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Graft subsidence after instrument-assisted anterior cervical fusion

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Object. Bone grafts used in anterior cervical fusion (ACF) may subside postoperatively. The authors reviewed a recent series in which instrument-assisted ACF was performed to determine the degree of subsidence with respect to fusion length, use of segmental screws, and patient smoking status, age, and sex.

Methods. Charts and implant records were reviewed for all 70 patients who underwent instrument-assisted ACF during a 2-year period. The procedures, grafting materials, plate types/lengths, and patient smoking status were recorded. The immediate postoperative and follow-up lateral radiographs were analyzed. The plate lengths and lengths of the fused segments were measured in a standardized fashion.

The mean intraoperative and follow-up fusion segment lengths were 54.3 and 51.9 mm, respectively. Greater subsidence occurred in multilevel fusions than in single-level fusions. There were noticeable changes in the position of plates or screws on 14 of 70 follow-up x-ray films. No new neurological deficits related to graft subsidence occurred, and the reoperation rate was 3%. There was no statistical relation between subsidence and the following variables: segmental fixation, smoking status, sex, age, or dowel size when corrected for length of the plate. Hardware migration correlated significantly with plate length in cases of two- and three-level fusions.

Conclusions. The length of a fusion segment decreases in the immediate weeks following instrument-assisted ACF. Construct length is the most important determinant of subsidence. When designing multilevel cervical constructs, consideration of the effects of graft subsidence may help to avoid hardware-related complications.

KEY WORDS • cervical spondylosis • anterior cervical fusion • graft subsidence

THE placement of ACPs has become an increasingly popular technique for augmenting ACF. As surgeons have become more proficient with the use of ACPs, their applications have grown. Anterior cervical plates have been cited as a material for correcting traumatic instability, preventing pseudarthrosis, graft collapse, graft migration (especially in patients who smoke), as well as avoiding the use of a postoperative collar, improving anatomical and functional results, and facilitating a speedy return to work.[1,4,6,10,11,14,16,18,19,22,24–26] The effect of graft subsidence on the stability of the construct has been largely overlooked. As we have gained experience at our institution, radiologically documented changes in the configuration of the spinal implants have become increasingly apparent in the short interval between surgery and the first follow-up visit. These observations have led us to hypothesize that graft subsidence may be a primary or contributing cause of these changes. Subsidence is a term used to describe a decrease in the vertical height of the bone graft prior to complete incorporation of the fusion mass (Fig. 1; note the changes in the facet joint height in Fig. 1 *center* as a result of subsidence and the screw fracture in Fig. 1 *right* as a result of further subsidence). Analysis of data from previous studies (RS Graham, et al., unpublished data) suggests that subsidence is a phenomenon occurring early in the fusion process, usually within the first 6 weeks.[21] It might be expected that structural features of the construct (type or size of bone graft, number of levels fused, and presence of segmental screws) or patient-specific variables (smoking status, age, and sex) would affect the extent of subsidence or other changes in configuration. In this study, we have reviewed our recent series of instrument-assisted ACF in which we used the current-generation ACPs to determine the frequency and degree of subsidence with respect to fusion length, dowel size, presence of segmental screws, and patient sex, age, and smoking status.

Abbreviations used in this paper: ACF = anterior cervical fusion; ACP = anterior cervical plate; ANCOVA = analysis of covariance; VB = vertebral body.

Clinical Material and Methods

Design and Objectives

This study is a retrospective review of charts and radiographs obtained over a 2-year period in patients undergoing ACF and placement of instrumentation for degenerative spinal processes. Our objectives were to determine the

FIG. 1. Lateral cervical radiographs. *Left:* Intraoperative x-ray film of C4–6 ACF with an ACP. (Note: this patient was outside the time limit of the study.) *Center:* Follow-up x-ray film obtained at 6 weeks, demonstrating decrease in facet joint height as a result of further 0.34 mm of subsidence. *Right:* Follow-up x-ray film obtained at 5 months, demonstrating inferior screw fracture as a result of further 4.24 mm of subsidence.

degree of subsidence and the hardware complication rate for the current generation of cervical plates. A secondary objective was to determine if "segmental" fixation alters the degree of subsidence or rate of hardware migration.

Measuring Technique

Subsidence was determined radiographically (Fig. 2). Plate and fusion lengths were measured using the immediate postimplantation lateral x-ray films and compared with cervical spine x-ray films obtained during the follow-up visits (usually 6 weeks). The length of the fusion segment was determined by multiplying the known plate length (determined from the implant-related records) by the measured fusion length and dividing by the measured plate length (FL = KPL × MFL/MPL). The measured fusion length was determined in a standardized fashion as the distance from the midpoint between the anterior and posterior aspects of the superior endplate of the top level of the fusion to the midpoint of the inferior endplate of the bottom level of the fusion. If the view of the inferior endplate was obscured preventing definitive measurement, the x-ray films were classified as uninterpretable and the data were not used. The majority of the x-ray films (60) were obtained during each patient's first postoperative visit at 6 weeks. In 10 patients, radiographic measurements were determined at later follow-up visits up to 22 weeks postoperatively. The patient's corresponding clinic notes were reviewed and complications were documented.

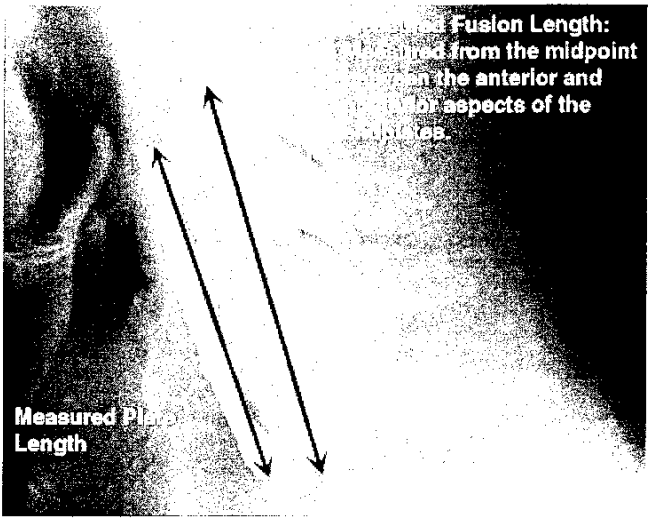
Patient Population

A retrospective analysis of patients undergoing ACF over the previous 2 years was performed. During this time period more than 600 ACF procedures were completed. Patients undergoing ACF for trauma-induced instability were excluded. One hundred seventy-six patients were identified as having undergone instrumentation-assisted ACF for diagnoses related to degenerative cervical disc disease. Implant records were retrieved for all patients. The essential data for the study were available in all cases. Of these, complete immediate postimplantation and follow-up x-ray films were available for review in 157 patients. Eighty-seven of the cases were excluded because measurements could not be determined. In nearly all cases this was because the inferior endplate at the bottom of the construct was obscured by the patient's shoulders. The study population was composed of the remaining 70 patients in whom we documented reliable measurements of the immediate postimplantation fusion length and the follow-up fusion length. A comparison of demographic features, fusion length, and dowel size obtained in the study population and a sample of 21 of the excluded patients revealed no significant differences with respect to age and number of fused vertebral levels. There was a higher percentage of men (71 and 41%) and smokers (57.1 and 45%) in the excluded group, compared with the study group, respectively.

The study population consisted of 29 men and 41 women, whose mean age was 48.3 years (range 27–74 years). Thirty-eight patients were nonsmokers and 32 were smokers. Anterior cervical fusion was performed for the following degenerative diseases: cervical spondylosis (46 cases), cervical herniated disc (20 cases), and cervical stenosis (five cases). There were two revision surgeries performed in patients in whom pain continued following the fusion surgery. One patient underwent posterior surgery for foraminal decompression to treat radicular pain, and the second patient underwent a second anterior discectomy and fusion for adjacent-level disease.

Surgical Procedure

In all cases a Cloward procedure was performed, and a 2-mm oversized dowel was inserted (that is, if a 10-mm hole was drilled, a 12-mm dowel was inserted). In one case involving a multilevel surgical revision, the segmental level was fused using the Smith–Robinson technique, and an autologous tricortical iliac crest graft was placed. Sixty-eight patients received donor bone, and two patients received autologous iliac crest bone. A total of 193 levels



Per level
1 1.11
2 1.11
3 0.90
4 0.75
mm/level

FIG. 2. Lateral cervical radiograph illustrating measurement technique.

were fused; 12-mm dowels were used in 136 of the levels and 14-mm dowels were used in 56 of the levels. In some cases, the same patient received a 12-mm dowel at one level and 14-mm dowel(s) at subsequent level(s). An Atlantis plate with fixed-angle screws was placed in 66 cases, a DOC-fixed plate (Depuy-Acromed, Raynham, MA) in two, and Orion plate (Medtronic Sofamor Danek, Memphis, TN) in two. In 38 of the patients screws were placed in the intervening VBs. In each case, the screws were placed just above the graft at the top of the construct and just below the graft at the bottom of the construct. Postoperatively all patients wore a rigid cervical collar for a minimum of 6 weeks.

The grafts (freeze-dried cortical bone dowels) were obtained from LifeNet (Virginia Beach, VA). The tissue was processed using Allowash, as well as bacitracin/polymyxin B sulfate and isopropyl alcohol. The cortical bone dowels were reconstituted according to the LifeNet guidelines.

Statistical Analysis

Statistical analysis was completed with the use of a personal computer, SAS, and StatView statistical software packages. Analyses with missing data were treated with case-wise deletion. Analysis of smoking-related data with respect to subsidence and plate length was performed using ANCOVA. Analysis of segmental screws with respect to subsidence and plate length was performed using analysis of covariance. Analysis of fusion length and plate length compared with subsidence was performed using Pearson correlation coefficient. Analysis of variance was used to study the effects of migration and sex. Age compared with subsidence was analyzed using regression analysis.

Results

The mean plate length was 50.3 mm (range 22–90 mm). The mean postimplantation and follow-up fusion segment heights documented in all patients were 54 and 51.8 mm, respectively ($p = 0.02$). There were 14 one-, 23 two-, 27 three-, and six four-level fusions performed. Single-level fusions decreased in length by a mean of 1.11 mm, two-level fusions by 2.21 mm, three-level fusions by 2.71 mm, and four-level fusions by 3.01 mm (Table 1). In 67 (96%) of the 70 patients we documented measurable subsidence, which was defined as decrease in the graft height on follow-up lateral cervical radiographs. The degree of subsidence correlated positively with the length of the ACP ($r = 0.319$, $p = 0.007$, Pearson correlation coefficient; Fig. 3 *upper*) and the number of levels fused ($r = 0.345$, $p = 0.003$, Pearson correlation coefficient; Fig. 3 *lower*).

Thirty-two patients were smokers at the time of surgery. Analysis of covariance was used to examine the relationship between smoking and subsidence with respect to plate length. The mean subsidence measurement was 1.76 mm in smokers and 2.67 mm in nonsmokers; however, smoking status was not a significant variable when plate length or the number of levels fused was considered ($p = 0.16$).

There was no statistically significant difference in subsidence if segmental screws were placed ($p = 0.85$), when corrected for plate length. Cases involving one-level fusions were not included in this analysis because by definition they had screws placed at each level. In patients in whom segmental screws were placed, fusion segments were longer (mean plate length with segmental screws 59 mm compared with 50.8 mm without segmental screws; $p = 0.02$).

No statistically significant difference was found when

TABLE 1

Summary of data in 70 patients who underwent instrument-assisted ACF

Parameter	No. of Cases	Subsidence*	p Value†
levels fused			
1	14	1.11 ± 0.19	
2	23	2.21 ± 0.45	
3	27	2.71 ± 0.31	
4	6	3.01 ± 0.48	
			0.003
smoking status			
nonsmoker	38	2.67 ± 0.30	
smoker	32	1.76 ± 0.34	
			0.16
segmental screws			
yes	38	2.54 ± 0.25	
no	32	1.90 ± 0.34	
			0.85
sex			
male	29	2.26 ± 0.33	
female	41	2.24 ± 0.27	
			0.60
dowel size (mm)‡			
12	23	1.95 ± 0.34	
14	14	2.10 ± 0.56	
			0.30
migration			
present	14	3.24 ± 0.50	
absent	56	2.00 ± 0.22	
			0.02§

* Values presented as the means ± error of the means.

† As determined when examined with respect to plate length.

‡ Cases in which more than one dowel size was used in the fusion construct were deleted.

§ For two- and three-level fusions.

subsidence was compared between men and women ($p = 0.95$). In men, however, longer fusion segments were required than in women (57.3 and 45.3 mm, respectively; $p = 0.0008$).

In comparison of subsidence with 12- or 14-mm dowels, there was no statistically significant difference ($p = 0.99$ [52 cases]; Fig. 4 *left*), nor when dowel size was adjusted for plate length ($p = 0.29$). Patients in whom more than one dowel size was included in their fusion were not included in this analysis. Likewise, using regression analysis, age was not a statistically significant variable in subsidence ($p = 0.66$).

In the present study, migration was functionally defined as an obvious change in plate or screw appearance on postoperative lateral radiographs. Migration was present on 14 (20%) of 70 follow-up lateral cervical radiographs. The incidence of migration varied significantly with plate length ($p = 0.02$) for two- and three-level fusions. Migration also varied significantly with subsidence. In those cases in which more subsidence occurred, there was a statistically significant increase in migration ($p = 0.017$; Fig. 4 *right*). Migration was not significantly related to the presence of segmental screws ($p = 0.08$), although there was a trend toward decreasing the incidence of migration when segmental screws were placed. Thirteen of 14 patients in whom migration occurred reported significant improvement in symptoms at the postoperative visits.

Only two patients (3%) required reoperation for pain.

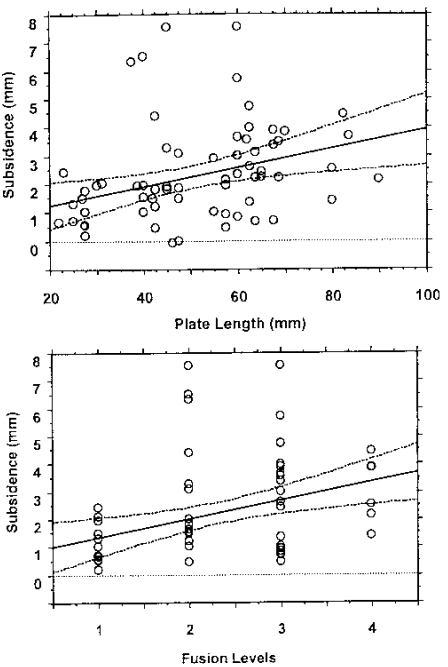


FIG. 3. *Upper:* Scatterplot of subsidence compared with plate length with 95% confidence interval. *Lower:* Scatterplot of subsidence compared with number of levels fused, with 95% confidence interval.

There were no postoperative wound infections, and 61 patients (87%) were characterized as having a good outcome by the operating surgeon. There were no instances of plate pullout (defined as anterior migration of the plate from the VB) or screw fractures. One patient, who had previously undergone ACF, experienced temporary hoarseness (that resolved completely) due to presumed recurrent laryngeal nerve neurapraxis. This was treated conservatively. One patient required a percutaneous endoscopic gastrotomy tube (later removed) because of difficulty swallowing postoperatively.

Discussion

Subsidence is the term given to the postoperative process of decreasing construct length due to the effects of load bearing. A variety of terms have been used to describe this process, including settling and telescoping.[20] Subsidence is relevant to surgeons performing anterior cervical interbody fusions because the grafts act to distract open the neural foramina, and this distraction can be lost as a result of subsidence, potentially resulting in the recurrence of radiculopathy.[21] Additionally, graft subsidence may

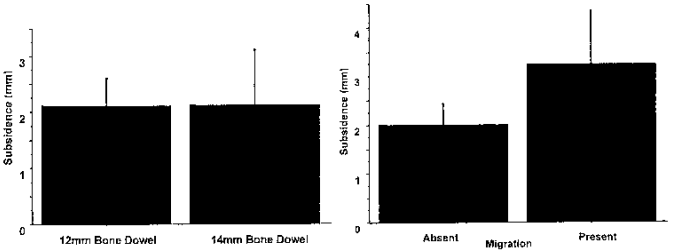


FIG. 4. Bar graphs demonstrating subsidence compared with dowel size *(left)* and migration *(right)*.

contribute to the formation of postoperative kyphosis. Graft subsidence in patients in whom anterior cervical instrumentation concomitantly is being placed is also likely to result in increased load bearing by the metal construct, with potential subsequent migration or failure.

White, et al.,[27] completed early studies of the load-bearing capacities of the Smith–Robinson, Cloward and Bailey–Badgley techniques for fusion. They used fresh cadaveric specimens to evaluate the immediate axial load–bearing characteristics of these fusion techniques. They concluded that the Smith–Robinson technique was superior in axial load–bearing strength compared with the other two techniques and believed this was because of a stronger graft and preservation of the vertebral endplate. They suggested that their information was applicable to the immediate postoperative period before any biological processes are active.

Closkey, et al.,[9] have examined the relationship between trabecular bone density, bone strength, and the size of the bone graft. They found that the area of contact for "the inter-body graft area should be significantly greater than 30% of the total end plate area to provide a margin of safety" for the prevention of subsidence. They noted that the compressive strength of the bone was important in influencing fusion mechanics. Analysis of their results showed that a graft should minimally cover 30 to 40% of the VB "if graft subsidence is to be avoided."

Brown, et al.,[7] have studied the postoperative radiographs obtained in 76 patients who underwent noninstrumented Smith–Robinson ACF in which frozen allograft and autograft were used. They found no statistically significant differences in the rate of fusion with allograft (94%) or autograft (97%). Collapse of the graft, however, defined as greater than 30% decrease in graft height, was found in 28% of patients receiving allograft compared with 16% of those receiving autograft. They reported a rate of collapse in cases of single-level fusion of 16% for allograft and 17% for autograft. Of patients in whom multilevel fusion was performed, a collapse rate of 36% was found in those in whom allograft was placed, which was significantly greater than that (6%) in those in whom autograft was used. The authors speculated that the high rate of graft collapse in this group might have been a result of host rejection or differences in the biomechanical properties of the allograft.

Zdeblick and Ducker[28] have reviewed the use of freeze-dried allograft for ACF in 87 patients in whom the Smith–Robinson technique was used. Patients were placed in a rigid collar for 6 weeks, in a soft collar for 2 additional weeks, and then allowed ad libitum activity. Autologous iliac crest grafts were used in 60 patients and freeze-dried iliac crests in the remaining 27. Graft collapse, defined as greater than a 2-mm loss of height, was more common in the group receiving freeze-dried allograft than in that receiving autograft (30 and 5%, respectively). Their 30% rate of graft collapse is significantly lower than our rate of subsidence, although it was comparable with our rate of 2-mm subsidence (45.7%). The rate of nonunion was identical for one-level fusions regardless of graft type but was "dramatically lower" for autograft in two-level fusions: 17% for autograft compared with 63% for allograft. Despite this, clinically there did not appear to be any intergroup difference, noting that relief of neck and arm pain was similar.[28] This is comparable with the incidence of 87% good outcome in this report.

Bishop, et al.,[3] have published a similar review of 132 patients who underwent noninstrumented Smith–Robinson fusions and determined rates of subsidence and loss of cervical lordosis with respect to graft type (autologous and allograft) and smoking status. They reported a mean single-level fusion subsidence of 1.4 mm for autograft and 2.4 mm for allograft. In cases of multilevel fusion, the mean graft subsidence was 3 mm (31% decrease in graft height) for allograft and 1.8 mm (18% decrease in graft height) for autograft.

The reports by Brown, et al.,[7] Zdeblick and Ducker,[28] and Bishop, et al.,[3] all suggest that the use of autologous bone results in decreased rates of subsidence when compared with allograft in noninstrumented fusions. It has yet to be determined whether these findings can be generalized to fusion procedures involving instrumentation. We believe that the introduction of fixation into the construct results in significant alteration in the load transfer through the fused segment in which transfer of load occurs from the graft to the plate especially during initial postoperative period. Although it remains to be proven, the use of anterior cervical fixation may minimize the differences in subsidence between autograft and allograft seen in earlier studies in which instrumentation was not placed.

Paramore, et al.,[21] have reported a radiographic review of Caspar plates in a study design similar to the present report. They examined the 4-week postoperative radiographs obtained in 49 patients. They noted a significant relation between plate length and plate failure (defined as radiograph-

ically demonstrated screw backout, screw pullout, plate breakage, or pseudarthrosis). Among the patients in whom plate failure occurred, a consistent finding of graft telescoping developed as the graft and VBs settled in the early phase of the healing process. Additionally, the investigators noted that the degree of telescoping was greater in the subgroup of cases classified as plate failures. Age, reoperation, and extent of procedure were associated with higher plate failure rates but were not statistically significant. They noted that "telescoping of the grafts and vertebral bodies, with concomitant migration of the plate and slippage of the screws, was common." Autologous bone grafts were used in all patients with single-level fusions. Allograft fibula bone was used when decompression included more than two VBs. Telescoping of the graft was for the most part tolerated by a combination of slot slippage and change in screw angulation. They also noted that if the telescoping became excessive, then screw pullout or plate breakage occurred. They theorized that telescoping occurred more frequently in cases involving the Caspar system because the screws were not locked into place. They believed that such a system allowed the VBs to share the load more effectively and improve the rate of fusion.

Greater than 2 mm of subsidence was a common finding (45.7%) in our patients. Like Paramore, et al.,[21] we found that subsidence increased with the length of the construct. We also observed evidence of migration on a number of postoperative x-ray films. Migration correlated significantly with the length of the plate in two- and three-level fusions. This did not correlate with outcome, because 13 of 14 patients with migration reported significant improvement in symptoms at the postoperative visits.

A number of authors have noted that radiographically detected complications must be correlated with the clinical neurological findings, because a spectrum of these complications may be compatible with satisfactory clinical results.[13,15,21] Results of our study also confirm the "forgiveness" of cervical spine fusions in the short term; in other words, despite the rate of subsidence (66 of 70 patients), only two patients have required reoperation for continued pain and not for revision of the fusion. Long-term follow-up review will be necessary to characterize the effects of sagittal-plane imbalance due to subsidence and to determine the incidence of subsequent spinal morbidity.

There was no statistically significant difference between subsidence in smokers and nonsmokers when plate length was taken into account. Furthermore, fusion lengths were shorter in smokers compared with nonsmokers. In 63.2% of nonsmokers either a three- or four-level fusion was performed, whereas in only 28% of smokers were three- or four-level fusions performed. Similarly, Martin, et al.,[17] have found no statistically significant difference with respect to fusion status and smoking status in patients in whom ACF was performed using freeze-dried fibular allograft.

In our study, we had one patient with a presumed recurrent laryngeal nerve neurapraxis, a complication well recognized, particularly in cases of lower cervical spine fusions.[2,5,12] The literature supports conservative management in these cases because, as was our experience, patients will typically improve.[8,18]

At our institution ACF is primarily performed using the Cloward technique. Typically, our surgical approach is from the right side. Careful attention is given to screw placement. We insert the screws just above the graft at the top of the construct and just below the graft at the bottom of the construct. We believe this technique allows for subsidence to occur without migration of the screws into adjacent disc spaces, and it may contribute to our low revision rate.

Segmental screws were placed in 38 (54%) of 70 cases. There was no statistically significant difference in subsidence with the presence of segmental screws. It is our opinion, however, that the addition of segmental screws provides a more solid construct, and although not statistically significant in this small series, there was a trend toward decreasing frequency of migration.

A potential for bias exists because of the exclusion of a large number of patients in whom the inferior endplate was visually obscured and reliable measurements were impossible. The study sample represented less than half of the total number of instrument-assisted ACFs performed. Analysis of a sampling of 21 of the excluded patients revealed that there were 17 in whom the C-6 or C-7 vertebra was the end fusion segment. Additionally in 17 (81%) of these 21 patients two or more levels were fused. Similarly, in the study population, 80% of cases had two or more levels fused. There were, however, more men (71 and 41%, respectively) and a higher percentage of smokers (57.1 and 45%, respectively) in the excluded population. The authors believe, that despite the number of excluded patients and other uncontrolled variables the primary finding (that is, the concept of the strong correlation between construct length and the degree of subsidence) would be unlikely to change because of minor differences between the study group and the excluded patients or because of other uncontrolled variables.

Finally, as mentioned earlier, the degree of subsidence likely depends on numerous variables such as surgical technique, bone graft type, the amount of distraction at the time of surgery, specific mechanical properties of the fixation used, and the patient's bone quality. The data in this study were acquired in a standardized fashion in cases of instrument-assisted Cloward fusion. Caution should be used in generalizing the results of the present study to other surgical techniques, graft types, and models of ACFs.

Conclusions

The length of a fusion segment commonly decreases in the immediate weeks following instrument-assisted ACF. The length of the construct is the most important determinant of the degree of subsidence. Hardware migration was significantly related to plate length in two- and three-level fusions. There was a trend toward decreased incidence of migration when segmental screws were used. There was no statistical relationship between subsidence and segmental fixation, sex, age, dowel size, or smoking status.

When designing multilevel cervical fusion constructs, particular attention should be given to selection of the appropriate plate length. Placement of screws just above and just below the grafts at the top and bottom of the construct may help to minimize hardware complications, resulting from graft subsidence. We also advocate the placement of segmental screws to help minimize hardware migration.

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