

Original Article

Dynamic anterior cervical plates for multilevel anterior corpectomy and fusion with simultaneous posterior wiring and fusion: efficacy and outcomes

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Study design: To prospectively evaluate major complications associated with the application of dynamic ABC plates (Aesculap, Tuttlingen, Germany) to multilevel Anterior Corpectomy/Fusion (ACF) followed by posterior fusion (C2–C7 PF).

Objectives: To determine whether dynamic ABC (Aesculap, Tuttlingen, Germany) plates would minimize major complications (plate/graft extrusion, pseudarthrosis) while maximizing neurological outcomes in 40 consecutive patients undergoing simultaneous multilevel ACF/PF with halo application.

Setting: USA.

Methods: Patients averaged 53 years of age and preoperatively exhibited severe myeloradiculopathy (Nurick Grade 3.9). MR/CT studies documented marked ossification of the posterior longitudinal ligament/spondylosclerosis. Surgery included two to four level ACF utilizing fibula strut allograft and ABC plates. Posterior spinous process wiring/fusions utilized braided titanium cables. The average operative time was 8.9 h. Fusion was confirmed on dynamic X-rays/CTs (3–12 months postoperatively). The average follow-up interval was 2.7 years. Outcomes (3 months–2 years postoperatively) were assessed utilizing Odom's Criteria, Nurick Grades, and SF-36 questionnaires.

Results: Major complications included one pseudarthrosis requiring secondary PWF. Minor complications in six patients included two pulmonary emboli (PE), two tracheostomies, and five superficial wound infections. At 1 year postoperatively, marked improvement was observed in all patients utilizing Odom's criteria (38 excellent/good), Nurick Grades (mild radiculopathy 0.4), and the SF-36 (3 Health Scales; Role Physical (12.5–38.6), Bodily Pain (39.9–65.5), and Role Emotional (53.8–75.8)]. The 2-year postoperative data showed minimal additional improvement. The average time to fusion was 6.3 months.

Conclusion: Patients undergoing multilevel ACF/PF demonstrated marked neurological improvement (SF-36), and only one of 40 developed a delayed pseudarthrosis.

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Introduction

Multilevel anterior corpectomy with fusion (ACF) performed with fixed-plates has been associated with a high incidence of major complications (graft/plate extrusion, pseudarthrosis).¹ Vaccaro *et al*² documented plate/graft-related failures for 9% of two level ACF and 50% of three level ACF. To avoid these failures, dynamic ABC plates (Aesculap, Tuttlingen, Germany) were prospectively applied for multilevel ACF (two to four level total corpectomies with additional partial

cephalad/caudad corpectomy) with simultaneous posterior wiring and fusion (PWF) in 40 consecutive patients. All patients exhibited severe myeloradiculopathy attributed to ossification of the posterior longitudinal ligament (OPLL) and spondylosclerosis. Major and minor complications along with surgeon-based (Odom's Criteria, Nurick Grades), and patient-based (Short-Form 36) outcomes were assessed.

Methods

Forty consecutive patients undergoing circumferential cervical surgery for OPLL and spondylosclerosis were

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Figure 1 Lateral 2D-CT of Klippel-Feil anomaly with spontaneous fusion of the C2–C3–C4 levels both anteriorly and posteriorly

prospectively evaluated (Figures 1–5). Total corpectomies included the removal of 2–4 (average 2.3) complete vertebral bodies (Table 1). Note that by definition, a C3–C7 ACF was called a three level corpectomy; three total vertebrae were removed (C4–C6) and the partial cephalad (C3) and caudad (C7) corpectomies were omitted from this notation. All patients received fresh frozen fibula strut allografts and dynamic anterior cervical ABC plates (Aesculap, Tuttlingen, Germany) utilizing variable angle screws. Under the same anesthetic, patients had simultaneous C2–T1 PWF performed. These utilized individual spinous process braided titanium cable wiring to fibula strut allografts (33 patients) or a rod/eyelet construct (Vertex, Sofamor Danek, Memphis, TN) (7 patients) (Figures 6 and 7). Based on surgeon preference, halo braces were utilized in all patients until fusion occurred rather than cervico-thoracic orthoses (CTO). All posterior fusions were performed utilizing iliac crest autograft supplemented with demineralized bone matrix (ICM, Inductive Conductive Matrix, Sofamor Danek, Memphis, TN). Patients averaged 53 years of age (27–74), and included 27 males and 13 females. In all, 16 patients were smokers and were strongly advised to stop post-



Figure 2 MR in patient also shown in Figure 1 with C2–C4 Klippel-Feil anomaly showing early OPLL characterized by hypertrophied posterior longitudinal ligament contributing to marked cord compression from C4 to C7. At surgery, the compression was due to early OPLL with an added disc herniation at the C4–C5 level. Dorsal intrusion from buckled yellow ligament was relieved following the anterior corpectomy and did not warrant laminectomy

operatively. Preoperatively, patients typically exhibited severe myeloradiculopathy (average Nurick Grade 3.9). The average operative time was 8.9 h (range 6.5–11). The average transfusion requirement was 2.0 units (range 0–4). Fiberoptic postoperative extubation was performed on average 1.3 days postoperatively (range 1–7 days). Postoperative fusion was evaluated with dynamic X-rays and 2D–CT examinations performed at 3, 4.5, and 6 months postoperatively, and up to 12 months where indicated. The average follow-up interval was 2.7 years. Surgeon-based outcomes were assessed utilizing Odom's Criteria and preoperative and postoperative Nurick Grades. Patient-based outcomes were determined with SF-36 questionnaires administered preoperatively, and at 3 months, 6 months, 1 year, and up to 2 years postoperatively.

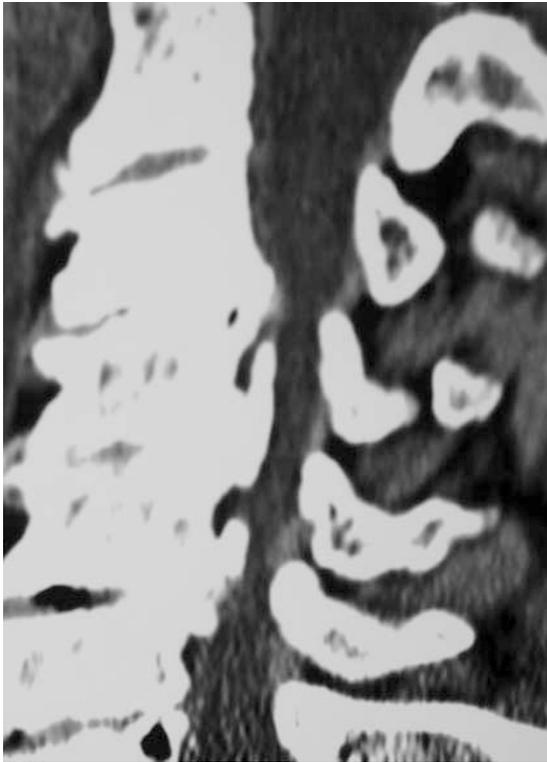


Figure 3 The parasagittal 2D-CT scan demonstrates mature multilevel continuous OPLL extending from C3 to C7

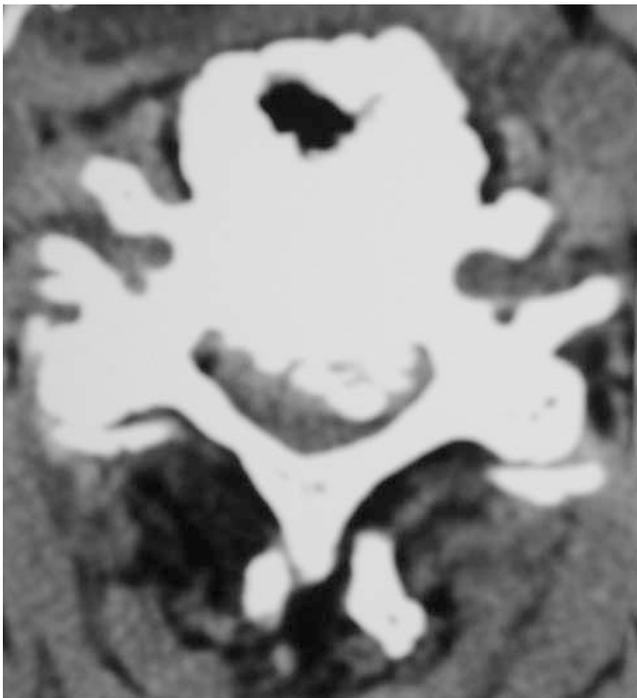


Figure 4 Transaxial noncontrast CT scan at the mid C6 vertebral level showing massive mature OPLL and early OPLL, characterized by pearls of ossification, contributing to marked ventral cord compression

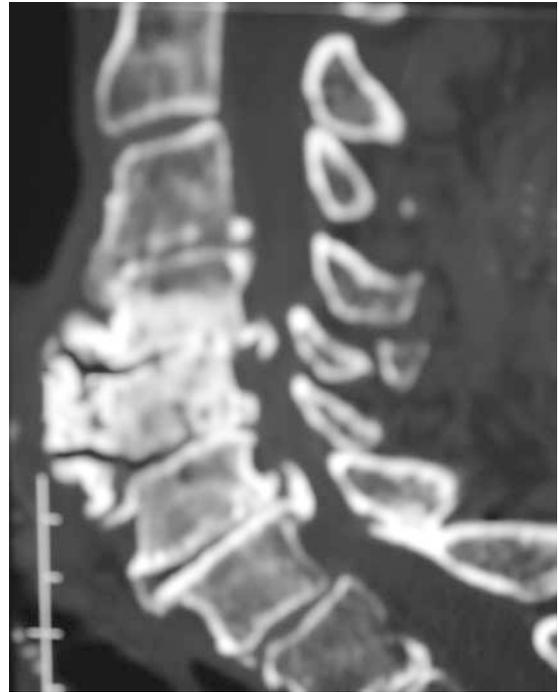


Figure 5 Multilevel OPLL is demonstrated on this paramedian sagittal 2D-CT scan extending from the inferior aspect of C4 through the superior aspect of C7. Also note the presence of advanced ossification of the anterior longitudinal ligament also involving the anterior vertebral bodies from C4, C5, C6

Results

The average time to fusion documented on dynamic X-rays and 2D-CT studies postoperatively was 6.3 months (range 4–9 months) (Table 1). Only one patient developed both a major (defined as requiring secondary surgery directly related to graft/plate failure, pseudarthrosis) and a minor (medical management/warranting no secondary spinal surgery) complication (Table 2). He was an obese 48-year-old male (6'4", 280 lbs) who developed pseudarthrosis 6 months postoperatively and required a second posterior fusion; he fused 6 months later. He also developed halo pin-site cellulitis 4 months following the second surgery, which was treated with halo removal followed by the application of a hard cervico-thoracic orthosis, and 10 days of intravenous antibiotics.

The remaining six patients developed overlapping minor complications (Table 2). A 44-year-old male substance abuser, developed a posterior cervical wound infection and DVT 10 days postoperatively; treatment included 6 weeks of intravenous antibiotics and an inferior vena cava filter (IVC); DVT resolved and required no heparin-based therapy. A 51-year-old male developed DVT 6 days postoperatively. An attempt at placement of a removable filter (Bard) resulted in embolization of this device to the right ventricle; a permanent filter was placed on the 7th postoperative day

Table 1 Clinical data for 40 patients undergoing multilevel anterior cervical corpectomy/fusion with posterior wiring/fusion utilizing dynamic anterior ABC plates

Clinical data	Dynamic ABC-plated multilevel anterior corpectomy/fusion/posterior fusion (40 patients)
Average age (range)	53 years old (range 23–74 years)
Sex	13 females 27 males
Anterior corpectomy/fusion	
Average number levels (range)	2.3 (range 2–4 levels)
4 Level ACF	2
3 Level ACF	13
2 Level ACF	25
Posterior wiring/fusion levels C2–T1	40 patients
<i>Nurick grades</i>	
Average preoperative grade	3.9
Average grade 1 year postoperatively	0.4
Odom's criteria (1 year postoperatively)	38 good/excellent 2 fair/poor
Average follow-up (range)	2.7 years (range 2–5.5 years)
Average operative time (range)	8.9 h (range 6.5–11 h)
Average time to extubation (range)	1.3 days (range 1–7 days)
<i>Major complications</i>	1 patient
Graft/plate fracture/extrusion	0
Pseudarthrosis	1 (6 months postoperatively)
<i>Minor complications (overlapping)</i>	7 patients
Tracheostomy	2
Infection	5
DVT/PE	4
PE	2 of 4
Average time to fusion (range)	6.3 months (range 4–9 months)

DVT = deep venous thrombosis; PE = pulmonary embolism

(Greenfield), and the embolized filter was removed via thoracotomy on the 13th postoperative day without incident. A moderately obese (5'2", 180 lbs) 60-year-old female, developed a posterior cervical wound infection 6 days postoperatively and DVT with pulmonary emboli (PE) 10 days postoperatively; the former was treated with 6 weeks of intravenous antibiotics and the latter with IVC filter placement and Heparin followed by Warfarin. A 68-year-old obese male (5'10", 240 lbs) with

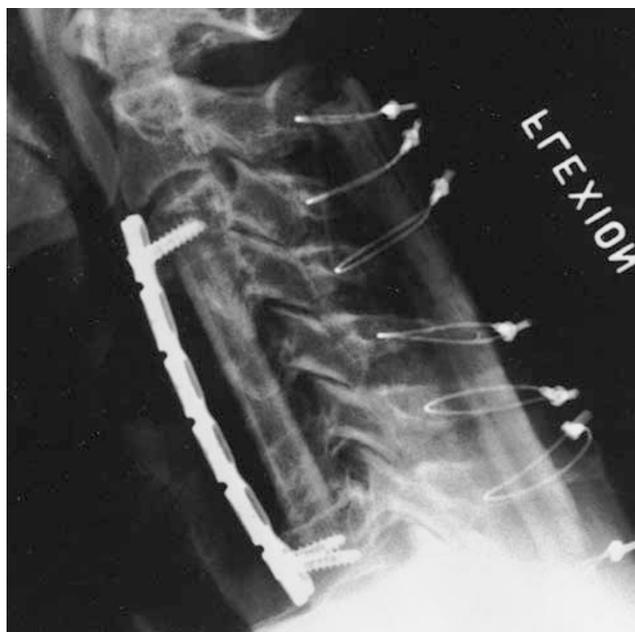


Figure 6 The anterior corpectomy and fusion from C3 to C7 was performed with a fibula strut allograft and dynamic ABC plate. Posteriorly, a fibula strut was affixed to each of the C2–T1 spinous processes utilizing braided titanium cable. The fusion was supplemented with iliac crest autograft and demineralized bone matrix (ICM: Sofamor Danek, Memphis, TN)



Figure 7 Anterior corpectomy and fusion performed from C4 to C7 with fibula strut allograft and ABC plate. Note, that the posterior spinous process wiring/fusion from C2 to T1 was performed utilizing titanium rods, eyelets (Vertex System (Sofamor, Danek, Memphis, TN)), and braided titanium cable without lateral mass screws. The posterior construct also included iliac crest autograft and demineralized bone matrix (ICM: Sofamor Danek, Memphis, TN)

Table 2 Major and minor complications in dynamic-plated multilevel anterior corpectomy/fusion and posterior wiring/fusion patients

Case	Age Sex Height Weight	Comorbidity Factors	Complications	Treatment
1	48 M 6'4" 280 lbs	Obesity Hypertension	<i>Pseudarthrosis</i> 6 months <i>Halo Pin Site</i> cellulitis	<i>2nd Surgery</i> Posterior fusion 6 months postoperatively <i>10 Days IV/oral</i> antibiotics
2	44 M 5'4" 180 lbs	Drug use	<i>Posterior</i> cervical infection Day 7 <i>DVT</i> day 10	<i>No surgery</i> 6 weeks IV antibiotics <i>Inferior vena cava</i> filter (IVC)
3	51 M 6'2" 220 lbs	Diabetes Hypertension	<i>DVT</i> day 6 (calf vein)	<i>6 days Bard filter</i> embolized to right ventricle Day 7: <i>Greenfield</i> inferior vena cava filter placed Day 13: <i>thoracotomy</i> Bard filter retrieval
4	60 F 5'2" 180 lbs	Obesity Hypertension	<i>Posterior</i> cervical infection Day 6 <i>DVT</i> / Pulmonary embolism Day 10	<i>6 Weeks IV</i> Antibiotics <i>Heparin and Warfarin</i>
5	68 M 5'10" 240 lbs	Obesity Diabetes Hypertension MI, COPD	<i>DVT</i> / Pulmonary embolism Day 14	<i>Tracheostomy</i> Heparin and Warfarin
6	44 F 5'2" 300 lbs	Morbid Obesity Asthma Hypertension	<i>Respiratory</i> Compromise <i>Posterior</i> cervical infection Day 14	<i>Tracheostomy</i> postoperative day 7 <i>Debridement</i> / 6 weeks IV antibiotics
7	59 M 5'9" 260 lbs	Obesity Hypertension	<i>Infection:</i> Halo-pin site cerebritis 6 months	<i>Removal of halo</i> 6 weeks of IV antibiotics

DVT = deep venous thrombosis, MI = myocardial infarct, COPD = chronic obstructive pulmonary disease

severe diabetes, hypertension, myocardial infarctions, chronic obstructive pulmonary disease and past pneumonias, developed DVT and PE on postoperative day 14 requiring a tracheostomy and intravenous Heparin followed by Warfarin. A 44-year-old morbidly obese (5'2", 300 lbs) female with asthma, required a tracheostomy on postoperative day 7, and developed a posterior cervical wound infection on postoperative day 14 requiring wound debridement plus 6 weeks of intravenous antibiotics. A 59-year-old obese male (5'9", 260 lbs) developed a halo-pin site cerebritis 6 months postoperatively managed with halo removal and 6 weeks of intravenous antibiotics.

Outcomes

Based on Odom's criteria, patients exhibited 35 excellent, three good, and two fair outcomes 1 year postoperatively. They also improved from showing severe preoperative myelopathy (average Nurick Grade

3.9) to demonstrating mild residual postoperative radiculopathy (average Nurick Grade 0.4).

Postoperative SF-36 scores demonstrated gradual improvement over the first postoperative year. Quantitative (Table 3a) data were placed into four qualitative categories to simplify data analysis (Table 3b); patients were graded as worse (negative numbers), or showing minimal (1–4 Points), mild (5–10 Points), moderate (11–20 Points), or marked (> 20 Points) improvement. Three months postoperatively, worsening was noted on 3 (General Health (GH), Social Function (SF), Mental Health (MH)), minimal improvement was seen on five (Physical Function (PF), GH, SF, Role Emotional (RE), MH), minimal improvement on one (Role Physical (RP)), and mild improvement on two (PF), and Vitality (V) Health Scales. At 6 months following surgery, one demonstrated worsening (PF), one showed minimal (GH), three demonstrated mild (V, SF, MH), two showed moderate (BP, RE), and one showed marked improvement (RP). One year following surgery, one was worse (GH) one showed minimal (PF), two showed mild

Table 3 (a) Quantitative SF-36 outcome data for 40 patients undergoing dynamic-plated multilevel anterior corpectomy/fusion with posterior fusion. (b) Qualitative summary of SF-36 outcome data for 40 patients undergoing dynamic-plated multilevel anterior corpectomy/fusion with posterior fusion

Date	Physical function	Role physical	Bodily pain	General health	Vitality	Social function	Role emotional	Mental health
<i>(a) Quantitative data</i>								
Preoperatively	42.9	12.5	39.9	72.7	49.4	56.2	53.8	69.7
3 months postop	33.1	13.5	57.5	72.1	56	50	48.7	68
Net preop/3 months postop	-9.8	+1.0	+17.6	-0.6	+6.6	-6.2	-5.1	-1.7
6 months postop	33.7	40.7	55.8	74.4	55.6	62.5	64.2	74.2
Net preop/6 months postop	-9.2	+28.2	+15.9	+1.7	+6.2	+6.0	+10.4	+4.5
1 year postop	45.5	38.6	65.5	70.3	55.5	71.6	75.8	76.7
Net points	2.6	+26.1	+25.6	-2.4	+6.1	+15.4	+22	+7
<i>(b) Qualitative data</i>								
3 months postop	Worse	Minimal	Mild	Worse	Mild	Worse	Worse	Worse
6 months postop	Worse	Marked	Moderate	Minimal	Mild	Mild	Moderate	Mild
1 year postop	Minimal	Marked	Marked	Worse	Mild	Moderate	Marked	Mild

Postop = postoperatively, 3 months = 3 months postoperatively, 6 months = 6 months postoperatively, 1 year = 1 year postoperatively
Worse (- numbers), Minimal (1-4 Points), Mild (5-10 Points), Moderate (11-20 points), Marked (>20 points).

(V, MH), one showed moderate (SF), while three showed marked improvement (RP, BP, RE).

Conclusion

Outcome data

Surgeon-based Odom's criteria have typically been utilized to evaluate the results of anterior cervical surgery performed with and without fixed plates.²⁻⁶ Odom's criteria yielded 90% good/excellent results for one level anterior discectomy/fusion (ACDF) performed with fixed plates and 88% without plates in Wang, McDonough, Endow *et al*⁷ series. Comparable rates of fusion and similar clinical outcomes (Odom's criteria) followed fixed-plated two level ACDF (32 patients) when compared with one level plated ACF (20 patients).⁸ In another series, utilizing Odom's criteria, 36 of 39-plated two level ACDF (allograft) exhibited excellent to good outcomes compared with 23 of 25 nonplated patients (allograft).⁹ Epstein utilized both Odom's criteria and Nurick Grades to evaluate outcomes of anterior cervical procedures varying from nonplated single level anterior discectomy/fusion to plated multilevel circumferential operations.¹⁰⁻¹⁷

Anterior cervical surgical series have increasingly utilized the patient-based SF-36. In Klein, Vaccaro and Albert's series of two level ACDF (28 patients), patients demonstrated significant postoperative improvement on five Health Scales: Bodily Pain

($P < 0.001$) V ($P = 0.003$), PF ($P = 0.01$) RP ($P = 0.003$) and SF ($P = 0.0004$).¹⁸ Epstein utilized Nurick Grades, Odom's criteria, and/or SF-36 to evaluate single level ACF procedures performed with fixed or dynamic-plate systems, with or without iliac crest reconstruction.¹⁹⁻²²

Other studies focus on integrating surgeon and patient-based outcome data. One spinal series utilized the SF-36, the Oswestry questionnaire, and the Low Back Pain Disability Scale.²³ Another study, evaluating neck pain for patients undergoing ACDF (87 patients), employed the Visual Analog Scale, North American Spine Society Satisfaction Questionnaire, the Modified Roland and Morris Disability Index, and the modified Oswestry Disability Questionnaire.²⁴ Evaluating 80 patients with cervical myelopathy, King and Roberts determined that the SF-36 proved 'valid' when compared with surgeon-based Nurick, Cooper Harsh, and a Western modification of the Japanese Orthopedic Association Scores.²⁵ Hacker *et al*²⁶ found that results following single-level ACDF utilizing cervical fusion cages *versus* noninstrumented procedures yielded similar results on both the Visual Analog Pain Scale and the SF-36.

Few have applied Odom's Criteria, Nurick Grades, and the SF-36 to evaluate the results of circumferential cervical surgery.²⁷ In a prior partially overlapping series of patients undergoing fixed-plated (28 patients) and dynamic-plated (19 patients) multilevel ACF accompanied by simultaneous PWF, 1 and 2 year postoperative data utilizing these three techniques was collected. For

both the first and second postoperative years, Odom's Criteria demonstrated 31/47 good/excellent results. Over the same period, Nurick Grades demonstrated mild radiculopathy/myelopathy, with mild improvement noted between the 1st and 2nd years with respective Nurick Grades of 0.8 to 0.4. In comparison, the 40 patients undergoing dynamic-plated multilevel ACF with PWF, Nurick Grades and Odom's criteria demonstrated maximal improvement 1 year postoperatively with 38 of 40 demonstrating excellent/good outcomes (Odom's Criteria) and all patients exhibited only mild residual radiculopathy/myelopathy (average Nurick Grade 0.4) (Table 1).

In both, a prior overlapping series²⁷ and the present study, SF-36 data demonstrated maximal improvement by the first postoperative year (Table 3a and b). In the previous series employing fixed plates (23 patients) and dynamic-plates (19 patients) to perform 47 multilevel ACF accompanied by PWF, SF-36 data demonstrated little difference in the degree of improvement occurring between the first and second postoperative years. At 1 year postoperatively, patients exhibited moderate improvement on five Health Scales (SF, BP, RP, PF, RE), with two showing mild (MH, V), and one demonstrating minimal improvement (GH). By the second postoperative year, marked improvement was noted on one (RP), moderate improvement on three (SF, BP, PF), mild improvement on three (RE, MH, V), and minimal improvement on one (GH) Health Scale. In the present study, utilizing only dynamic ABC plates for all 40 patients undergoing multilevel ACF with PWF, progressive improvement from 3 to 6 month postoperative data were observed 1 year postoperatively on 3 of 8 Health Scales: RP, and Bodily Pain, with RE. RP and Bodily Pain seem to consistently reflect maximal improvement in these two series, while GH, V, and MH appear to show the smallest changes before and following operative intervention; the remaining 3 Health Scales fall somewhere in between. Note that the degree of neurological improvement documented on the SF-36 was not attributed to either the utilization of fixed or dynamic-plating devices, as both fixed and dynamic-plates had been utilized in the series cited.

Dynamic-plate versus fixed plate considerations

The dynamic-plate was developed secondary to failures encountered utilizing fixed-plated systems particularly for multilevel anterior cervical constructs, typically corpectomies (Figure 8). Vaccaro *et al*² observed a 9% failure rate following fixed-plated two level ACF and a 50% failure rate with three level ACF performed without simultaneous posterior fusions. Schultz *et al*²⁸ later observed a 100% fusion rate for 64 patients undergoing fixed-plated two and three level ACF accompanied by simultaneous lateral mass plating; 2 years postoperatively, 1 plate dislodged while 15 of 516 lateral mass screws partially 'backed out' (none required secondary surgery). For multilevel ACF performed with simultaneous posterior fusion, the author previously



Figure 8 At 6 weeks following a fixed-plated (Orion: Sofamor Danek, Memphis, TN) C3–C7 ACF with C2–T1 PWF, the patient complained of dysphagia. Although the lateral X-ray and CT showed anterior/inferior plate extrusion, the graft remained in place. The patient was maintained in the halo device until fusion occurred 6 months postoperatively as shown on this mildine sagittal 3D–CT study, and then underwent anterior plate removal for persistent dysphagia

determined that three of 22 nonplated patients experienced failures, and successively that five of 38 fixed-plated patients required secondary surgery attributed to fixed-plate failures (major complications: graft/plate extrusion, pseudarthrosis).^{10,16,27} In this study, the safety and efficacy of dynamic ABC plates for multilevel anterior cervical constructs accompanied by simultaneous posterior fusion were demonstrated, as here, only one (2.5%) of 40 patients developed pseudarthrosis warranting secondary posterior fusion 6 months postoperatively.

Other considerations

The choice for spinous process wiring for posterior fusion over lateral mass screw/plate placement was based on surgeon preference (ease, rapidity and safety of application) and on its FDA approval status. Certainly, lateral mass plates as utilized by Schultz *et al*²⁸ constitute part of the 'standard of care' for posterior fusion, and are preferred by many surgeons, although not FDA approved in the US.

Additionally, surgeon preference led to the choice of halo bracing postoperatively rather than utilization of cervico-thoracic orthoses. Of note, in Vaccaro *et al*'s study, the 9% extrusion rate for two level plated ACF, and 50% failure rate for three level plated ACF (both

without posterior fusions) were comparable whether patients wore halo devices or CTO orthoses.²

Conclusions

One of the 40 patients undergoing complex circumferential cervical surgery developed a major postoperative complication, pseudarthrosis, warranting secondary posterior fusion; no other graft or plated-related complications, no cerebrospinal fluid fistulas, no cord or root deficits, and no deaths were encountered. Six other patients developed overlapping minor complications. Furthermore, patients exhibited marked neurological improvement based on Odom's Criteria (38 good/excellent), Nurick Grades (average + 3.5), and the SF-36 outcomes questionnaire (+ 22 to + 26.1 on three Health Scales). Multilevel ACF performed utilizing dynamic-plates, accompanied by PWF, proved to be safe and effective while promoting excellent outcomes.

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