A biomechanical comparison of three surgical approaches in bilateral subaxial cervical facet dislocation

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Object. In bilateral cervical facet dislocation, biomechanical stabilities between anterior locking screw/plate fixation after anterior cervical disectomy and fusion (ACDFP) and posterior transpedicular screw/rod fixation after anterior cervical disectomy and fusion (ACDFTP) have not been compared using the human cadaver, although ACDFP has been performed frequently. In this study the stability of ACDFP, a posterior wiring procedure after ACDFP (ACDFPW), and ACDFTP for treatment of bilateral cervical facet dislocation were compared.

Methods. Spines (C3–T1) from 10 human cadavers were tested in the intact state, and then after ACDFP, ACDFPW, and ACDFTP were performed. Intervertebral motion was measured using a video-based motion capture system. The range of motion (ROM) and neutral zone (NZ) were compared for each loading mode to a maximum of 2 Nm.

The ROM for spines treated with ACDFP was below that of the intact spine in all loading modes, with statistical significance in flexion and extension, but NZs were decreased in flexion and extension and slightly increased in bending and axial rotation; none of these showed statistical significance. The ACDFPW produced statistically significant additional stability in axial rotation ROM and in flexion NZ than ACDFP. The ACDFTP provided better stability than ACDFP in bending and axial rotation, and better stability than ACDFPW in bending for both ROM and NZ. There was no significant difference in extension with either ROM or NZ for the three fixation methods.

Conclusions. The spines treated with ACDFTP demonstrated the most effective stabilization, followed by those treated with ACDFPW, and then ACDFP. The spines receiving ACDFP also revealed a higher stability than the intact spine in most loading modes; thus ACDFP can also provide a relatively effective stabilization in bilateral cervical facet dislocation, but with the aid of a brace.

Key Words • bilateral cervical facet dislocation • biomechanical testing • anterior cervical disectomy and fusion • anterior cervical plate fixation • posterior wiring procedure • posterior transpedicular fixation

Bi lateral facet dislocation injuries of the subaxial cervical spine are common after nonpenetrating cervical trauma, are highly unstable, have discoligamentous three-column injury, and are frequently associated with neurological deficits. Bilateral cervical facet dislocations, or the distractive flexion Stage III injury described by Allen, et al., involve distraction and translation of the superior over the inferior VB. This injury requires some degree of disruption of the inter- and supraspinous ligaments, the ligamentum flavum, facet capsules, the anterior longitudinal ligament and PLL, and/or disc. Although the disruption of the posterior ligaments is severe in this injury, all three columns are usually affected. The dislocation of the bilateral facets compresses the spinal cord and damage to the nerve roots is caused by narrowing of the spinal canal and the neural foramina. The treatment for bilateral cervical facet dislocation injuries includes prompt reduction by nonsurgical or surgical procedures and stabilization.

Traditionally, the surgical treatments for bilateral cervical facet dislocation have been performed posteriorly with wiring or screw/plate fixation after closed reduction because of the disruption of the posterior ligamentous complex and facet joints. In the last several years, however, the technique of ACDFP has become popularized and has been used in bilateral cervical facet dislocation because decompression and indirect reduction, interbody grafting, and stabilization with additional anterior plating instruments can be done through the same surgical field. Recently, even though a relationship between the presence of a herniated disc before reduction and subsequent neurological deterioration after closed traction–reduction in awake patients has failed to be established, there has been interest in the relationship between bilateral cervical facet dislocation and traumatic disc herniation. Herniated disc fragments causing compression of
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the cervical spinal cord at the level of injury have been reported in up to half of patients with bilateral cervical facet dislocation. The presence of a significant disc herniation is a relative indication for an anterior decompressive procedure before reduction. Both anterior and posterior cervical fusion procedures are successful, however, in achieving spinal stability for most patients with subaxial bilateral cervical facet dislocation injuries.

Although in previous biomechanical studies significantly greater stiffness of the posterior instrumentation compared with the anterior plate fixations has been demonstrated, there have been many clinical reports on treatment with ACDFP in bilateral cervical facet dislocations in which excellent results have been recorded. The ACDFP has the following theoretical advantages: 1) an increased fusion bed area under compression; 2) removal of the associated disc herniation via a single approach; and 3) potential restoration of normal cervical lordosis. In posterior instrumentation, even though the lateral mass screw plating technique provides effective stabilization in the cervical spine, the posterior transpedicular screw/rod fixation system offers three-column stability and has proven to be the most rigid posterior fixation technique. It has some biomechanical and surgical advantages over the lateral mass screw plating, which primarily depends on compressive force to reduce the dislocation of the injured segment. Transpedicular screw/rod fixation has a significantly higher pullout strength than lateral mass screw plating, and it can easily correct kyphotic and translation deformities through a distraction maneuver.

The differences between the biomechanical stabilities of anterior cervical locking screw/plate fixation compared with posterior transpedicular screw/rod fixation after ACDF in bilateral cervical facet dislocations (distractive flexion Stage III injury) have not been investigated in the human cadaveric model. Thus, the purpose of this study was to compare the initial biomechanical stability achieved using three different surgical approaches, which are as follows: 1) the ACDFP, in which tricortical iliac graft was used (Fig. 1A); 2) ACDFPW, in which a simple wiring procedure with the Rogers technique was used (Fig. 1B); and 3) ACDFTP (Fig. 1C). These procedures were performed in a simulated distractive flexion Stage 3 injury created at the C5–6 level.

Materials and Methods

Cadaveric Specimen Preparation and Fixation

Ten human cadaveric cervical spines with the first thoracic vertebra attached (C3–T1) were obtained from Science Care Anatomical (Phoenix, AZ). The mean age of the five male and five female donors in whom specimens were obtained was 62.8 ± 6.6 years (mean ± SD) with a range between 55 and 78 years. Anteroposterior and lateral radiographs of the specimens were obtained to exclude bone abnormalities, and BMD measurements were also obtained using dual-energy x-ray absorptiometry (DEXA Hologic QDR 4500A; Hologic, Inc., Waltham, MA) scanning. The mean BMD of the C5–6 level was 0.54 ± 0.07 g/cm² (range 0.44–0.69 g/cm²). En bloc specimens for biomechanical testing were stored at −20°C until they were thawed at room temperature overnight; they were kept moist during all procedures. The attached musculature was removed, with care taken to preserve the joint capsules, ligaments, discs, and bone structures. After completion of the specimen preparation, several screws were drilled into C-3 and T-1. These rostral and caudal ends were then primarily potted in polymethylmethacrylate (COE Tray Plastic; GC America, Alsip, IL) and then the polymethylmethacrylate was secondarily potted into polyester resin (Bondo, Atlanta, GA). The potting fixtures for C-3 and T-1 were attached to the upper and lower spine fixators, respectively, of the loading frame (858 Minibionix; MTS, Eden Prairie, MN). In this fixation, the motion between C4–5, C5–6, and C6–7 was preserved (Fig. 2).

Instability Model

Bilateral cervical facet dislocation injury was created at the C5–6 level according to the definition given by Allen, et al., who defined it as a distractive flexion injury, Stage III. To accomplish this, the bilateral facet joint capsules, the PLL, the posterior half of the annulus and disc, the posterior ligamentous complex including the supraspinous and interspinous ligaments, and the ligamentum flavum were cut. The anterior longitudinal ligament and anterior half of the disc were also cut because an ACDF with tricortical iliac graft was performed in this study.

Surgical Techniques

After bilateral cervical facet dislocation injury was created at the C5–6 level, a one-level anterior discectomy, interbody grafting with a tricortical iliac graft, and an anterior cervical locking screw/plate fixation in which a DOC plate system was used (DePuy AcroMed Co., Cleveland, OH) were performed at the C5–6 level. A discecto-
my was performed to visualize the previously incised PLL. A tri-
cortical iliac graft of 6- to 7-mm height was inserted with a disc
height distraction of less than 2 mm and preservation of suitable
anular tension, and anterior screw plating was performed using
Caspar instrumentation with a proper compression load under fluo-
roscopic guidance.

After testing the ACDFP with its plate and 14-mm-long locking
screws, we performed an additional posterior simple wiring pro-
cedure in which a multistrand, braided titanium Songer cable (DePuy
AcroMed Co.) was used. (The Rogers technique, a simple wiring
method involving adjacent spinous processes, was used.) A cervical
posterior transpedicular screw/rod fixation was done using the
SUMMIT fixation system (DePuy AcroMed Co.) after testing the
ACDFPW, after which removal of the anterior plate fixation and
posterior wiring was performed. After complete removal of the lig-
amentum flavum from the exposed area, transpedicular screws were
placed using the “laminoforaminotomy and palpation” technique
under fluoroscopic guidance, in which a laminoforaminotomy is
followed by direct palpation of the pedicle with a right-angled nerve
hook and then placement of a pedicle screw. A 2-mm burr was used to
start a hole in the pedicle and a hand-guided 1.25-mm drill bit was
used for further placement of the screw into the pedicle. The point of
screw penetration at the posterior cortex of the articular mass was lat-
eral to the center of the mass and close to the inferior margin of the
inferior articular process of the cranially adjacent vertebra. The
intended angle of screw insertion in the sagittal plane was parallel to
the upper endplate attached to the VB. The screw was angled 30 to
45° medially in the transverse plane. Three-millimeter-diameter rods
were used and all screws were polyaxial and 3.5 mm in diameter, 22
to 24 mm in length, and were inserted unicortically into the pedicle
after the screw hole was tapped with a 3.5-mm tapper.

Biomechanical Testing

Stability was tested in six modes of motion: flexion, extension,
right and left lateral bending, and right and left axial rotation.
Nondestructive tests were performed under flexion–extension, lat-
eral bending, and axial rotation (2 Nm each) with an applied axial pre-
load of 20 N. Motions of C-5 and C-6 were captured by a video-
based motion capture system (Qualisys, Gothenburg, Sweden) aided
by placement of reflective markers on C-5 and C-6. Three optical
markers were attached to each vertebra. The normal angle to the
plane formed by the three markers was found, and as the vertebra
moved, the change of the normal angle was determined. Axial com-
pression and axial rotation were provided by the upper spine fixator,
whereas flexion, extension, and lateral bending were provided by
rotation of both spine fixators in the coronal/sagittal plane (Fig. 2).
Each mode of testing was performed three times; however, only the
third result was used to stabilize the viscoelastic effect.

For each mode of loading, the ROM and NZ were determined:
the ROM is defined as the angular deformation in all directions at
maximum load and the NZ is defined as the difference at zero load
between the angular positions in all directions of the loading and
unloading phases. For comparison of the biomechanical stabilities,
three different surgical procedures were performed in each speci-
men, and after each procedure six modes of motion were tested on
the spine (C3–T1). Thus, the following conditions were used: 1) the
intact spine; 2) ACDFP after creation of bilateral cervical facet dis-
location injury; 3) ACDFP plus additional Rogers posterior wiring
technique in which a Songer titanium cable was used (Depuy
AcroMed Co.); and 4) posterior transpedicular screw/rod fixation in
which a SUMMIT fixation system (Depuy AcroMed Co.) was used
after ACDF.

Fig. 2. Photograph showing the testing setup. Two wands with three reflective markers each were attached to C-5 and
C-6, respectively. The spine loading fixture provides different modes of motion.
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Statistical Analysis
The ROM and NZ values obtained after each surgical procedure were normalized by dividing them by those of the intact spine. The mean value of the normalized ROM and NZ for each specimen group was determined and nonparametric statistical methods were used to ascertain the statistically significant differences among the treatment groups, because the number of specimens was limited and the data could not be assumed to be normally distributed. Paired comparisons were made between different treatment groups by using the Wilcoxon pairs test, and statistical significance was assigned at a probability level of less than 0.05.

Results
The values of ROM and NZ (mean ± SD) for all specimens are shown in Table 1. The ROM and NZ values for individual specimens were normalized in relation to that of the intact spine, as shown in Figs. 3 and 4, respectively.

Flexion Mode
For the flexion mode, the normalized ROM values (mean ± SD) were 70 ± 59% for ACDFP, 29 ± 35% for ACDFPW, and 61 ± 84% for ACDFTP, and the normalized NZ values were 68 ± 58% for ACDFP, 32 ± 50% for ACDFPW, and 62 ± 95% for ACDFTP. The ROM values in the flexion mode for all three surgical methods were significantly lower than those of the intact spine (p < 0.05, Fig. 3). The NZ values in the flexion mode for all three surgical methods were also lower than those of the intact spine, but without statistical significance (Fig. 4). In the flexion mode, the ACDFPW method showed the highest biomechanical stability, followed by the ACDFTP and then the ACDFP methods.

Extension Mode
The normalized ROM values for the extension mode were 74 ± 56% for ACDFP, 41 ± 25% for ACDFPW, and 89 ± 47% for ACDFTP, and the normalized NZ values were 92 ± 77% for ACDFP, 63 ± 72% for ACDFPW, and 72 ± 67% for ACDFTP. The ROM values in the extension mode for all three surgical methods were lower than those of the intact spine, with statistical significance in the ACDFP and ACDFPW methods (p < 0.05, Fig. 3). The NZ values in the flexion mode for all three surgical methods were also lower than those of the intact spine, but with no statistical significance (Fig. 4). In the flexion mode, the ACDFPW method showed the highest biomechanical stability, followed by the ACDFTP and then the ACDFP methods.

Lateral Bending Mode
For the lateral bending mode, the normalized values of ROM were 107 ± 68% for ACDFP, 89 ± 38% for ACDFPW, and 28 ± 14% for ACDFTP, and the normalized values of the NZ were 105 ± 80% for ACDFP, 88 ± 76% for ACDFPW, and 25 ± 14% for ACDFTP. The values of ROM in the lateral bending mode for the ACDFTP and ACDFPW methods were lower than those of the intact spine, with statistical significance (p < 0.05) in the ACDFTP method. The ROM value for ACDFP was slightly higher than that in the intact spine (Fig. 3). The NZ values in the lateral bending mode for all three surgical methods revealed similar patterns, as did the ROM values (Fig. 4). In the lateral bending mode, the ACDFTP method showed much better stability than the other two methods, reaching statistical significance (p < 0.05).

Axial Rotation Mode
The normalized ROM values for the axial rotation mode were 96 ± 63% for ACDFP, 66 ± 35% for ACDFPW, and 42 ± 40% for ACDFTP, and normalized NZ values were 116 ± 90% for ACDFP, 87 ± 77% for ACDFPW, and 40 ± 59% for ACDFTP. The ROM values in the axial-rotation mode for all three surgical methods were lower than those of the intact spine, reaching statistical significance in the spines treated with the ACDFTP and ACDFPW methods (p < 0.05, Fig. 3). The NZ values for the ACDFTP and ACDFPW methods were lower than those of the intact spine, with statistical significance for the ACDFTP method (p < 0.05), and the NZ value for ACDFP was slightly higher than that of the intact spine (Fig. 4). In axial rotation mode, the ACDFTP method showed the highest biomechanical stability, followed by the ACDFPW and then the ACDFP methods.

Discussion
Bilateral Facet Dislocation Injuries of the Subaxial Cervical Spine
Bilateral cervical facet dislocations are highly unstable, three-column discoligamentous injuries and are frequently associated with neurological deficits. Facet fractures associated with cervical facet dislocation injuries may preclude successful closed reduction, but they may be associated with a high rate of arthrodesis in patients treated with external immobilization alone. Alternatively, discoligamentous disruption without facet fracture is associated with an increased likelihood of failure when external immobilization is achieved using a Halo device or Minerva cast. Results in numerous recent studies have shown a high incidence of disc herniation in patients with bilateral cervi-

### Table 1

<table>
<thead>
<tr>
<th>Type of Approach</th>
<th>ROM/NZ</th>
<th>Flexion</th>
<th>Extension</th>
<th>Lat Bending</th>
<th>Axial Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact spine</td>
<td></td>
<td>6.71 ± 3.50/2.52 ± 2.00</td>
<td>3.70 ± 2.38/1.70 ± 1.71</td>
<td>4.52 ± 1.99/1.19 ± 0.62</td>
<td>6.27 ± 4.28/1.48 ± 1.18</td>
</tr>
<tr>
<td>ACDFP</td>
<td></td>
<td>3.58 ± 2.92/1.50 ± 2.21</td>
<td>2.06 ± 1.05/0.95 ± 0.90</td>
<td>4.10 ± 1.69/1.07 ± 0.68</td>
<td>4.41 ± 2.28/1.15 ± 0.68</td>
</tr>
<tr>
<td>ACDFPW</td>
<td></td>
<td>1.15 ± 0.46/0.29 ± 0.27</td>
<td>1.36 ± 1.11/0.65 ± 0.84</td>
<td>3.58 ± 1.45/0.83 ± 0.57</td>
<td>3.17 ± 1.57/0.79 ± 0.53</td>
</tr>
<tr>
<td>ACDFTP</td>
<td></td>
<td>2.16 ± 0.61/0.51 ± 0.39</td>
<td>2.68 ± 0.60/0.63 ± 0.39</td>
<td>1.18 ± 0.56/0.23 ± 0.09</td>
<td>1.77 ± 1.90/0.32 ± 0.33</td>
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cal facet dislocations. Therefore, anterior locking screw/plate instrumentation has become popular in the treatment of bilateral cervical facet dislocation. The major advantage of this anterior approach is that decompression, reduction, interbody grafting, and instrumental stabilization can all be performed using the same operative field. Although in many biomechanical studies researchers have reported that anterior locking screw/plate fixation alone may not provide adequate stability in cervical injuries, reports of clinical series indicate general success with this method of treatment. Instrumentation has also been used to achieve posterior cervical fixation. Excellent results have been obtained using both the traditional Rogers wiring or the Bohlman triple wiring methods as well as more modern techniques in which lateral mass or transpedicular screws are used. Because definitive treatment depends on the need for neurological decompression and spinal stabilization, closed reduction followed by posterior fusion and instrumentation has been used in patients with bilateral cervical facet dislocations without significant disc herniation. If a large disc herniation is identified in a patient with intact neurological function or incomplete neurological deficits, then anterior decompression, reduction, interbody grafting, and anterior instrumentation have been recommended.

Biomechanical Comparisons of Cervical Stabilizations in Bilateral Facet Dislocation

In a previous biomechanical study of bilateral cervical facet dislocation injury, Sutterlin, et al., compared the strength of various posterior cervical instrument constructs with that of anterior plate fixation in which the Caspar system was used. They found that an anterior plate with bicortical screw fixation restored flexural stability to only half that of an intact specimen and was the least rigid in axial flexural loading (p < 0.05). Coe, et al., also suggested that Caspar anterior plating was clearly an inferior method of treating distractive flexion injuries of the cervical spine when compared with all posterior fixation techniques. They also indicated that, in posterior injury, anterior plate fixations did not provide as much stability as did posterior fixation procedures because the cortex of the anterior cervical VBs is not as strong as that of the posterior bone elements. Alternatively, Traynelis, et al., suggested that anterior plate fixation provided significantly more stability in extension and lateral bending than did posterior wiring procedures when treating a C-5 teardrop.
fracture with posterior ligamentous instability in human cadaveric spines. They reported that the injured anterior plate–stabilized spines were more stable than the intact specimens in all modes of testing.

In our study, anterior interbody grafting was performed in addition to anterior locking screw/plate fixation. Because the intervertebral surface is highly vascular and the graft has a wide contact area in the weight-bearing axis of the spine, interbody fusion permits a high load transmission through the anterior column, restores disc height, and may increase stability. In our study, the anterior locking screw/plate fixation method performed after ACDF by using a tricortical iliac graft provided more stability than that of the intact spine in most loading modes except for lateral bending, with statistical significance for ROM values in flexion and extension modes. As expected, the addition of posterior simple wiring with the Rogers technique after ACDF resulted in more stability in all loading modes, and it also provided statistically significant differences in axial-rotation ROM and in flexion NZ.

Do Koh, et al.,9 suggested that posterior lateral mass screw plating with an anterior interbody graft was biomechanically superior to anterior plating with locking fixation screws for stabilizing one-level flexion–distraction injuries. The posterior lateral mass screw plating resulted in effective stabilization of the unstable cervical segments in all loading modes, whereas the anterior fixation alone was inadequate to stabilize the cervical spine after flexion–distraction injury. In their study, anterior plating provided significant stabilization in the extension mode only. In our study, posterior transpedicular screw/rod fixation was compared with anterior locking screw/plate fixation after ACDF performed using a tricortical iliac graft. It has been reported that the three-column fixation provided by the transpedicular screw/rod fixation system is advantageous in stabilizing the cervical spine.20 In another study, cervical pedicle screws imparted significantly higher resistance to pullout forces than did lateral mass screws.17 Kotani, et al.,20 reported that the overall stability of transpedicular screw fixation in the calf cervical spine was nearly identical to that of the combined anterior plate and posterior triple wiring for one-level fixation in three-column instability. They did not include anterior plate fixation with anterior interbody grafting in their comparisons, however.

Only three methods of cervical pedicle screw placement have been reported. Abumi, et al.,1 reported a method for identifying the entry point of screw placement in the posterior aspect of the lateral mass by using a decortication procedure without laminoforaminotomy under

**FIG. 4.** Bar graphs showing normalized NZ values (mean ± SD) for spine specimens after the ACDFP, ACDFPW, and ACDFTP methods. Significant differences (p < 0.05) are shown with asterisks.
fluoroscopic guidance. The second method, performed in our study under fluoroscopic guidance, is placement of a screw after direct palpation of the pedicle with a rightangled nerve hook after a small laminoforaminotomy. The third method is a computer-guided image identification system that is highly accurate with respect to screw placement. Successful placement of a pedicle screw in the cervical spine requires accurate identification of the pedicle axis because transpedicular screw insertion in the cervical spine is associated with risks to major neurovascular structures, including the vertebral artery, nerve root, and spinal cord. Abumi, et al., however, reported just one vertebral artery injury without neurological complications, 45 screws (6.7%) penetrating the pedicle, and two of 45 screws causing radiculopathy in 180 patients with 669 pedicle screws.

In our study, the ACDFTP method imparted significantly more stability than that of the intact spine in all loading modes, except for the ROM in the extension mode and the NZ in the flexion and extension modes. The ACDFTP method also resulted in better stability than the ACDFP method in the bending and axial-rotation modes, and yielded better stability than the ACDFPW method in the bending mode for both ROM and NZ. Anterior locking screw/plate fixation methods with or without posterior wiring, however, provided significantly more stability in the extension mode than with the ACDFTP method.

Like all cadaveric studies, ours has some limitations. Most of the cadaveric specimens were obtained in elderly patients. Our results may reveal lower spinal stability than in a young, healthy population because BMD influences the primary stability of screw fixation. Bilateral cervical facet dislocation injury usually occurs as a result of motor vehicle accidents in younger age groups in whom the BMD value is high.

Conclusions

In bilateral facet dislocation of the subaxial cervical spine, posterior transpedicular fixation with an anterior interbody graft resulted in the most effective biomechanical stabilization, followed by the ACDFPW, and the ACDFP method in treatment of bilateral cervical facet dislocation at the C5–6 level. Even though the ACDFP method yielded an inferior biomechanical stability when compared with the ACDFP method in almost all loadings, with the exception of the extension mode, the use of the anterior locking screw/plate fixation after ACDF by using a tricortical iliac graft provides a higher biomechanical stability than that of the intact spine in almost all loading modes. Therefore, the ACDFP method can provide a relatively effective stabilization in bilateral cervical facet dislocation injury treated with a brace, although the specific fixation method is determined by the proper clinical and radiological characteristics in each patient.

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