The Radiographic Failure of Single Segment Anterior Cervical Plate Fixation in Traumatic Cervical Flexion Distraction Injuries

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Study Design. A radiographic review of 87 patients with either unilateral or bilateral facet dislocations or fracture/dislocations treated with anterior cervical discectomy, fusion, and plating.

Objective. The primary objective of this study was to report the incidence of radiographic failure and factors that would predispose to this loss of alignment. The secondary objective was to report the rate of pseudarthrosis.

Summary of Background Data. Biomechanical and clinical data conflict regarding the appropriate approach and method of fixation of distractive flexion cervical injuries. Unilateral and bilateral facet fracture subluxations may be surgically stabilized by anterior cervical discectomy, fusion, and plating, posterior instrumentation, or both. There are no documented reports of the rate of radiographic failure of this procedure when limited to a single level injury from a distractive flexion mechanism.

Methods. Inclusion criteria were all single-level unilateral and bilateral facet fracture dislocations or subluxations treated with a single-level anterior cervical discectomy, fusion, and plating. Retrospectively, 107 cases were identified (87 with complete radiographs) from January 1994 to December 2001. Radiographic failure was defined as a change in translation of greater than 4 mm and/or change in angulation of greater than 11° between the immediate postoperative films and the most recent follow-up. Fusion was assessed radiographically.

Results. A 13% incidence of radiographic loss of alignment is reported in 87 unilateral and bilateral facet fracture subluxations stabilized with anterior cervical discectomy, fusion, and plating. Radiographic failure correlated with the presence of endplate compression fracture and facet fractures on injury radiographs. There was no correlation between radiographic failure and age, gender, surgeon, unilateral or bilateral injury, plate type, level of injury, degree of translation, or sagittal alignment at the time of injury.

Conclusion. Loss of postoperative alignment occurred in 13% of facet fracture subluxations treated with anterior cervical discectomy, fusion, and plating. Concern regarding mechanical failure of flexion/distraction injuries should be high when they are associated with fractures of either the facets or of the endplate. Endplate fracture was associated with both mechanical failure and pseudarthrosis.

Key words: cervical spine trauma, facet fracture, anterior plate. **Spine 2004;29:2815–2820**

Cervical distractive flexion injuries may be treated with anterior[1–3] or posterior[4–6] stabilization alone, or a combined anterior and posterior surgical approach.[7–11] Successful clinical results have been reported with each of these techniques. Beyond the individual surgeons' belief and current practice, there are few objective criteria on which to base a decision to stabilize these cervical injuries with either an anterior or posterior surgical approach or both.[9,12,13]

A distractive flexion mechanism of injury may produce a posterior cervical ligament rupture, a unilateral or bilateral facet dislocation, or even complete translation of one vertebral body relative to another. In the mechanistic classification system of Allen *et al*, these distractive flexion injuries are divided into 4 stages that span a range of ligamentous and bony injury.[14] Unilateral and bilateral facet fractures, as well as laminar and endplate fractures, are commonly associated with these subluxations and dislocations. Following the basic principles of fracture management, these injuries, which primarily affect the posterior bony and ligamentous structures, were most frequently stabilized using a posterior approach with posterior wiring, plate and screw, hook-plate, and more recently rod and screw segmental fixation.[4,6,15] Benefits of the posterior approach for fixation include a high rate of successful arthrodesis and the safety and familiarity of the approach.[5,16–18] Despite this, there has been a shift to anterior surgery for many of these injuries that has paralleled the introduction of improved anterior cervical plate designs.[1,19]

Anterior cervical decompression, fusion, and plate stabilization (ACFP) has become increasingly popular due to several advantages over the conventional posterior approach.[20] The anterior approach enables the surgeon to decompress the spinal canal by removing the disc and thus ensure that disc sequestration will not cause neurologic deterioration.[21–24] The anterior approach en-

ables stabilization of 1 motion segment, whereas posterior element fractures, particularly those that extend into the lateral mass or facet, often require the fusion to extend over 2 or more segments. Finally, the exploitation of natural anatomic planes obviates the need for extensive muscle stripping, potentially leading to a reduced infection rate and less postoperative pain.[25]

Several biomechanical studies have raised concern regarding the adequacy of anterior plating for stabilizing these posterior element injuries.[26–28] Anterior plating has been found to be inferior to posterior fixation, particularly in resisting flexion moments.[29,30] Furthermore, several authors have called for combined anterior and posterior stabilization for injuries such as bilateral facet dislocations, or "3 column" cervical injuries without clearly identifying the morphologic features of these injuries that would identify the potential for the failure of anterior cervical plating alone.[7–11] We are not aware of any studies that have critically analyzed distractive flexion injuries to identify objective criteria that would assist the surgeon in deciding when anterior fixation alone is not adequate and when either posterior fixation or a combination of anterior and posterior fixation is more advisable.

The primary purpose of this study was to identify patient and radiographic features of single segment distractive flexion injuries that predispose to mechanical failure when these injuries are treated with anterior cervical discectomy, fusion, and plating (ACDFP). Our secondary study objectives were to assess the failure rate in all patients whom we have treated with single segment anterior cervical plating for traumatic distractive flexion injuries.

■ Materials and Methods

Inclusion and Exclusion Criteria. A retrospective search of a research database at the Vancouver General Hospital Acute Spinal Cord Injury Unit was performed. Patients were eligible for inclusion in the study if they:

- Had a diagnosis of acute unilateral or bilateral facet injury (either facet dislocation and/or subluxation or facet fracture/dislocation and/or subluxation) Allen *et al* distractive flexion injury stage 1 through 4.[14]
- Had a single level anterior cervical discectomy and iliac crest bone graft fusion (ACDF) and plating with either a CSLP (Synthes™) or Peak plate (DePuy™) performed between January 1994 and December 2001; and
- Were over 18 years of age.

Patients were excluded from the study if they:

- Were not treated acutely, within 1 week of injury; or
- Had injuries requiring vertebrectomy, corpectomy, or concomitant posterior fixation; or
- Had pathologic fractures due to infection, inflammatory disease (rheumatoid or spondylitis), or neoplasm; or
- Had other noncontiguous cervical spine injuries.

The diagnosis (unilateral or bilateral) was established from the surgeon's preoperative diagnosis and was confirmed by a careful review of the presurgical imaging, particularly the computed tomography (CT) scans and reformatted images. In our center, equal numbers of these injuries are treated with anterior
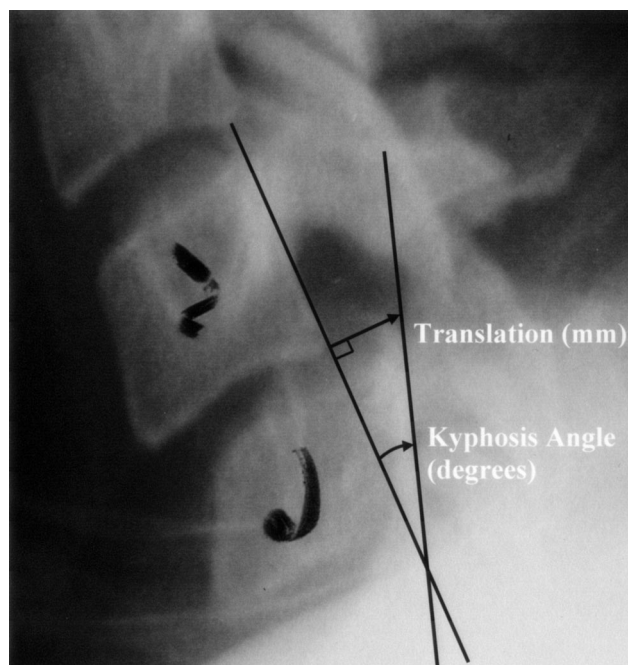

Figure 1. Measurements recorded from these injury radiographs included; the maximal degree of translation at the injury level and the degree of kyphosis at the injury level measured from a line parallel to the posterior vertebral margin of each vertebra.

versus posterior approaches, and in most cases, the decision is based on surgeon preference.

A facet joint complex was defined as being injured if there was any radiographic evidence of fracture, subluxation, or dislocation of that joint. Demographic data (patient age; gender; date of injury, surgery, and follow-up; and operating surgeon) as well as injury data (level of injury, plate type) were recorded.

Injury Radiographic Measurements. One of the authors (M.J.) reviewed all the plain radiographs as well as CT scans and reformatted images from the time of injury. Measurements recorded from these injury radiographs included the maximal degree of translation and the degree of kyphosis at the injury level. The translation was measured as the perpendicular distance between the posterior-inferior corner of the vertebral body and a line drawn parallel to the posterior vertebral margin (Figure 1). The degree of kyphosis was defined as the angle between the lines parallel to the posterior vertebral margin of adjacent vertebra (Figure 1). When the posterior vertebral body lines were parallel, the alignment was measured as 0°. A positive angle reflected kyphotic angulation, whereas a negative degree measurement reflected lordosis at that segment.

Also measured on each radiograph were the presence or absence of facet fracture, as well as the percent of facet overlap. We also recorded the presence or absence of fracture of the superior endplate. Translation and sagittal alignment were measured from all images including the plain radiographs and CT scans, but the measurement from the image revealing the most severe translation was the one that was used in the analysis.

Postoperative and Follow-up Radiographic Measurements. The postoperative radiograph was the plain radiograph taken on the first postoperative day. Follow-up radiographs were taken at regular clinical intervals, including 6
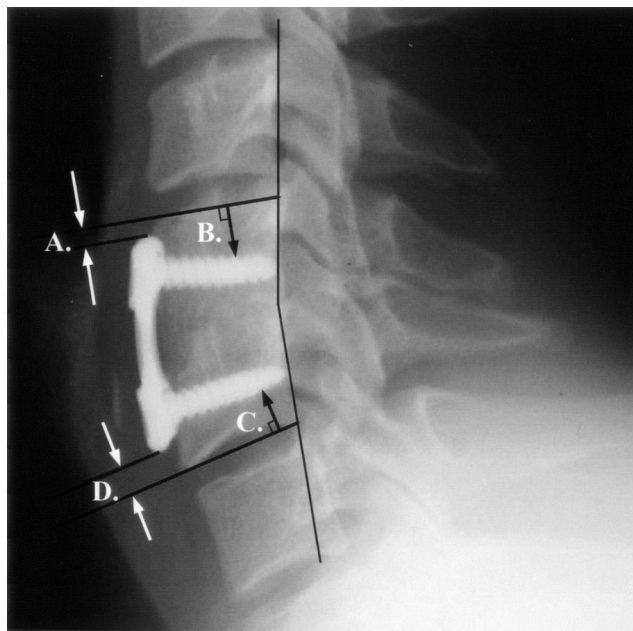
Figure 2. The position of the plate and screws was measured on the postoperative and follow-up radiographs. The distance between the superior and inferior endplates of the fused vertebral bodies and the end of the plate was recorded.

weeks and 3, 6, and 12 months postinjury. The latest follow-up radiograph, which had to be at least 9 months postsurgery, was the one used for analysis, except in the case of early radiographic failure that may have been identified as early as 2 weeks after surgery.

All of the above-noted measurements were repeated on the postoperative and last follow-up radiographs. In addition to the above-noted measurements, the position of the plate and screws was measured on the postoperative and follow-up radiographs. The distance between the superior and inferior endplates of the fused vertebral bodies and the end of the plate was recorded (Figure 2: measurements A and D). We also recorded an assessment of "descriptive failure," which referred to the presence of fracture of the plate or screws or gross failure of the construct.

Fusion was defined by noting the presence or absence of bridging trabeculae across the interspace, radiolucent lines between the graft and vertebral body, and loss of endplate definition. A fusion grade was assigned using the Bridwell *et al* fusion grade defined as grade I (fused with remodeling and trabeculae), grade II (graft intact, not fully remodeled and incorporated, no luciencies), grade III (graft intact with definite lucency at the top or the bottom of the graft), and grade IV (definitely not fused with graft resorption and collapse).[31]

Our primary outcome was radiographic failure. Radiographic failure was defined as translation of greater than 3.5 mm and/or a change in angulation of greater than 11° or gross descriptive failure (device failure such as screw breaking or plate dislodgment) in the interval between the immediate postop film and the most recent follow-up radiograph.[32]

Statistical Analysis. Descriptive statistics included the number of samples for each measurement and the mean, standard deviation, median, quartiles, and range for all numerical variables. Categorical or qualitative variables were described using percent distribution tables.

Bivariate analyses were performed to define the relationships between radiographic failure and the baseline quantitative and qualitative variables relating to the patients and the measurements made on preoperative and postoperative radiographs. For nominal variables, such as presence of facet or endplate fracture, the Pearson χ^2 test was used. Where the sample size was less that 5 per group, the Fisher exact test was used.

When continuous variables such as translation and alignment were analyzed to determine their relationship to failure, the Wilcoxon rank sum test was used. When results were compared between surgeons, the Kruskall-Wallis test was used.

■ **Results**

One hundred seven patients met the inclusion criteria. Eighty-seven of the 107 patients (81.3%) had radiographs available from the time of injury, a CT scan from the time of injury, immediate postoperative radiographs, and follow-up radiographs at least 9 months postsurgery. The patient ages ranged from 18 to 88 years (mean 37 years, SD 16 years.). There were 62 (71%) males and 25 (29%) females. Six surgeons, all full-time adult spine surgeons, performed the procedures with 86% of the procedures performed by 4 of the 6 surgeons.

Bilateral facet injury was identified in 65 (75%) patients, with the remaining 22 (25%) patients exhibiting unilateral facet injuries. Facet fractures were present in 47 patients (54%). Endplate fractures were present in 15 patients (17%). Peak plates (DePuy-AcroMed, Raynham, MA) were used in 28 (32%) patients and Cervical Spine Locking Plates (CSLP) (Synthes USA, Paoli, PA) in 59 (68%) patients. There were 33 (38%) injuries at both the C5–C6 and the C6–C7 levels. The C4–C5 level had 12 (14%) injuries, whereas the C3–C4 level had 6 (7%) and the C7–T1 level had 3 (3%) injuries.

At the time of injury, the mean translation measured 4.6 mm (range −3–18 mm, SD 4.5 mm.). The kyphosis averaged 7.5° (range −16–36°, SD 10.4) at the time of injury. Anterior surgical stabilization reduced the mean translation to 0.3 mm (range −2–4 mm, SD 0.9 mm) and corrected the alignment to −4.5° (range −27–10°, SD 8.3), reflecting correction of kyphosis to the more normal lordotic alignment of the cervical spine.

At final follow-up, the mean translation measured 0.9 mm (range −1–12 mm, SD 2.4) and the sagittal alignment was maintained at a mean of −3.6° (range −22–18°, SD 8.4), suggesting that lordosis was maintained in the majority of cases. The length of time between the surgical procedure and the follow-up radiograph was a mean of 32 weeks (range 2–112 weeks, SD 26 weeks). The short radiographic follow-up was due to the patients who had early failure.

Radiographic failure, defined as a change in translation of greater then 3.5 mm and a change in angulation greater than 11°, was present in 11 (13%) patients (Figure 3). Eight (73%) of the 11 failures occurred at the C6–C7 level. Five of these 11 patients who had radiographic failure also had gross migration or pullout of the screws from the vertebral body. Change in angulation greater than 11° and translation greater that 3.5 mm
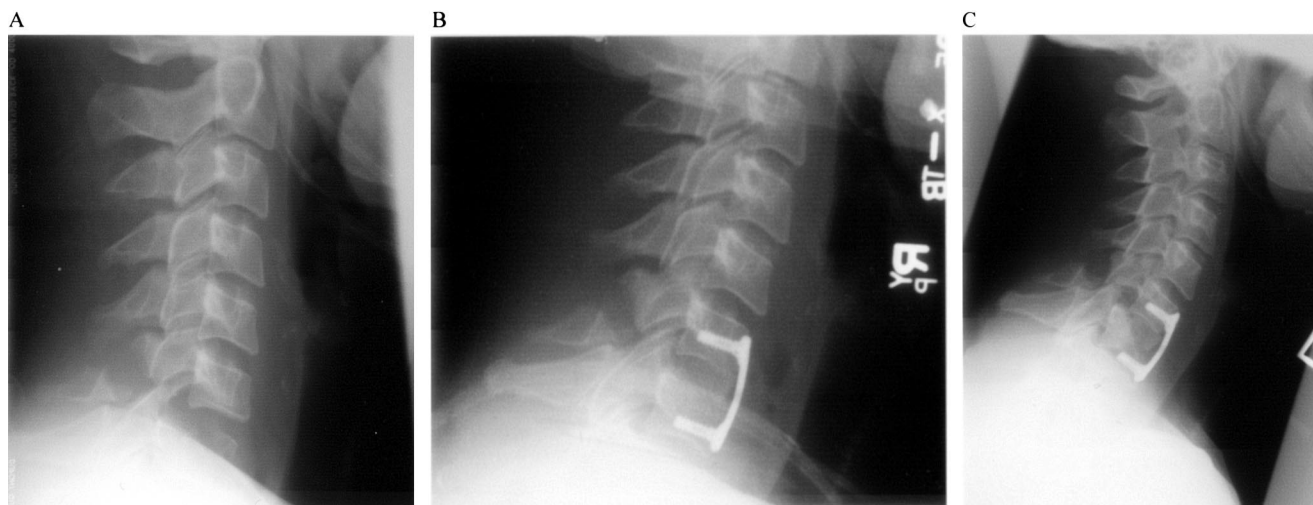
Figure 3. A. Lateral radiograph at the time of a C6-7 bilateral facet dislocation with fracture of the superior endplate of C7. **B.** Lateral radiograph immediately postopertively, showing no translation and satisfactory alignment. **C.** Final follow-up radiograph revealing significant translation, kyphosis, and pull-out of the C7 screws.

were both present in 7 of the 11 patients. Nine of the 11 patients had either a grade 3 or 4 Bridwell *et al* grade of their fusion, suggesting pseudarthrosis or fusion failure. Two of the 11 patients with radiographic failure had solid arthrodeses at follow-up (Table 1). Of the 11 patients that failed, none exhibited neurologic changes, the 2 that appeared to be solidly fused were asymptomatic, and the remaining 9 had local mechanical pain in association with radiographic failure.

Grade I and II fusions were identified in 38 (51%) and 11 (15%) patients, respectively, for a total of 66% likely solidly fused. Grade III fusion was recorded in 20 (27%) patients, and 5 (7%) patients clearly had gross failure of fusion, grade IV. There were 13 additional patients in which the radiographic technique was adequate to assess alignment and radiographic failure, but not adequate for fusion grade determination.

Bivariate analyses identified a strong correlation between radiographic failure and both endplate fracture ($P < 0.001$) and facet fractures ($P = 0.004$) (Table 2). Endplate fracture was not only correlated with mechan-

ical failure ($P < 0.001$) but also strongly correlated to failure of fusion ($P = 0.012$) and the Bridwell *et al* grades ($P < 0.001$) by Fisher exact test.

As expected, the bilateral facet dislocations exhibited significantly greater translation ($P = 0.011$) and angulation ($P = 0.003$) on the injury radiographs than did the unilateral injuries (Wilcoxon rank sum test).

Confirming the criteria that we used to define failure, there was a significant correlation between the translation measured at follow-up and radiographic failure ($P < 0.001$, Wilcoxon rank sum test). Although it did not reach significance, there was a trend to improved lordosis on the initial postoperative films in patients without facet fractures ($P = 0.057$). Mean translation was also greater on the immediate postoperative films in those patients with facet fractures ($P = 0.088$) (Wilcoxon rank sum test).

There was no correlation between radiographic failure and age, gender, surgeon, unilateral or bilateral injury, plate type, level of injury, degree of translation, or sagittal alignment at the time of injury.

■ Discussion

Early anterior plate designs were plagued by screw loosening and the requirement for bicortical fixation.[22,33–35] Newer designs of anterior cervical plates with constrained screw plate interfaces have led to the wider ac-

Table 1. Characteristics of 11 Patients With Radiographic Failure

Patient No.	Level	Screw Pullout	Change in Translation (mm)	Change in Angulation (°)	Bridwell Fusion Grade
1	C6–C7	Yes	0	12	4
2	C6–C7	—	0	23	4
3	C6–C7	—	5	15	4
4	C7–T1	—	10	12	4
5	C6–C7	Yes	9	17	4
6	C6–C7	—	6	7	3
7	C5–C6	Yes	0	17	1
8	C6–C7	Yes	5	8	4
9	C6–C7	—	4	8	3
10	C6–C7	—	5	2	1
11	C5–C6	Yes	0	14	3

— = data not available.

Table 2. Bivariate Analysis of the Relationship Between Radiographic Failure and Endplate Fracture and Facet Fracture

		Radiographic Failure		
		Yes	No	
Facet fracture	Yes	10 (26%)	28 (74%)	$P = 0.004$, Pearson χ^2 test
	No	1 (3%)	35 (97%)	
Endplate fracture	Yes	9 (64%)	5 (36%)	$P < 0.001$, Fisher exact test
	No	2 (3%)	58 (97%)	

ceptance of anterior cervical plate fixation and its subsequent application to cervical trauma.[1–3,36] The majority of cervical trauma results from a flexion moment that leads to failure of tensile (posterior) elements. Resection of what are frequently the only remaining intact structures, the anterior anulus and anterior longitudinal ligament, would seem to contradict basic principles of fracture management. Furthermore, biomechanical studies have reported the superiority of posterior fixation over anterior plating for these injuries.[26–30]

Despite these theoretical drawbacks, the use of anterior plating for cervical flexion distraction injuries has slowly increased in popularity.[1,20] The reported rates of pseudarthrosis and mechanical failure are low.[2,3] The ability to resect the intervertebral disc and avoid disc displacement and further neurologic injury that can occur with posterior surgery is a distinct advantage. Anterior plating enables the immobilization of only 1 motion segment, whereas the posterior fixation limitations seen with posterior element fractures often necessitate 2 level fusions.

It is clear from the multiple clinical reports of satisfactory outcomes that anterior plating is likely to be successful in many cervical distractive flexion injuries.[1–3,19,22,23,33–36] In select cases, either a primary posterior stabilization or combined anterior and posterior stabilization may be required; however, it is not clear from the existing literature how to identify these cases.[7–11]

This study has included many high energy injuries, with 75% of our cases involving bilateral facet fracture, subluxation, or dislocation. We report an overall radiographic failure rate of 13% that is strongly correlated with fractures of the facets and fractures of the superior endplate of the lower vertebra on injury radiographs or CT scan. This study does not assess the fusion rate of this technique. Patients were not followed after the identification of radiographic failure.

Some authors have suggested that the presence of a bilateral facet dislocation requires combined anterior and posterior fixation due to the high degree of ligamentous injury.[7–10] We did not identify a correlation between failure and the initial degree of translation or the type (unilateral vs. bilateral) of facet injury. Neither did we find a correlation between failure and the degree of kyphosis on the injury films, the type of plate used, the patient's gender, or the surgeon performing the procedure.

Although there were an equal number of injuries at C5–C6 and C6–C7, there was a significant increase in the risk of failure at the C6–C7 level. It is possible that both the surgical exposure and ability to obtain intraoperative radiographs confirming adequate reduction were compromised at this lower level, particularly in physically large patients.

Most constructs failed with loss of fixation of the screws in the caudal vertebra and progressive anterior subluxation and kyphosis. The screws in the caudal vertebra would frequently cut out inferiorly, thus the inverse correlation between failure and the distance between the inferior endplate and the lower screw (Figure 2: measurement C).

The strongest correlation with radiographic failure was with endplate fractures. Many of these endplate fractures were only apparent on the sagittal reconstructions of the CT scans and would be described as minimal. It is possible that these endplate injuries may identify higher energy injuries. It is also possible that the disruption of the vertebral endplate may lead to interference with the fixation of the screws in the caudal vertebral body. It was often the inferior screw that failed in these cases, potentially due to the local inflammatory cascade initiated in the fractured vertebral body.

Fractures involving the facet joints also correlated strongly with radiographic failure. The presence of facet fractures also demonstrated a trend to less lordotic alignment and a slight increase in the intervertebral translation on the initial postoperative radiographs. It is possible that facet fractures are a herald of less intrinsic stability even after successful anterior cervical fusion and plating.[37] From a purely descriptive analysis of the radiographs of the cases that failed, the authors believe that in some cases, particularly those with posterior element fractures, infolded facet capsules or ligaments may prevent restoration of normal facet joint apposition and restoration of lordosis, and thus predispose to failure. It is also possible that in the presence of a facet fracture, it is more difficult to achieve restoration of lordosis and avoidance of any residual subluxation. Furthermore, when adequate lordosis is restored and the facets are intact, they will offer resistance to anterior translation. When a facet is fractured, this buttress is lost, and increased shear forces are placed on the plate, possibly leading to failure.

The authors acknowledge limitations within the study. The study is retrospective, so data collection, treatment, and diagnostic techniques are not standardized and controlled in the manner of a prospective study. We acknowledge that there is controversy regarding the diagnosis and clinical significance of fusion. Our use of the Bridwell et al grading system for fusion does not represent a validated gold standard, because none exists. Fusion status, however, was not the primary outcome of our study. We recognize that the true "global" failure rate would add symptomatic pseudarthroses to the early catastrophic failures on which we have reported. It is beyond the scope of this paper to report clinical outcomes, data that are necessary to identify which radiographic pseudarthroses are "failures" and which are asymptomatic radiographic findings.

The radiographic follow-up did not reach 2 years in all patients, but this is probably not relevant in that clinical and radiographic union is usually apparent at 6 to 9 months. The anterior technique can be technically demanding if intraoperative reduction is required; however, we believe that the results of this study are still generalizable to spine surgeons who provide trauma care on a regular basis. Finally, standardized health-related

quality of life patient outcomes were not done, but were not felt to be germane to the objectives of the study.

The low number of failures probably does not warrant the desired logistic regression modeling appropriate to control for the confounding or interaction effect of the independent variables on the binary outcome of radiographic failure. Therefore, statistical evaluation is limited to bivariate analysis. One must accept that although statistical significance in a setting of multiple comparisons is not conclusive, high levels of statistical significance supported by biomechanical and theoretical evidence justifies strong inference. This is particularly relevant for a difficult-to-study, infrequent postoperative event of striking clinical significance, such as radiographic failure.

■ Conclusion

The authors have modified their enthusiasm for ACDFP in distractive flexion injuries. Particularly in patients with facet fractures and in those with even minimal endplate compression fractures, we recommend either a primary posterior fusion and instrumentation or a combined anterior and posterior stabilization procedure.

■ Key Points

• A 13% radiographic failure rate is reported for anterior plate fixation of distractive flexion injuries of the subaxial cervical spine where 75% of the subjects had bilateral facet injuries.
• Radiographic failure was strongly correlated to the presence of endplate fracture and less strongly with facet fracture on the injury radiographs.
• Pseudarthrosis was correlated to the presence of endplate fracture.
• The presence of an endplate fracture or facet fracture, even subtle, in association with a unilateral or bilateral facet fracture dislocation or fracture subluxation, should alert the surgeon to a high risk of radiographic failure with anterior plating alone.

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