An Original Study

Characterization of Graft Subsidence in Anterior Cervical Discectomy and Fusion With Rigid Anterior Plate Fixation

Dino Samartzis, DSc, MSc, Rex A. W. Marco, MD, Louis G. Jenis, MD, Nitin Khanna, MD, Robert J. Banco, MD, Edward J. Goldberg, MD, and Howard S. An, MD

Abstract

This study addressed radiographically the evaluation, presence, location, and degree of subsidence with secondary focus on the various clinical parameters and outcomes in 32 patients who underwent anterior cervical discectomy and fusion (ACDF) with tricortical iliac crest bone grafts and rigid anterior plate fixation.

Postoperative follow-up plain radiographs were evaluated to determine subsidence on lateral neutral images by measuring the change in height of interscrew distance (ISD) and anterior (AVD), mid (MVD), and posterior (PVD) vertebral endplate-to-endplate vertical distances. Clinical functional outcome and various risk factors were also addressed.

A 100% fusion rate was achieved, no instrumentation-related complications were noted, and mild graft subsidence occurred in each patient after the initial 2 months of surgery. Mean AVD, MVD, and PVD were 1.2 mm, 0.4 mm and 0.6 mm, respectively. Mean ISD was 0.6 mm. Percent change for AVD, MVD, PVD, and ISD was 2.3%, 0.8%, 1.2%, and 1.2%, respectively. Subsidence was more pronounced at the anterior vertebral graft–endplate interface (*P*<.05). Satisfactory clinical results were reported in 90.9% of the patients. With such a sample size, age, sex, smoking status, plate design, graft type, and operative or number of fused levels did not demonstrate statistically significant differences to the degree of subsidence. This paper has shown that ACDF with tricortical bone grafts and rigid plating is associated with slight subsidence, graft load-sharing, high fusion rate, and excellent clinical outcome.

Dr. Samartzis is with the Department of Epidemiology, Radiation Effects Research Foundation, Hiroshima, Japan, and Beebe Fellow and Scholar, National Academies, Washington, D.C.
Dr. Marco is Associate Professor, Department of Orthopaedic Surgery and Department of Neurosurgery, and Chief of Spine Surgery and Musculoskeletal Oncology, University of Texas Medical School, Houston, Texas.
Dr. Jenis is Clinical Associate Professor, Orthopaedic Surgery, Tufts University School of Medicine, and with Boston Spine Group and New England Baptist Hospital, Boston, Massachusetts.
Dr. Khanna is Spine Surgeon, Orthopaedic Specialists of Northwest Indiana, Munster, Indiana.
Dr. Banco is Assistant Clinical Professor, Tufts University School of Medicine, and Chief, Spine Section, Department of Orthopaedic Surgery, New England Baptist Hospital, Boston, Massachusetts.
Dr. Goldberg is Assistant Professor, Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, Illinois.
Dr. An is the Morton International Professor of Orthopaedic Surgery and Director of the Division of Spine Surgery and Spine Fellowship, Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, Illinois.

Requests for reprints: Howard S. An, MD, Department of Orthopedic Surgery, Rush–Presbyterian–St. Luke's Medical Center, 1725 W Harrison St, Suite 1063 POB, Chicago, IL 60612 (tel, 312-243-4244; fax, 312-942-1516; e-mail, han@ortho4.pro.rpslmc.edu).

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Anterior cervical discectomy and fusion (ACDF) is an accepted procedure yielding favorable clinical outcomes in cases of cervical degenerative disease.[1-8] Furthermore, optimal outcome is heightened with successful bone fusion and proper graft integrity, which stabilize the spine and preserve sagittal alignment for neural decompression.[2,9-12]

Subsidence in spinal fusion is a settling or sinking of the bone graft superiorly, inferiorly, or both into the adjacent vertebral body.[13-24] Theoretically believed to occur and be completed within the first 6 weeks of the fusion process, subsidence could allow for optimal bone healing by providing motion and compressive forces to the graft and the host. However, subsidence may prevent proper bone healing because motion and an increase in load on the bone graft could decrease rigid fixation and lead to improper healing. Excessive subsidence may result in interbody collapse of the fused segment, nonunion, spinal deformity, and neural compression. To address such concerns, surgeons have advocated use of an anterior cervical plate in single-level or multilevel ACDF.

Numerous plating systems have been developed with varied biomechanical capabilities. Rigid anterior plate fixation assumes the role as the primary load-bearer by decreasing motion throughout the graft interface to obtain minimal to no subsidence,[16,24] thereby minimizing the risk for instrumentation-related complications, preserving neuroforaminal dimensions for indirect decompression of the exiting nerve roots, and in theory allowing the bone graft to achieve optimal healing. Others believe that anterior plate instrumentation should take on the role of a load-sharing device with the host bone and graft substrate contributing to an increase in graft settling, leading to better healing and clinical outcome. However, varied fusion rates and an increased incidence of instrumentation-related complications have been well documented in load-sharing anterior cervical plating systems as opposed to more rigid fixation devices.[13,15,16,22,23,25-27] Nevertheless, the amount of subsidence may also be influenced by systemic factors, endplate preparation, amount of interbody distraction, graft height and width, graft type, graft positioning, postoperative activity, and patient adherence to postoperative external immobilization.

Although subsidence has been indicated to occur after spine procedures in which bone fusion is key, it has not been well defined in the peer-reviewed literature. Cloward[28] attributed loss of interspace height to subsidence in several patients who received nonfrozen, ethylene oxide–sterilized allogeneic iliac crest bone grafts in anterior cervical fusion at multiple levels. Dennis and colleagues[17] reported change in midinterspace height after anterior lumbar interbody fusion. Using radiographic measurements, they noted that, on last follow-up evaluation, 100% of patients exhibited a 1% (0.1 mm) mean decrease in interspace height, and 46% of the fused levels lost more height as compared with preoperative status, irrespective of graft type. Later, Kumar and colleagues[20] denoted subsidence by measuring the anterior and posterior interspace dimensions on the lateral plain radiographs of patients who underwent single-level anterior lumbar fusion with femoral strut allograft and preservation of the bony endplate. The authors noted subsidence in both adjacent vertebral endplates in 47% of cases. Overall, subsidence occurred in 85% of cases and was more pronounced posteriorly, with a mean interspace height loss of 2.8 mm (range, 0-12.4 mm).

In an effort to increase fusion rate in ACDF procedures, Emery and colleagues[18] modified the Smith-Robinson technique by decorticating the vertebral endplates with a high-speed burr to enhance vascularity and promote osteoinduction to increase the propensity for fusion. Assessing the integrity of the graft–host construct, the authors measured the height of the fused segments by evaluating the vertical distance of the midpoint of the superior endplate of the upper vertebra and the inferior endplate of the lower vertebra. Loss of height across the fused segment was found to be significantly greater in the modified technique as opposed to the standard method. Similar postoperative pain outcomes were reported for both groups, and loss of lordosis was noted in both the standard and modified techniques, with the latter showing less change in alignment. In a study by Martin and colleagues,[21] subsidence developed in 5% of 311 ACDF patients with fibula allograft and endplate decortication. The authors attributed such graft settling to early cases that underwent overaggressive endplate decortication. Jenis and colleagues[19] evaluated the standard and reverse Robinson cervical grafting techniques and noted a loss in interbody height at the fusion site for all patients who underwent ACDF with decortication of the endplates and the creation of 3-mm centralized endplate hole perforations. The authors assessed anterior and posterior disc heights within the interbody space and noted no significant difference between the regions and grafting techniques in height loss, but more settling was noted anteriorly.

Several studies have noted high overall fusion rates with similar solid union in both autograft and allograft, low incidence of instrumentation-related complications, and good to excellent clinical outcomes with rigid anterior plate fixation for single-level or multilevel ACDF.[26,29-34] Nevertheless, the issue of the efficacy and dynamics of subsidence in the healing process is controversial, and little is known regarding its evaluation, presence, location, degree, and effects on clinical outcome in ACDF with rigid anterior plate fixation and tricortical iliac crest bone grafts.

Thus, the purpose of the study reported here was multifaceted. Our primary intent was to evaluate radiographically the presence, location, and degree of graft subsidence throughout the graft–endplate interface in patients who underwent ACDF via a Smith-Robinson procedure with tricortical iliac crest bone grafts and application of rigid anterior plate fixation. Our secondary objectives were to evaluate the role of various factors in graft settling and the effects of subsidence on overall clinical outcome.

Materials and Methods

After investigational review board approval was obtained, 17 men and 15 women (mean age, 48 years; range, 28-83 years) who met inclusion criteria were retrospectively reviewed for various radiographic and clinical data. As such, patients included in this study underwent ACDF with rigid anterior plate fixation and had postoperative plain radiographs available at 1 month, 3 months, and a minimum of 12 months. Failed conservative treatment for cervical radiculopathy, myelopathy, or myeloradiculopathy secondary to a herniated disc or spondylosis were indications for surgery. Surgeries were performed by fellowship-trained spine surgeons.

Nine patients (28.1%) underwent instrumented ACDF at 1 level, 19 (59.4%) at 2 levels, and 4 (12.5%) at 3 levels. Operative levels were C5–C7 (n = 14), C4–C7 (n = 4), C4–C6 (n = 3), C5–C6 (n = 3), C6–C7 (n = 3), C3–C4 (n = 2), C3–C5 (n = 2), and C4–C5 (n = 1). Anterior cervical plating devices were all rigid screw-plate systems: 10 PEAK (Depuy-Acromed, Rayham, Mass), 9 Orion (Sofamor-Danek, Memphis, Tenn), and 13 Atlantis (Sofamor-Danek, Memphis, Tenn). Each surgeon decided which plate type to use.

Graft material was selected according to patient preference. Nineteen patients (59.4%) received autogenous tricortical iliac crest graft, and 13 (40.6%) received frozen, vacuum-sealed, nonradiated tricortical iliac crest allograft. In the autograft group (mean age, 47 years; range, 28-64 years), 2 patients had a 1-level ACDF, 15 had a 2-level ACDF, and 2 had a 3-level ACDF; in the allograft group (mean age, 52 years; range, 30-83 years), 7 patients had a 1-level ACDF, 4 had a 2-level ACDF, and 2 had a 3-level ACDF. All allografts were defrosted in saline for 20 minutes before use. Eleven patients reported being smokers before surgery.

Each patient was brought into the operating room, and general anesthesia was administered. A left-sided anteromedial Smith-Robinson approach to the cervical spine was performed in all cases. A transverse incision with blunt finger dissection was made for appropriate exposure of the pathology site. The disc material was thoroughly removed, and the endplates were slightly decorticated with a curette and a high-speed burr. Appropriate distraction (≥2 mm of disc space) was accomplished with interlaminar spreaders, and traction (10 lb) with Gardner-Wells tongs.[35] Each graft was properly contoured in a Smith-Robinson fashion and countersunk 2 mm from the anterior vertebral border with the cortical rim positioned anteriorly. The anterior border of the involved vertebrae was smoothed with a high-speed burr to create a flat surface to enhance the surface contact area and facilitate flush application and fixation of the anterior cervical plating device. Traction by Gardner-Wells tongs was gradually released, and each plate was properly positioned using midline surgical markings for guidance. Plate screws were then inserted and directed toward the midline, with care taken to avoid breaching the adjacent disc space and spinal canal. Unicortical screw purchase was achieved in all cases. Each patient was placed in a soft collar for 3 to 4 weeks and was then gradually weaned off and encouraged to resume normal activities and undergo neck muscle range-of-motion strengthening exercises.

A single, independent, blinded observer evaluated each patient's lateral neutral, flexion, and extension plain radiographs to assess fusion, instrumentation integrity, and graft-related complications and to analyze various parameters of graft settling. Fusion was noted if a bony bridge incorporated the graft and the adjacent endplates and no radiolucencies or motion was evident on the instrumentation. Subsidence was measured on available postoperative plain lateral radiographs (mean, 2.5 months; range, 1-4 months) and consistently compared with lateral view sets (mean, 18 months; range, 12-65 months). Of the initial postoperative radiographs, 4 were from 4 weeks after surgery, and all others were from a minimum of 8 weeks after surgery. Subsidence was assessed on lateral neutral images by measuring height change (in millimeters) of interscrew distance (ISD) and anterior (AVD), mid (MVD), and posterior (PVD) vertical distances of the superior endplate of the upper vertebra to the inferior endplate of the lower vertebra involved in the construct (Figure). AVD, MVD, and PVD measurements were standardized and established to entail the outermost edge of the anterior vertebral border, the midpoint (distance across the endplate was measured, and the centermost point was determined), and the outermost edge of the posterior vertebral border, respectively. Measurement methods and

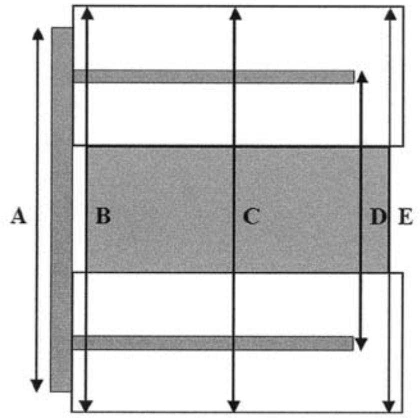

Figure. Quantitative measurements based on lateral plain radiographs of the cervical spine to evaluate graft subsidence: (A) plate length (PL), (B) anterior vertical distance (AVD), (C) midvertical distance (MVD), (D) interscrew distance (ISD), (E) posterior vertical distance (PVD).

ruling devices were kept consistent, and each patient's assessments were repeated for accuracy. To further minimize measurement error, we measured plate length in each image to obtain consistency in the event of radiographic tube and target repositioning on initial and last image capture; thus, measurements were verified and properly calculated to account for such discrepancies. Late subsidence was defined as graft settling noted at a minimum of 8 weeks.

In addition, each chart was reviewed for demographic data, medical history, and descriptions of preoperative, intraoperative, and postoperative treatment. Clinical outcome was evaluated blindly on last follow-up (mean, 23 months; range, 12-55 months) according to Odom's criteria (Table I).[36] Excellent and good clinical outcomes were considered satisfactory.

All data were collected, structured, organized, and coded within a Microsoft Excel spreadsheet and then transferred into SPSS software (version 11.5) for statistical analyses. Appropriate descriptive and frequency analyses were conducted. Various parametric and nonparametric tests were performed to determine presence of normality within the distribution and to decide appropriate statistical testing. When a distribution was non-normal, log transformation was considered, or Mann-Whitney and Wilcoxon tests were conducted to compare independent and paired samples, respectively. In addition, analysis of variance, correlation tests, χ^2, and Fisher's Exact Test analyses were also conducted when appropriate. The threshold for statistical significance was established at $P<.05$.

Table I. Odom's Clinical Outcome Classifications

Excellent	No complaint referable to cervical disease; able to perform daily occupation without impairment
Good	Intermittent discomfort referable to cervical disease; no significant interference with work
Fair	Subjective improvement in symptoms; physical activity significantly impaired
Poor	Worsening or no improvement

Results

Solid bone fusion was achieved in all 32 patients. No intraoperative or postoperative complications were noted. No graft dislodgement or instrumentation-related complications occurred. Mean intraoperative blood loss was 140.4 c^3 (125.0 c^3 for 1 level; 135.7 c^3 for 2 levels; 187.5 c^3 for 3 levels), but a statistically significant difference was not found among number of operative levels or between graft types ($P>.05$).

Radiographic measurements indicated mild subsidence in each patient. Mean AVD change was 1.2 mm (range,

Table II. Mean Amount of Subsidence in the Anterior, Mid, and Posterior Vertebral Regions of the Anterior Column and in the Interscrew Distance in Relation to the Number of Fused Levels in ACDF with Rigid Anterior Plate Fixation*

No. Fused	Change (mm)			
Levels	AVD	MVD	PVD	ISD
1	0.9	0.2	0.6	0.4
2	1.4	0.6	0.7	0.7
3	1.2	0.2	0.7	0.7
Overall	1.2	0.4	0.6	0.6

*ACDF indicates anterior cervical discectomy and fusion; AVD, anterior vertical distance; MVD, midvertical distance; PVD, posterior vertical distance; ISD, interscrew distance.

0.0-3.0 mm), mean MVD change was 0.4 mm (range, 0.0-2.0 mm), and mean PVD change was 0.6 mm (range, 0.0-3.5 mm). Mean ISD change was 0.6 mm (range, 0.0-2.0 mm). Percent changes were 2.3% (range, 0.0%-5.7%) for AVD, 0.8% (range, 0.0%-3.9%) for MVD, 1.2% (range, 0.0%-5.1%) for PVD, and 1.2% (range, 0.0%-7.1%) for ISD. Mean height change (Table II) and percent change (Table III) in AVD, MVD, PVD, and ISD were analyzed with respect to the number of fused levels, but were not found to be statistically significant in this sample size (P>.05). Percent change in AVD, MVD, PVD, and ISD was also evaluated in relation to graft type (Table IV) but was not found to be statistically significant (P>.05). There was no statistical difference in amount of graft subsidence between plate types (P>.05), which were all rigid plate-screw constructs. Comparison of 3 distinct measuring zones (AVD, MVD, PVD), composed of 32 obtained measurements each (N = 96), found statistically significantly more subsidence in the anterior vertebral graft–endplate interface (P<.05).

Five patients (15.6%), or 2 patients with a 1-level ACDF and 3 patients with a 2-level ACDF, had excellent clinical results; these patients reported no complaints associated with the cervical spine as well as nonimpairment in daily

Table III. Mean Percent Height Change in the Anterior, Mid, and Posterior Vertebral Regions of the Anterior Column and the Mean Amount of Percent Change in the Interscrew Distance in Relation to the Number of Fused Levels in ACDF with Rigid Anterior Plate Fixation*

No. Fused	Change (%)			
Levels	AVD	MVD	PVD	ISD
1	1.9	0.5	1.1	0.8
2	2.5	1.0	1.3	1.4
3	2.2	0.3	1.1	1.4
Overall	2.3	0.8	1.2	1.2

*ACDF indicates anterior cervical discectomy and fusion; AVD, anterior vertical distance; MVD, midvertical distance; PVD, posterior vertical distance; ISD, interscrew distance.

Table IV. Mean Percent Height Change in the Anterior, Mid, and Posterior Vertebral Regions of the Anterior Column and the Mean Amount of Percent Change in the Interscrew Distance in Relation to Smoking Status and Graft Type*

Smoker	Graft Type	Change (%) AVD	MVD	PVD	ISD
Yes	Autograft	2.7	1.2	0.4	1.0
	Allograft	1.6	0.0	1.7	0.9
	Overall	2.5	1.0	0.6	1.0
No	Autograft	2.5	0.8	2.0	1.6
	Allograft	1.9	0.6	1.2	1.1
	Overall	2.1	0.7	1.6	1.4
Total	Autograft	2.6	1.0	1.2	1.3
	Allograft	1.8	0.5	1.2	1.1
	Overall	2.3	0.8	1.2	1.2

*AVD indicates anterior vertical distance; MVD, midvertical distance; PVD, posterior vertical distance; ISD, interscrew distance.

functional activities. Further outcome analyses were also grouped according to Odom's classification (Table I): Twenty-five patients (78.1%), or 7 patients with a 1-level ACDF, 16 with a 2-level ACDF, and 2 with a 3-level ACDF, had good results; in addition, 2 patients (6.3%), 1 patient with a 2-level ACDF and 1 patient with a 3-level ACDF, had fair results. Poor clinical outcome was not noted in this series. Clinical outcome in relation to percent change in AVD, MVD, PVD, and ISD was assessed (Table V), and no statistical significance was found (P>.05).

Tobacco use and its relation to degree of subsidence (Table IV) and clinical outcome were evaluated in all patients. Among smokers, 2 patients (18.2%) reported excellent results; 8 (72.7%), good results; 1 (9.1%), fair results; and 0, poor results. Among nonsmokers, 3 (14.3%) reported excellent results; 17 (81.0%), good results; 1 (4.8%), fair results; and 0, poor results. Clinical outcome in relation to presence of smoking and its effects on degree of subsidence could not be discerned from this study. No statistically significant difference was established in demographics, operative level, plate design, or graft type when compared with clinical outcome or presence of smoking (P>.05).

Table V. Mean Percent Height Change in the Anterior, Mid, and Posterior Vertebral Regions of the Anterior Column and the Mean Amount of Percent Change in the Interscrew Distance in Relation to the Clinical Outcome Based on Odom's Criteria*

Clinical	Change (%)			
Outcome	AVD	MVD	PVD	ISD
Excellent	3.6	1.9	1.5	1.7
Good	2.0	0.6	1.1	1.0
Fair	2.2	0.7	2.2	3.2
Overall	2.3	0.8	1.2	1.2

*AVD indicates anterior vertical distance; MVD, midvertical distance; PVD, posterior vertical distance; ISD, interscrew distance.

Discussion

To enhance internal stability, decrease potential graft-related complications, facilitate fusion, maintain cervical alignment, and improve functional outcome, anterior cervical plate fixation is commonly used for single-level and multilevel ACDF.[26,33,34,37-40] However, in the peer-reviewed literature, evaluation of subsidence in ACDF with rigid anterior plate fixation and tricortical iliac crest bone grafts has not been well defined and is speculative. To assess subsidence, Tye and colleagues[24] retrospectively reviewed 70 patients who underwent ACDF with rigid anterior plate fixation. The Cloward approach used in their report involved allograft freeze-dried cortical bone dowels (68 patients) and tricortical iliac crest autograft (2 patients). Subsidence was based on the relationship (in millimeters) among known plate length, measured plate length, and measured fusion length (MVD, as noted in our study). The majority of initial postoperative radiographs analyzed were at 6 months or less, and all patients wore rigid collars for 6 weeks after surgery. Subsidence occurred in 96% of patients—a significant result given the increased number of fused levels and the presence of plate migration. No incidence of plate pullout or screw fractures was noted in their series. Furthermore, the authors noted subsidence of more than 2.0 mm in 47% of patients; however, the additive effects of varied fusion levels on graft settling were unclear, as percent change in subsidence was not reported, and regional graft–endplate interface assessment of subsidence was minimal. Good clinical outcomes were observed in 87% of patients, but this assessment (by the operating surgeon) was subjective. However, the biomechanical factors entailed in cortical bone dowels on the endplate may predispose the graft to settling, irrespective of plate type. In addition, evaluation of subsidence has been addressed in more load-sharing and dynamic anterior cervical plating systems in ACDF with interbody bone grafts; however, methods to assess graft settling varied and to some degree were nominal.[13,15,16,22,23,27,41,42]

Our study, using a Smith-Robinson technique with tricortical iliac crest bone grafts, demonstrated that subsidence occurs in ACDF with rigid anterior plate fixation in patients with bone fusion, and it occurs throughout the anterior vertebral column (range of change in vertical height of fused construct, 0.0-3.5 mm, 0.0%-7.1%). In addition, more graft settling occurred at the anterior graft–endplate interface, perhaps because positioning the graft cortex anteriorly provided a hard contact surface that may have driven the graft into the cancellous bone. However, studies evaluating cortex positioning within the interbody space suggest that cortex location does not significantly affect graft settling.[19] Biomechanical testing has suggested increased load on the anterior aspect of the graft when the neck is in a flexed position, which may account for excessive settling of the graft material in the anterior region of the vertebral body.[43]

Although subsidence occurred throughout the graft–endplate interface, the largest amount of graft settling with respect to duration (monthly intervals after surgery) could not be discerned because evaluation of such radiographic follow-up periods was not conducted and was not the intent of this study. However, initial postoperative images were compared radiographically with images obtained 1 year after surgery, and beyond, to avoid factors that may be at play with primary bone-healing within that 1-year period. Furthermore, results from our series illustrate that late subsidence is associated with rigid anterior plate fixation of the cervical spine. Late subsidence occurred in each patient evaluated between 8 weeks to a minimum of 1 year—dispelling the theory that graft settling is completed within the first 6 weeks after surgery.

Although this series entails a small sample size, our previous review of 146 consecutive ACDF patients with rigid anterior plate fixation found a 96.5% overall fusion rate (95.5% for 1-level fusion; 97.5% for multilevel fusion).[30,32] Thirty-two consecutive patients were included in the current study for analysis of subsidence based on radiographs. Furthermore, although the risk for nonunion is higher in allograft versus autograft in noninstrumented ACDF,[14,44,45] studies have found similar fusion rates for both graft types in ACDF with rigid plate fixation.[30,32] Although our current study implemented 2 types of graft material, no statistically significant difference in degree of subsidence was found between the fresh-frozen tricortical iliac crest allograft and tricortical iliac crest autograft used in this series. However, the sample sizes for the graft types in this series were relatively small, and we wish to underline the importance of conducting larger studies to measure the graft-settling effects of various graft substrates and respective operative levels in instrumented ACDF patients. Nevertheless, rigid anterior plate fixation is meant to be largely a load-bearing construct that prevents excessive compressive forces on the graft, resulting in high fusion rates and minimal subsidence.

Various systemic and local factors have been known to complicate proper graft–host incorporation and contribute to nonunion. Smoking is a known systemic factor that affects revascularization, circulation, and expression of various cytokines that are all instrumental in bone growth and formation.[46-54] In this study, smokers and nonsmokers did not differ significantly in degree of subsidence. However, presence of smoking in its relation to clinical outcome or amount of graft settling and graft type could not be discerned from this study because of the small sample groups. Although smoking has been associated with high incidence of nonunion in noninstrumented ACDF,[14,55,56] application of an anterior cervical plate has been found to diminish the risk for nonunion and other graft complications often associated with presence of smoking.[30,31,33,38] Thus, if smoking does affect subsidence, the effects may have been minimal and nonsignificant in this series.

Although several factors contribute to clinical outcome, maintenance of cervical alignment is imperative to achieve optimal postoperative results. After attempting to address axial neck symptoms and degree of cervical alignment after ACDF, Kawakami and colleagues[57] concluded that extent of postoperative symptoms was related to degree of cervical alignment maintained after surgery. Furthermore, they reported, risk for developing axial symptoms after surgery was significantly related to loss of cervical lordosis and amount of loss of height of the interspace at the fused segment. Others have reported that loss of cervical lordosis affected clinical outcome[58-60] and that loss of cervical alignment was inevitable after ACDF but diminished with plating.[33,61,62] It has been suggested that graft collapse or subsidence from interbody fusion contributes to loss of segmental and overall cervical lordosis. Our current study results indicated that subsidence occurred in ACDF with rigid anterior plate fixation throughout the anterior vertebral column and was more prevalent at the anterior graft–endplate interface. Therefore, subsidence, primarily at the anterior region of the interbody construct, contributed to loss of integrity of sagittal balance of the cervical spine, which may contribute to segmental and overall cervical spine deformity and possible diminished neuroforaminal dimensions. However, loss of interbody height with use of rigid anterior plate fixation was minimal and may not pose a clinical dilemma in comparison with other load-sharing–promoting instrumentation constructs.[16] Nevertheless, our data suggest that designers of interbody prosthetic constructs and makers of graft substrates should take into account the excessive height loss at the anterior region of the graft–endplate interface. Furthermore, excellent and good clinical outcomes were noted in 90.9% of our patients. These results seemed relatively in accord with those from our previous consecutive series[30,31] and from other reports of ACDF with rigid anterior plate fixation.[33,40] In addition, amount of subsidence in our current series was relatively small, and the effects of number of fused levels and its association with graft settling could not be discerned from this sample size.

Instrumentation complications have occurred in plated ACDF, even in patients with bone fusion.[22,25,27,38,63-66] More notably, screw loosening and screw backout are common complications associated with instrumentation, primarily with nonconstrained or dynamic plating devices.[22,25,27,63] Biomechanical studies have suggested that cyclic loading may contribute to a toggling between screw loosening and screw backout.[67,68] However, graft settling may contribute to instrumentation-related complications by supplying excessive motion. Such instrumentation failures have contributed to dysphagia, esophageal perforation, or laryngeal nerve injury, all of which demand operative intervention if not resolved with conservative treatment.[22,25,38,64-66] Evaluating risk for injury from instrumentation failure in anterior cervical fusion, Lowery and McDonough[27] concluded that constrained plating systems (vs nonconstrained systems) were significantly less likely to develop instrumentation-related complications. The patients studied all achieved successful bone fusion, and a larger amount of bone settling occurred, though it was not measurably scaled, in patients with failed instrumentation versus patients with no instrumentation-related complications. The authors also noted that, in cases of excessive subsidence, screw breakage or plate pullout ensued. Nevertheless, such systems maintain minimal screw migration, which could be noted to be even greater in nonconstrained or dynamic plates, which promote subsidence. Although different plating systems were used in our series, they were all rigid plate-screw mechanisms, and in this study they all obtained rigid anterior fixation and yielded no instrumentation-related complications. In our previous review of such rigid plating systems (N = 146 ACDF patients), screw loosening and screw backout occurred in only 1.4% of cases (all multilevel), and there were no instrumentation-related fractures.[30,32] However, intravertebral screw migration was evident, with an ISD percent change of 1.2 % (range, 0%-7.1%), representing a 0.0- to 2.0-mm shift in position within the vertebral body. With the rigid plating systems in our study, though screw motion occurred within the vertebral body (stemming from graft settling), successful fusion was obtained. Thus, though some subsidence may establish fusion, risk for developing instrumentation-associated complications is a concern, as they may necessitate reoperation if excessive settling and motion occur at the segmental construct.

The radiographic measuring techniques proposed in our study provide a clear and easy assessment of graft subsidence and address the various regions (throughout the graft–endplate interface) where graft settling may occur—thus properly addressing the dynamics of subsidence and its interplay throughout the anterior cervical vertebral column. As such, this study suggests that minimal subsidence occurs in ACDF patients with rigid anterior plate fixation and tricortical iliac crest bone grafts. Furthermore, late subsidence, past the initial 8 weeks after surgery, occurred in ACDF patients with rigid instrumentation. In this series, subsidence seemed to occur irrespective of patient demographics, level of fused segment, number of fused levels, rigid plate design, graft type, and presence of smoking. However, a larger, randomized, controlled study is required to further investigate such factors in graft settling. Subsidence occurred in all 3 regions of the anterior cervical vertebral column but was predominant in the anterior graft–endplate interface, which may contribute to alterations in cervical alignment after ACDF surgery. Furthermore, screw motion in the vertical plane was associated with the presence of graft settling, which can lead to instrumentation failure in cases of excessive motion. However, subsidence in ACDF patients with rigid anterior plate fixation seemed to be minimal and yielded a high fusion rate with satisfactory clinical results. Additional investigation is needed to evaluate the varying instrumentation dynamics, degree of postoperative patient adherence, and additional radiographic assessment in a larger number of patients. A minimal amount of subsidence seems necessary to obtain solid fusion, but excessive graft settling may result in instrumentation failure and related morbidities, increase the risk for nonunion, contribute to cervical kyphosis, reduce neuroforaminal dimensions, and cause neural compression. Nevertheless, proper patient selection and meticulous operative technique are imperative to achieve optimal clinical outcome.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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