.[24] The extent of the buttress was graded as follows (Figs. 2 and 3):

Grade 0, The plate does not touch the vertebral body.

Grade 1, The bony spur extends within the lower margin of the plate.

Grade 2, The bony spur extends beyond the lower margin of the plate but does not migrate upwards.

Grade 3, The bony spur migrates upwards anterior to the plate but does not reach the screw head.

Grade 4, The bony spur covers the caudal screw heads.

Surgimap v 2.3.1.5 (Surgimap, New York, NY, USA) was employed for the measurements.

5. Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics ver. 20.0 (IBM Co., Armonk, NY, USA). The data in each group were tested for normality using Shapiro-Wilk test. Paired t-test or Wilcoxon signed-rank test were used to assess changes in parameters in an individual within a group, as appropriate. Analysis of variance was used for the comparative analysis of multiple groups. Comparison of categorical variables were done using chi-square and Fisher exact test. Statistical significance was defined as $p < 0.05$.

RESULTS

1. Demographics

A total of 214 patients meeting the aforementioned clinical indications underwent anterior cervical fusion during the study period. Seventeen patients were lost to follow-up within 4 months, and 1 patient underwent early revision surgery and was excluded. Among the remaining 195 patients, 32 received anterior cervical fusion with concurrent posterior segment fixation and were investigated separately. The analysis included 163, 129, and 114 patients at the postoperation follow-up of 4 months, 1 year, and longer than 24 months, respectively. Among the 163 patients undergoing ACDF (41 females, 122 males; mean age, 57.03 ± 10.32 years; age range, 32–83 years) at the 4-month postoperation follow-up, 12 underwent concurrent corpectomy with a mesh cage filled with autogenous bone, with 6 located in the caudal segment. For ACDF patients, graft materials in the caudal-most segment included 46 cases of autogenous bone, 77 cases of fibular allogeneic bone, 31 cases of PEEK cage filled with autogenous bone, and 9 cases of ceramic cage (Table 1). Among the 163 patients, 3 showed screw breakages in the caudal-most segment. Screw pullouts in one or more levels occurred in 17 patients, among whom 7 patients had the screw heads completely pulled off the plate, while the remaining cases showed only mild displacement from the interface. Pullouts only occurred at either the proximal or distal most segments, sparing the middle segments. A total of 3 patients required revision surgery due to screw breakage or screw pullout.

2. Fusion Rate

Overall fusion rates were 26.38% (33.90% for 3-level and 6.67% for 4-level ACDF) at 4 months, 64.34% (65.31% for 3-level and 29.03% for 4-level ACDF) at 1 year, and 81.58% (83.52% for 3-level and 73.91% for 4-level ACDF) at the final follow-up. Fusion rates significantly varied among different constructed levels as presented in Table 2. Constructs that end at C7 caudally showed significantly lower fusion rate, while all pseudarthrosis occurred in the caudal-most segment within individual constructs. Fusion rate of constructs using autobone, allobone and PEEK as graft materials in the caudal-most segment were 82.93%, 84.62%, and 87.50%, respectively. However, the fusion rate and the time taken to fusion did not differ significantly among different graft materials (Fishers exact test, $p = 0.948$).

3. Bony Buttress Formation and Fate of Pseudarthrosis

The extent of bony buttress formation during different follow-up periods is presented in Table 3. At 4-month postoperation, 27.16%, 45.06%, and 25.31% of cases showed grade 0, 1, and 2 buttress formation, respectively, while only 2.47% showed grade 3 bony buttress formation. The degree of bony buttress formation increased with the follow-up period, with 25.74% and 62.07% showing a buttress grade of 3 or higher at 12 months and the final follow-up, respectively (Fig. 4). Among the 51 patients with pseudarthrosis at the 4-month follow-up, 13, 21, and 16 patients showed a buttress grade of 0, 1, and 2 or higher at 4 months, respectively, and in 1 patient the buttress formation

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Table 1. Patient demographics and surgical characteristics

Parameter	According to levels fused				According to timing of fusion† (n = 114)					According to Buttress grade (n = 162)			
	Total (n = 163)	3 Levels (n = 118)	4 Levels (n = 45)	p-value	Fusion at 4 mo	Fusion at 1 yr	Fusion at final F/U	Pseudarthrosis at > 2-yr F/U	p-value	Buttress G0 at 4 mo	Buttress G1 at 4 months	Buttress G2 & 3 at 4 mo	p-value
Age (yr)	57.03 ± 10.32	55.86 ± 10.23	60.11 ± 10.02		55.27 ± 10.38	53.73 ± 10.14	53.00 ± 10.05	59.59 ± 8.58	0.070	58.73 ± 9.78	55.82 ± 10.59	57.02 ± 10.26	0.336
Sex, male:female	122:41	89:29	33:12		30:12	23:10	16:2	16:5	0.467	34:10	53:20	34:11	0.843
BMI (kg/m^2)	24.48 ± 2.81	24.49 ± 2.93	24.44 ± 2.44		24.23 ± 2.98	24.92 ± 2.99	25.49 ± 3.05	24.17 ± 2.33	0.364	24.18 ± 2.48	24.05 ± 2.75	25.32 ± 3.08	0.047*
Smoking, yes:no	114:49	74:44	38:7		11:31 (26.19)	9:24 (27.27)	4:14 (22.22)	4:17 (23.53)	0.932	10:22	17:40	8:32	0.469
DM, yes:no	137:26	99:19	37:8		8:34 (19.05)	3:30 (9.09)	3:15 (16.67)	5:16 (23.81)	0.476	5:27	12:45	6:34	0.695
Fusion segment (n)									< 0.01‡				
C3–6	32	32	-		18	4	4	-		4	10	17	
C4–7	73	73	-		16	18	6	15		27	33	14	
C5–T1	13	13	-		6	2	1	1		2	7	5	
C3–7	-	-	39		2	7	5	5		11	21	7	
C4–T1		-	6		1	2	-	1		-	2	4	
Graft material (n)									0.948‡				N/A
Autobone	46	41	5		16	10	8	7		10	23	13	
Allobone	77	55	22		20	16	8	8		15	39	23	
PEEK	31	15	16		6	4	4	2		2	16	13	
Ceramic	9	7	2		2	3	-	-		3	5	2	
Revision	3	1	2		-	-	-	-		2	-	1	N/A
Hardware failure													
Screw pullout	17	13	4		3	3	2	4		3	12	4	
Screw breakage	3	2	1		-	-	-	3		1	2	-	
Sagittal parameters§	(n = 131)	(n = 105)	(n = 26)										
CL	10.04 ± 9.98	10.63 ± 9.90	7.69 ± 10.17	0.180	10.05 ± 10.54	9.30 ± 12.15	10.26 ± 6.49	10.65 ± 6.15	0.979	9.78 ± 9.57	11.88 ± 10.99	10.11 ± 9.04	0.657
T1S	25.58 ± 6.69	25.56 ± 6.65	25.66 ± 5.64	0.950	24.01 ± 5.81	26.83 ± 6.69	24.97 ± 6.48	27.10 ± 6.59	0.460	26.77 ± 7.54	25.82 ± 7.53	24.84 ± 6.14	0.601
cSVA	18.16 ± 12.03	17.59 ± 11.91	20.47 ± 12.46	0.275	14.95 ± 11.06	19.04 ± 10.87	19.45 ± 13.61	19.20 ± 13.47	0.605	19.67 ± 15.51	16.49 ± 11.90	18.03 ± 9.85	0.610
T1S–CL	14.75 ± 9.31	14.13 ± 9.30	17.97 ± 8.55	0.120	13.36 ± 5.45	16.78 ± 8.49	15.68 ± 8.21	16.84 ± 8.19	0.548	16.99 ± 9.84	13.94 ± 8.87	14.73 ± 8.99	0.438

Values are presented as number (%, yes/[yes+no]) or mean ± standard deviation unless otherwise indicated.
F/U, follow-up; BMI, body mass index; DM, diabetes mellitus; PEEK, polyetheretherketone; CL, cervical lordosis; T1S, T1 slope; cSVA, cervical sagittal vertical axis; NA, not available.
*$p < 0.05$, analysis of variance comparing BMI of the 3 different bony buttress group. †At least 2-year follow-up. ‡Fisher exact test. §Preoperative sagittal parameter values.

could not be assessed. In general, the intersegmental motion in these patients decreased with postoperation follow-up. However, 2 patients with buttress grade of 0 at 4 months, showed increasing intersegmental motion after 12 months postoperation (Fig. 5). Pseudarthrosis patients with grade 1 and grade 2 or higher bony buttress at 4-month postoperation were more likely to show fusion in the final follow-up compared to grade 0 patients with odds ratio of 7.20 and 15.75, respectively.

Table 2. Fusion rate of multilevel ACDF

Variable	4-Month FU	1-Year FU	> 2-Year FU
Total	43/163 (26.38)	83/129 (64.34)	93/114 (81.58)
3 Levels	40/118 (33.90)	64/98 (65.31)	76/91 (83.52)
C3–6	19/31 (61.29)	22/28 (78.57)	26/26 (100)
C4–7	16/74 (21.62)	34/60 (56.67)	41/56 (73.21)
C5–T1	6/13 (46.15)	8/10 (80.00)	9/10 (90.00)
4 Levels	3/45 (6.67)	9/31 (29.03)	17/23 (73.91)
C3–7	2/39 (5.13)	7/26 (26.92)	14/19 (73.68)
C4–T1	1/6 (1.67)	2/5 (40.00)	3/4 (75.00)

Values are presented as number (%)
ACDF, anterior cervical discectomy and fusion; FU, follow-up.

Table 3. Bony buttress formation

Buttress grade	4-Month FU (n = 162)	1-Year FU (n = 101)	> 2-Year FU (n = 58)
0	44 (27.16)	18 (17.82)	3 (5.17)
1	73 (45.06)	32 (31.68)	9 (15.52)
2	41 (25.31)	25 (24.75)	10 (17.24)
3	4 (2.47)	26 (25.74)	36 (62.07)

Values are presented as number (%)
FU, follow-up.

DISCUSSION

Since the introduction of the surgical technique of ACDF and its modified techniques in mid 90's, it has quickly become a popular method to effectively treat multilevel cervical spondylotic diseases.[1,25] A firm arthrodesis of the construct was considered the main goal of the surgery. However, earlier reports of

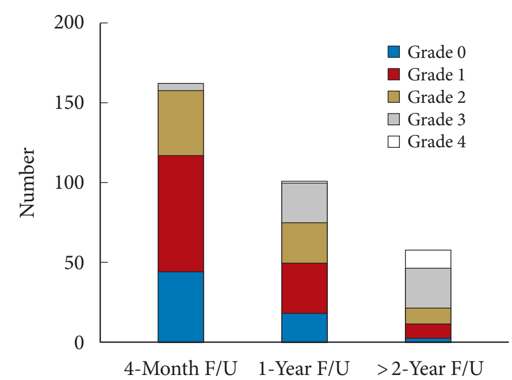

Fig. 4. The proportion of bony buttress grades at 4-month, 1 year, and > 2-year follow-up (FU). A gradual increase in bony buttress is noticed.

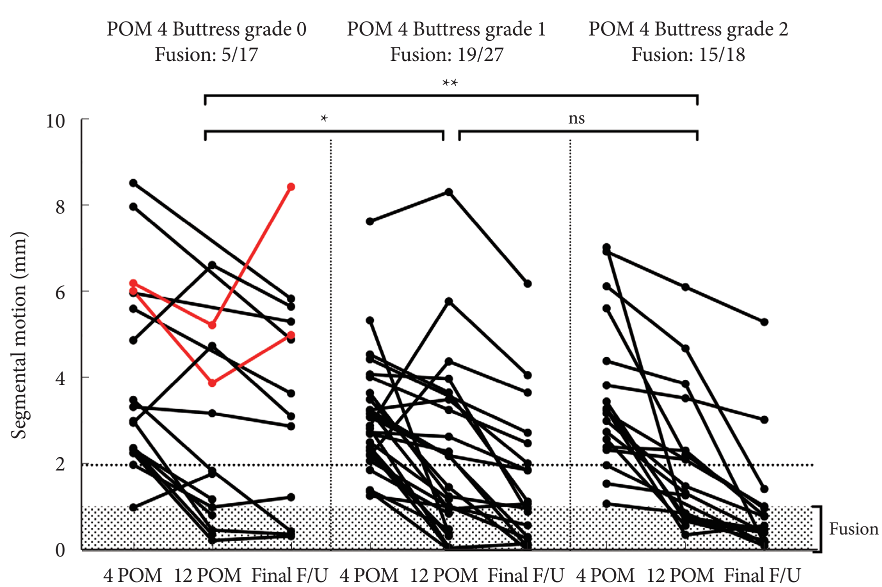

Fig. 5. Intersegmental motion in the caudal-most construct gradually decrease. Higher bony buttress grade at 4-month postoperation leads to significantly higher fusion rate. Two patients with grade 0 bony buttress showed increasing intersegmental motion. POM, postoperation months; F/U, follow-up. *p = 0.01; odds ratio [OR], 5.70. **p < 0.01; OR, 12.00. ns, not significant (p = 0.482).

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multilevel ACDFs showed low fusion rates.[26] The advancement of instruments and graft materials played an important role in increasing the fusion rate, which is evident in recent literatures on fusion rates of anterior cervical fusion.[27-30] Although pseudarthrosis of ACDF does not necessarily result in worse clinical outcome due to stable fibrotic union, its long-term clinical outcome is uncertain.[31] Symptomatic nonunion exists due to residual motion at the affected site and delayed complications that may include instrument failures such as screw pullout and breakage, and anterior plate displacement, which eventually result in dysphagia and neurologic deficit.[32] Therefore, surgical strategies to achieve solid fusion of the construct should be carefully made.

Fusion rate for multilevel ACDF in current literatures vary widely between 54.2% to 96% with different follow-up periods and criteria for fusion.[9,16,32-36] Of notice, Lee et al.[31] reported 32.6% pseudarthrosis 1 year after ACDF of 1 to 3 levels, which decreased to 9% within 2 years. Our result was consistent with these reported outcomes as overall fusion rate gradually increased from 26.38% at 4-month postoperation, 64.34% at 1 year, and up to 81.58% thereafter. Furthermore, in all of the pseudarthrosis cases the caudal-most segment of the multilevel ACDF construct were involved with or without proximal pseudarthrosis. This result was consistent with Lambrecht et al.[19] who reported that predominance of lowest instrumented level pseudarthrosis. Anderst et al.[37] described segmental motion contribution during cervical flexion movement, in which upper cervical segments contributed to initial flexion movement, and then the lower cervical segments upon fully flexing the cervical spine. This means the theoretical pivot may exist in the caudal segments.[38] Therefore, pseudarthrosis in the caudal-most segment may have occurred due to higher pivotal motion generated in the distal part of fixed segments. The same mechanism may explain the lower pseudarthrosis rate in the proximal segment and higher incidence of pseudarthrosis in 4-level ACDF rather than in 3 levels. In our study, proximal pseudoarthrosis seldom occurred and had a strong tendency to fuse with time. Middle segments showed 100% fusion at final follow-up. Notably, the fusion rates among different segments of construction were different as constructs that caudally ended at C7 showed significantly higher pseudarthrosis rate.

In this study, we have observed the correlation bony buttress formation underneath the anterior plate of the construct and the fusion rate. The result demonstrated that the phenomenon may positively relate to fusion. All of pseudarthrosis cases at 1-year postoperation that finally fused in the following years, showed early bony buttress formation of grade 1 or higher. It seems that a tight engagement of anterior plate to the caudal vertebral body is important in 2 aspects. Firstly, it may aid in overcoming the concentrated pivotal mechanical force. Secondly, a rigid fixation in the caudal part would transmit the mechanical stimuli onto osteoprogenitor cells, which is an underlying biomechanism of the 'Wolff's law.'[39] This mechanotransduction mechanism may play an important role in forming bony buttress, which may have stabilized the motion at the caudal segment to some extent. On the other hand, patients who presented pseudarthrosis beyond 2-year follow-up showed little bony buttress formation—grade 0 or 1—at 4 months postoperation. Nine out of 16 delayed pseudarthrosis patient showed grade 0 bony buttress, which means the anterior plate was not in complete contact with the vertebral body. In 2 of delayed pseudarthrosis cases, the lower end of anterior plate was located close to lower part of vertebral body close to lower endplate, leaving little space for bony buttress formation. In these 2 cases, even though grade 3 to 4 bony buttress was formed, it was thin and weak to be effective in limiting the motion. These patients could not take the advantage of stabilization provided by the bony buttress. Unrestricted continuous and repeated motion from lack of bony buttress formation left the instruments vulnerable to failures, such as early screw pullouts and breakage. Multilevel ACDF without anterior plate that result in fusion had been reported.[35] In these patients, tight anterior plate engagement may not have a great role. However, the extra stabilization in the caudal-most vertebra may play an important role in those cases vulnerable to pseudarthrosis.

It is often debatable whether pseudarthrosis should be opted for a revision surgery and combined anterior-posterior circumferential operation is necessary.[40] In this study, patients who had undergone additional posterior support showed nearly 100% fusion at 4-month postoperation. However, the authors are in doubt whether additional posterior support is necessary. According to Lambrecht et al.,[19] patients who showed pseudarthrosis—more than 1-mm interspinous motion—at 1-year postoperation had low positive predictive value for revision. Patients with pseudarthrosis at 1-year postoperation in our study show gradually decreasing interspinous motion with concurrently increasing bony buttress formation. Five of these patients showed fusion beyond 2-year follow-up. Therefore, even those patients who presented pseudarthrosis in the delayed period may still have some room to fuse and simple wait-and-see may result in successful fusion.

Surgical strategies should aim at early bony buttress formation. The authors recommend to place the anterior plate firmly on the bony surface of vertebral body. Spondylotic bony spurs should thoroughly be removed and any undulations in the anterior surface of vertebral body need to be flattened for the anterior plate placement. Longus coli muscle should be stripped off adequately to prevent jamming of the muscle between the plate and the vertebral body. Drilling and scraping off the periosteum and anterior edge of endplate may aid inducing bony buttress formation. Furthermore, caudal screws should be tightly inserted using screws with a larger diameter and longer length—exceeding 75% of the body's anterior-posterior diameter—which is a known factor for increasing fusion rates by improving rigidity and pullout strength.[41] For effective screw placement, image guidance is recommended.

This study has notable limitations associated with retrospective design with long-term study period. Various graft materials and anterior plates were used with their advancements during the studied period. However, the fusion rate of various graft material did not vary within the cohorts of this study. Furthermore, bone mineral density could not be integrated into the study for evaluating pseudarthrosis, as the majority of patients did not meet the criteria for National Health Insurance reimbursements. For future studies evaluating the correlation between bony buttress and pseudarthrosis, a larger number of patients with clinical information such as Neck Disability Index and visual analogue scale will be required.

CONCLUSION

This study underscores the significance of pseudarthrosis following multilevel ACDF. Pseudarthrosis occurs mostly in the caudal-most segment of the construct, especially when it ends at C7. Constructs that lack the bony buttress formation in the caudal part of the multilevel ACDF are more likely to develop pseudarthrosis. Tight engagement of the anterior plate to the vertebral body may enhance the fusion rate.

NOTES

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