Anterior cervical plate fixation: biomechanical effectiveness as a function of posterior element injury

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Object: The primary goal of this study was to determine if the stabilization provided to the spine by anterior cervical fixation with plating (ACFP) was dependent on the degree of posterior element injury. The secondary goal was to evaluate the effectiveness of additional posterior screw/rod stabilization in these injuries.

Methods. Following ACFP with interbody bone graft and stepwise transection of the posterior ligaments and facets at C5–6, eight fresh-frozen human C4–7 spine segments were loaded using pure moments of ±1.5 Nm in flexion–extension, axial rotation, and lateral bending in the intact state. Posterior screw/rod fixation was performed after complete ligamentous destruction and complete removal of the facets. Repeated-measures analysis of variance and pairwise Student-Newman-Keuls tests were used to detect changes in the range of motion (ROM) and neutral zone (NZ). Statistical significance was assumed at a 95% level.

Significant increases in ROM occurred in each loading direction after transection of the capsular ligaments (p < 0.001) and again following facetectomy (p < 0.001) compared with the ACFP condition. Additional posterior fixation resulted in a significant decrease in ROM in all loading directions (p < 0.001). There was a significant increase in NZ for complete ligamentous destruction compared with ACFP (p < 0.05) and facetectomy compared with ACFP (p < 0.05) for flexion–extension. In lateral bending, a significant increase in NZ was found for facetectomy compared with ACFP (p < 0.05).

Conclusions. Capsular ligaments and articular facets are important structures in limiting three-dimensional vertebral motion in the presence of an anterior plate. Supplementary posterior fixation does reduce motion for all injury conditions.

Key Words • cervical spine • biomechanics • ligament • implants • injury

Abbreviations used in this paper: ACFP = anterior cervical fixation and plating; MR = magnetic resonance; NZ = neutral zone; ROM = range of motion.

Flexion–Distraction injuries include facet fractures, subluxations, and dislocations and represent a spectrum of injury severity and instability. Recommendations for surgical treatment of these injuries in the cervical spine remain controversial. In most cases ACFP or posterior fixation alone appear to be sufficient; however, this is not so in other cases. Combined anterior–posterior procedures have been reported to produce successful results; however, clinical experience suggests that combined anterior–posterior stabilization performed for every cervical injury would result in overtreatment in a relevant number of cases. Apart from opinion and anecdotal evidence there are no guidelines as to when ACFP alone will provide sufficient stabilization for various posterior element injuries.

Biomechanical studies can provide insight into instances in which anterior or posterior fixation alone may not be sufficient. Authors of several biomechanical stud-

ies have noted that anterior plate fixation alone is less effective than posterior fixation for flexion–distraction injuries in which the posterior elements are injured. As outlined previously in a study highlighting the positive biomechanical behavior of anterior plating, the quality of some of these studies suffers due to methodological problems such as the lack of an interbody bone graft, the use of animal models that may not replicate the human model, and improper statistical analysis. More recent research suggests that anterior plating in the presence of complete posterior ligament destruction is substantially less stiff than posterior plating.

The apparent discrepancy between positive clinical results when using ACFP and negative biomechanical behavior for flexion–distraction injuries may lie in the differences between the in vivo situation and the in vitro simulation or in the wide spectrum of clinical injuries. With respect to the latter point, the effect of different degrees of posterior element injury on the stabilization provided to the cervical spine by an anterior plate has not been previously studied. This is an important question because new imaging modalities are better able to discretely and accu-
Anterior cervical fixation and posterior element injury

The ability to identify accurately varying degrees of ligament injury is continuing to evolve, and it is reasonable to assume that future advances in imaging technology will enable clear delineation of degrees of posterior cervical ligament and soft-tissue damage. If the integrity of the posterior elements in the cervical spine could be defined after an injury, then this information would enable more accurate assessments of the stability of the injured cervical spine. The knowledge of the degree of cervical instability, when coupled with basic biomechanical data, will enable the surgeon to make better evidence-based decisions with respect to the optimal technique of fixation.

The contribution of the posterior elements to the flexibility of the injured cervical spine has been described, as have the biomechanical properties of various configurations of internal fixation; however, the contribution of varying degrees of posterior element injury to the biomechanical behavior of the spine after anterior plate placement has not been described. It is not appropriate to extrapolate the effect of adding fixation to the biomechanical information about the injured cervical spine because the fixation alters the center of rotation of the segment and thus modifies the functioning of the segment. The changes seen after the addition of anterior fixation will likely modify the functional importance of the posterior elements. The primary objective of this study was to determine the effect of sequential posterior element damage on the three-dimensional flexibility of the cervical spine after stabilization with an anterior plate. The secondary objective was to determine the subsequent effect of posterior fixation on the flexibility.

Materials and Methods

Eight fresh human C4–7 spine segments obtained in patients with a mean age of 53.2 years (range 20–73 years) were harvested during autopsy, stored in double plastic bags, frozen at −20°C, and thawed before dissection. Following careful removal of the muscles to avoid damaging the ligaments or facet joints, anterior-posterior and lateral x-ray films were obtained to exclude tumorous or traumatic destruction and to orient the C5–6 disc space precisely in the horizontal plane. The upper part of C-4 and the lower part of C-7 were potted in dental plaster.

A custom-made spine testing machine (Fig. 1) was used for loadings of the specimens in flexion-extension, axial rotation, and lateral bending. The machine consisted of a DC motor, a planetary reduction gearhead, an articulated arm comprising two universal joints, a ball spline, and a torque cell (model TRT-200; Transducer Techniques, Temecula, CA). For each specimen condition, pure moments were applied to the upper vertebra at 0.5°/second to a moment maximum of 1.5 Nm under displacement control. This load level was selected to be nondestructive. The specimen was moistened with gauze throughout the entire testing procedure. Three complete loading cycles were applied as described previously in flexion-extension, axial rotation, and lateral bending. A six-axis load cell (model MC 3-6-1000; Advanced Mechanical Technology Inc., Watertown, MA) below the specimen monitored the reaction forces and moments. Marker carriers with four infrared light-emitting diodes were mounted on each vertebra. An optoelectronic camera system (Optotrak 3020, Northern Digital, Waterloo, ON, Canada) was used to monitor the three-dimensional positions of the marker carriers and therefore allow the relative motion of the vertebrae to be determined. The accuracy of this system exceeds 0.1°. Data were collected during three cycles, but only data from the third cycle were used for statistical analysis. The ROM and NZ at C5–6 across the different specimen conditions in each loading direction were analyzed and compared. The ROM was defined as the difference in angular deformation for each loading condition at the peak moments of ±1.5 Nm, respectively. The NZ was calculated as the maximum motion across the C5–6 segment that was measured between a moment of +0.2 and −0.2 Nm for each loading modality. The ROM and NZ of the third cycle were used for statistical analysis.

To address the specific research questions, the specimens were tested in the following configurations: 1) intact; 2) after discectomy and resection of the anterior and posterior longitudinal ligaments at C5–6; 3) after interbody stabilization using an iliac crest bone graft and plate (Caspur plate with monocortical screws) at C5–6 in lordotic alignment; 4) after transection of the supraspinous and interspinous ligaments at C5–6; 5) after transection of the ligamentum flavum at C5–6; 6) after transection of the capsular ligaments bilaterally at C5–6; 7) after bilateral posterior screw/rod fixation at C5–6; 8) after resection of the C5–6 facets (posterior rods removed); and 9) after posterior fixation at C5–6.

The ligamentous injuries were created by transection of the liga-
ments with the aid of a scalpel. The destruction of the bone elements of the facet joints was created by complete resection of the corresponding articular processes of C-5 and C-6 by using punches and rongeurs such that the facet joints were not in contact.

Two types of implants were used for fixation of the injured functional spinal unit C5–6 (Fig. 2). The Caspar trapezoidal plate with corresponding monocortical screws and the Spine System Evolution, a new device for posterior stabilization of the cervical spine (Aesculap AG + CoKG, Tuttingen, Germany). The classic Caspar plate for anterior osteosynthesis of the cervical spine is a trapezoidal, titanium plate that can be bent to accommodate the patient’s individual lordosis. The screw for monocortical fixation is a titanium, self-tapping, conical screw of 14, 15, 16, 17, or 19 mm in length with an outer diameter of 4 mm and an inner diameter of 2.2 mm at the tip, increasing to 2.7 mm at its head. This is a nonconstrained plate–screw system for anterior cervical fixation. The posterior stabilization system consists of titanium screws placed in the lateral mass of the facets. The head of the screws can be moved unconstrained in the unlocked condition. The screws on each side are connected by a titanium rod, which is fixed to the head of the screws by a locking mechanism consisting of an inner screw and an outer nut. Once the locking screws and nuts are tightened, the angles between the screw and the rod remain fixed.

After the final testing step, both the posterior and anterior instrumentation systems were removed. The specimen was examined for the presence of any apparent loosening of the implants. Loosening of the implants as a result of testing or deterioration was not seen in any of the specimens.

To address the effect of posterior element injury in the presence of an anterior plate, repeated-measures analysis of variance between Configurations 3, 4, 5, 6, and 8 and pairwise Student-Newman-Keuls tests were used. To determine the effect of posterior stabilization, paired t-tests with Bonferroni corrections were conducted between Configurations 6 and 7 as well as 8 and 9. Statistical significance for all tests was assumed at a 95% level.

Results

Effect of Discectomy and ACFP

The mean ROM after discectomy was 226% of intact in flexion–extension, 133% in axial rotation, and 135% in lateral bending. The corresponding NZ after discectomy was 239% of intact in flexion–extension, 150% of intact in axial rotation, and 155% in lateral bending.

The ACFP procedure reduced the mean ROM in each loading direction, being 12% of intact in flexion–extension, 19% in axial rotation, and 12% in lateral bending (Figs. 3–5). The mean NZs after ACFP were 37% of intact in flexion–extension, 35% in axial rotation, and 47% in lateral bending.

Effect of Posterior Element Injury

Transection of the interspinous/supraspinous ligaments resulted in an increase in the mean ROM of 29% in flexion–extension and 17% in axial rotation with respect to ACFP, but these changes were not significant. In lateral bending, an increase in the mean ROM with respect to ACFP condition was not seen in this configuration. Transection of the ligamentum flavum increased the mean ROM to 45% in flexion–extension, 20% in axial rotation, and 22% in lateral bending with respect to ACFP. Again, these changes were not significant. Additionally, the motion at this condition was well below the intact level. Transection of the capsular ligaments produced a statistically significant increase of the mean ROM with respect to the ACFP condition in all loading modalities (320% in flexion–extension, 360% in axial rotation, and 620% in lateral bending).

Bilateral facetectomy resulted in a further increase in the mean ROM, which again was significant when compared with the ACFP condition. A 470% increase in flexion–extension, 630% in axial rotation, and 770% in lateral bending was found. Moreover, the mean ROM was now close to the intact state for flexion–extension (Fig. 3). For lateral bending and axial rotation, the mean ROM was even higher than in the intact state (Figs. 4 and 5).

An analysis of the NZ data in flexion–extension detected a significant increase in the mean NZ following complete ligamentous destruction with respect to ACFP (p = 0.007) and again following facetectomy with respect to ACFP (p = 0.023). For lateral bending, a significant increase in the mean NZ was found for the complete ligamentous and bone destruction with respect to ACFP (p = 0.013). For axial rotation, no significant differences were detected for any posterior destruction with respect to ACFP. The results for NZ are summarized in Table 1.

Effect of Posterior Fixation

Supplementary posterior fixation significantly reduced the ROM in all loading directions from the injury conditions preceding the fixation condition. The ROM after bilateral posterior screw/rod fixation at C5–6 and after complete ligamentous destruction was 13% of the preceding injury condition in flexion–extension, 14% in axial rotation, and 9% in lateral bending.

A reduction of the ROM was seen again after posterior instrumentation was placed for the second time, that is, after removal of the facets. The reduction in ROM at this point was 10% in the facetectomy condition in flexion–extension, 18% in axial rotation, and 8% in lateral bending. Furthermore, the ROM at these levels was now significantly less with respect to the intact state (Figs. 3–5).
The current study addressed the biomechanics of stabilization for simulated flexion-distraction injuries in a human cadaveric model. The data demonstrated that the effectiveness of ACFP in stabilizing the injured segment was dependent on the degree to which the posterior elements were injured. Specifically, a significant increase in ROM in each loading direction was observed following destruction of the capsular ligaments and after facetectomy. Additional posterior screw/rod instrumentation stabilized the injured segment significantly in each loading direction.

The clear difference in spinal flexibility after transec-

Fig. 3. Graph showing the ROM at C5–6 in flexion-extension. Values are given as mean ± standard deviation (in degrees). Following posterior destabilization, a significant increase in ROM was seen for capsular ligaments compared with ACFP, bilateral screw fixation compared with capsular ligaments, and posterior fixation compared with facetectomy. Note, that even after complete resection of the facets the mean value of ROM is below that of the intact segment. CAPS = capsular ligaments; DISC = discectomy and resection of the anterior and posterior ligaments; FAC = facetectomy; INT = intact; ISL = intraspinous-supraspinous ligaments; LF = ligamentum flavum; 1PI = bilateral screw fixation; 2PI = posterior fixation.

Fig. 4. Graph showing the ROM at C5–6 in left and right lateral bending. Values are given as mean ± standard deviation (in degrees). Following posterior destabilization, a significant increase in ROM was seen for capsular ligaments compared with ACFP, bilateral screw fixation compared with capsular ligaments, and posterior fixation compared with facetectomy. Note, that in this loading case, the ROM for CAPS exceeds that of the intact level. This is even more pronounced in the facetectomy state.
tion of the capsular ligaments highlights the importance of at least some posterior ligamentous structures to spinal stabilization. Because the interspinous/supraspinous ligaments, the ligamentum flavum, and the capsular ligaments were not transected in a random order, the importance of the capsular ligaments was most likely due to these structures being the final ligaments of the three to be damaged in this model. The relevance of this finding may lie in clinical imaging data of flexion–distraction injuries. Our study suggests that those injuries with some posterior ligament integrity may do better clinically with anterior plate fixation alone than those injuries with complete posterior ligament destruction. Until now, it is unlikely that clinical studies have been able to assess precisely the ligamentous damage to this degree; however, with advances in imaging technology, particularly MR imaging, these assessments should be possible in the future.

The results of the current study are consistent with those of previous investigations, which have focused on complete posterior element destruction. McLain, et al.,22 created complete cervical ligamentous instability, applied ACFP, and tested the segments in flexion. They concluded that the anterior fixation in these highly unstable injuries was inadequate. Sutterlin, et al.,31 evaluated the effectiveness of different implants in a bovine model of the cervical spine after complete anterior and posterior disruption. They found that the Caspar anterior instrumentation did not restore enough flexural stability when compared with the intact segment. In extension this instrumentation produced a higher quality of stiffness than that in the intact segment; in torsion the stiffness was comparable to that of the intact condition, thus being in good accordance with the results found in our study. In another model of complete C5–6 instability, Clausen and coworkers7 investigated the stabilizing potential of ACFP by using a Caspar plate with bicorticallly placed screws compared with a Cervical Spine Locking Plate with unicortically placed screws. In their model, the Caspar plate produced stabilization in flexion–extension, lateral bending, and axial rotation even after complete transection of the posterior ligaments. The ROM of the intact segment and the destabilized and plated segment were similar to the results found in our study for the most severe injuries. In a recent study Do Koh and coworkers12 addressed anterior, posterior, and combined fixation methods and concluded that posterior plating was more effective biomechanically than anterior plating in stabilizing flexion–distraction injuries in the cervical spine. They noted that preservation of the posterior ligaments may be an important factor in the effectiveness of the anterior fixation, but this effect was not evaluated. This brings us to the current study, in which we addressed precisely this point, and it thereby provides additional information regarding important factors for spinal stabilization in the presence of an anterior plate. Our results clearly show the loss of stabilization in the presence of an anterior plate when the last posterior ligamentous structure (the capsular ligaments in this study) is destroyed.

Clinical experience in treating these highly unstable distractive flexion injuries suggests that anterior plating alone is associated with satisfactory results. Lifeso, et al.,20 found clinical results in rotationally unstable unilateral facet fractures and subluxations were improved in a group treated with ACFP compared with those treated with posterior fixation. Goffin, et al.,15 reported good results in 25 patients treated with anterior plating for cervical dislocations. Aebi, et al.,2 reported on 64 patients with posterior discoligamentous injuries who were treated with anterior plating and experienced excellent results. Authors of some studies found that anterior plating alone is not always so effective: complications such as loss of correction or implant failure
Anterior cervical fixation and posterior element injury

TABLE 1

Values of NZ for each configuration and loading case*

<table>
<thead>
<tr>
<th>Configuration</th>
<th>INT</th>
<th>DISC</th>
<th>ACFP</th>
<th>ISL</th>
<th>LF</th>
<th>CAPS</th>
<th>IPI</th>
<th>FAC</th>
<th>2PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>flex–ext</td>
<td>2.65 ± 1.74</td>
<td>6.33 ± 1.43</td>
<td>0.97 ± 0.80</td>
<td>1.40 ± 0.86</td>
<td>1.47 ± 0.87</td>
<td>2.05 ± 1.17</td>
<td>0.93 ± 0.62</td>
<td>1.84 ± 1.00</td>
<td>0.98 ± 0.72</td>
</tr>
<tr>
<td>axial rotation</td>
<td>1.17 ± 1.19</td>
<td>1.76 ± 1.15</td>
<td>0.41 ± 0.47</td>
<td>0.46 ± 0.48</td>
<td>0.48 ± 0.49</td>
<td>0.59 ± 0.57</td>
<td>0.24 ± 0.17</td>
<td>0.75 ± 0.57</td>
<td>0.36 ± 0.28</td>
</tr>
<tr>
<td>lat bending</td>
<td>0.61 ± 0.45</td>
<td>0.95 ± 0.56</td>
<td>0.29 ± 0.20</td>
<td>0.29 ± 0.24</td>
<td>0.35 ± 0.27</td>
<td>0.73 ± 0.71</td>
<td>0.21 ± 0.18</td>
<td>0.93 ± 0.95</td>
<td>0.26 ± 0.19</td>
</tr>
</tbody>
</table>

* Data are presented as means ± standard deviations.

were encountered. Unpublished data from our institution reveal a radiographically demonstrated failure rate of 13% in 87 patients with distractive flexion injuries, all of whom were treated with ACFP. In general, the results of ACFP appear to be satisfactory, but this is not universally accepted and guidelines that highlight injuries that may be prone to failure are lacking. Biomechanical studies can assist in the definition of these guidelines.

There are some limitations of the current study. First, pure moments without preload represent only one aspect of the physiological loading of the cervical spine. Certainly compression and shear loads occur in vivo, but the complete loading scenario is not known. The loading conditions used in this test are widely accepted in spinal biomechanics. Our load magnitude of 1.5 Nm has been used by many authors and is now recommended by some. This load level is sufficient to produce the physiological ROM of a cervical spine segment, but is generally considered nondestructive. The current results apply only to immediate postoperative fixation and do not include the effects of cyclic loading. Another limitation of the current study is that the results apply to simulated flexion–distraction injuries. The particular sequence of ligament transection used probably resembles the continuum of injury seen clinically; however, it is possible that the importance of particular ligaments observed here may be due to the sequence in which they were transected rather than their inherent physical properties.

The technique of stepwise transection of the posterior spinal structures was described in a classic study by Panjabi et al., in which they investigated the importance of each single component for spinal stability. These authors found no major increase in flexibility with posterior ligament transection. There are two major differences between the current study and the study by Panjabi and colleagues. First, in this study, ACFP was applied to the specimen before stepwise transection. A second difference is that in the current study we applied pure bending moments in three motion planes, whereas in the study by Panjabi et al., they were two dimensional and only an anterior shear force was applied. These methodological differences may help explain the varying results. Because the application of an anterior plate shifts the center of rotation anteriorly, the importance of the posterior ligaments for stabilization is enhanced, especially under the application of a pure moment.

Direct transfer of biomechanical results to clinical problems is difficult because we do not know the optimal degree of stabilization required for healing; however, the results highlight the importance of the posterior ligaments in the effectiveness of ACFP in the spine. Clinical application of this material will require careful evaluation of the degree of ligamentous damage, presumably using MR imaging techniques.

**Conclusions**

The effectiveness of ACFP in the injured spine is dependent on the degree of posterior element damage. The capsular ligaments and facet joints are important structures for cervical spine stabilization in case of anterior destruction. Their destruction may be significant in determining when additional posterior stabilization is necessary. In cases of destruction of both the anterior and the posterior elements of the cervical spine, a combined anterior–posterior fixation provides stabilization that exceeds that of the intact segment.

**Disclaimer**

The authors have no financial interest in any of the implants used in this study.

**References**


