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Clinical Article

A Biomechanical Comparison among Three Surgical Methods in Bilateral Subaxial Cervical Facet Dislocation

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Objective : The biomechanical stabilities between the anterior plate fixation after anterior discectomy and fusion (ACDFP) and the posterior transpedicular fixation after ACDF(ACDFTP) have not been compared using human cadaver in bilateral cervical facet dislocation. The purpose of this study is to compare the stability of ACDFP, a posterior wiring procedure after ACDFP(ACDFPW), and ACDFTP for treatment of bilateral cervical facet dislocation.
Methods : Ten human spines (C3-T1) were tested in the following sequence : the intact state, after ACDFP(Group 1), ACDFPW(Group 2), and ACDFTP(Group 3). Intervertebral motions were measured by 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 2.0Nm.
Results : ROMs for Group 1 were 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 without significances. Group 2 produced additional stability in axial rotation of ROM and in flexion of NZ than Group 1 with significance. Group 3 provided better stability than Group 1 in bending and axial rotation, and better stability than Group 2 in bending of both ROM and NZ. There was no significant difference in extension modes for the three Groups.
Conclusion : ACDFTP(Group 3) demonstrates the most effective stabilization followed by ACDFPW(Group 2), and ACDFP(Group 1). ACDFP provides sufficient strength in most loading modes, ACDFP can provide an effective stabilization for bilateral cervical facet dislocation with a brace.

KEY WORDS : ACDF · Additional posterior wiring · Anterior cervical plate fixation · Bilateral cervical facet dislocation · Biomechanical testing · Posterior transpedicular fixation.

Introduction

Bilateral facet dislocation injuries of the subaxial cervical spine are common after nonpenetrating cervical trauma and are frequently associated with neurological deficits. Bilateral cervical facet dislocations, or the distractive flexion stage III injury described by Allen et al[5], involve distraction and translation of the superior vertebral body over the inferior vertebral body. This injury requires some degree of disruption of the inter- and supraspinous ligament, the ligamentum flavum, and facet capsules, and the anterior longitudinal ligament(ALL) and posterior longitudinal ligament(PLL), and/or disc. Although the disruption of the posterior ligaments is severe in this injury, all three columns are usually affected.

Traditionally, the surgical treatments of bilateral cervical facet dislocation have been performed posteriorly with a wiring or plate screw fixation after closed reduction because of the disruption of the posterior ligamentous complex and facet joints[7]. In the last several years, however, the techniques of the anterior cervical plate fixation after anterior cervical discectomy and interbody fusion(ACDF) have become popularized and used in bilateral cervical facet dislocations because decompression and indirect reduction, interbody grafting, and stabilization by using additional anterior plating instruments can be done through the same surgical field[8,12,13,25,28]. Moreover, traumatic disc herniation causing compression of the cervical cord at the level of bilateral cervical facet dislocation have been reported in up to half of patients with bilateral cervical facet dislocation by several authors[15].

Although previous biomechanical studies have demonstrated significantly greater stiffness of the posterior instrumentation compared with the anterior plate fixation[9,17,19,20,33,36], these

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studies did not include ACDF procedure along with anterior plate fixation. On the contrary, however, there have been many clinical reports associated with an anterior plate fixation after ACDF in bilateral cervical facet dislocations, with excellent results[12,18,22,25,29]. In the posterior instrumentation, transpedicular screw rod fixation system offers 3-column stability and it has proven to be the most rigid posterior fixation technique[9,19]. It has some biomechanical and surgical advantages over the lateral mass screw plating, which primarily depends on compressive force to reduce dislocation of the injured segment. Transpedicular screw rod fixation has a significant higher pullout strength than the lateral mass screw plating[17] and it also can easily correct kyphotic and translation deformities via a distraction maneuver.

The differences of the biomechanical stabilities between an anterior cervical locking screw plate fixation and posterior transpedicular screw rod fixation after ACDF in bilateral cervical facet dislocations (distractive-flexion stage III injury) have not been compared in the human cadaveric model to date. Thus, the purpose of this study was to compare the initial biomechanical stabilities of three different surgical methods, which are 1) an anterior locking plate screw fixation after ACDF using tricortical iliac graft (ACDFP, Group 1), 2) followed by additional posterior simple wiring procedure using Rogers' technique after ACDFP (ACDFPW, Group 2), and 3) ACDF followed by additional cervical posterior transpedicular screw rod fixation (ACDFTP, Group 3) in a simulated distractive flexion stage III injury created at the C5-C6 level.

Materials and Methods

Cadaveric specimen preparation and fixation

Ten human cadaveric cervical spines with the first thoracic spine attached (C3-T1) were obtained from Science Care Anatomical (Phoenix, AZ). The mean age of the 5 male and 5 female specimens was 62.8±6.6years±SD with a range between 55-78 years. Anteroposterior and lateral radiographs of the specimens were performed to exclude bony abnormalities, and bone mineral density(BMD) measurements were also obtained using dual-energy x-ray absorptiometry (DEXA; Hologic QDR 4500A, Hologic Inc, Waltham, MA) scan. The mean BMD of the C5-C6 level was $0.54\pm0.07g/cm^2$ with a range of 0.44-$0.69g/cm^2$. En bloc specimens for biomechanical testing were stored at -20°C until thawed at room temperature overnight and were kept moist during all procedures. The attached musculature was removed, with care taken to preserve the joint capsules, ligaments, discs, and bony structures. After completion of the specimen preparation, several screws were drilled into C3 and into T1. The C3 and T1 were primarily potted in polymethylmethacrylate (PMMA, COE Tray plastic, GC America, Alsip, IL) and then the PMMA was secondarily potted into the Polyester Resin (Bondo, Atlanta, GA). The potting fixtures for the C3 and T1 were attached to the upper and lower spine fixtures of the MTS loading frame (MTS 858 Minibionix, Eden Prairie, MN), respectively. In this fixation, the motions between C4-C5, C5-C6 and C6-C7 were preserved.

Instability model

Bilateral cervical facet dislocation injury was created at the C5-C6 level using the definition described by Allen et al[5]. They defined bilateral cervical facet dislocation injury as a distractive flexion injury stage III. The bilateral facet joint capsules, the PLL, posterior half of the annulus and the disc, and posterior ligamentous complex including supraspinous and interspinous ligaments, and ligamentum flavum were cut. The ALL and anterior half of the disc were also cut because an ACDF using tricortical iliac graft was performed in this study.

Surgical techniques

After a bilateral cervical facet dislocation injury was created at the C5-C6 level, one-level anterior discectomy, interbody grafting with a tricortical iliac graft, and an anterior cervical locking plate screw fixation using a DOC plate system (DePuy AcroMed, Cleveland, OH) were performed at the C5-C6 level. A discectomy was carried out to visualize the previous incised posterior longitudinal ligament. A tricortical iliac graft of 6 to 7mm height was inserted with the preservation of suitable annular tension with a disc height distraction of less than 2-mm, anterior screw plating was done using Caspar instrumentation with a proper compression load under fluoroscopic guidance.

After testing the ACDFP with a plate and 14-mm length locking screws, an additional posterior simple wiring procedure with a multistrand braided titanium Songer's cable (DePuy AcroMed, Cleveland, OH) was performed after an ACDFP. Rogers' technique, a simple wiring method involving adjacent spinous processes, was used. The cervical posterior transpedicular screw rod fixation using a SUMMIT fixation system (DePuy AcroMed, Cleveland, OH) was done after testing of ACDFPW with removal of anterior plate fixation and posterior wiring. After complete removal of the ligamentum flavum from the exposed area, transpedicular screws were placed according to the laminoforaminotomy-and-palpation technique under fluoroscopic guidance[23]. This technique includes placing all pedicle screws following direct palpation of the pedicle with a right-angled nerve hook after performing a laminoforaminotomy.

A 2-mm burr was used to start a hole in the pedicle and a hand-guided 1.25mm 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 lateral to the center of the articular 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. The screw was angled 30 to 45 degrees medially in the transverse plane. Three-mm 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 taper (Fig. 1).

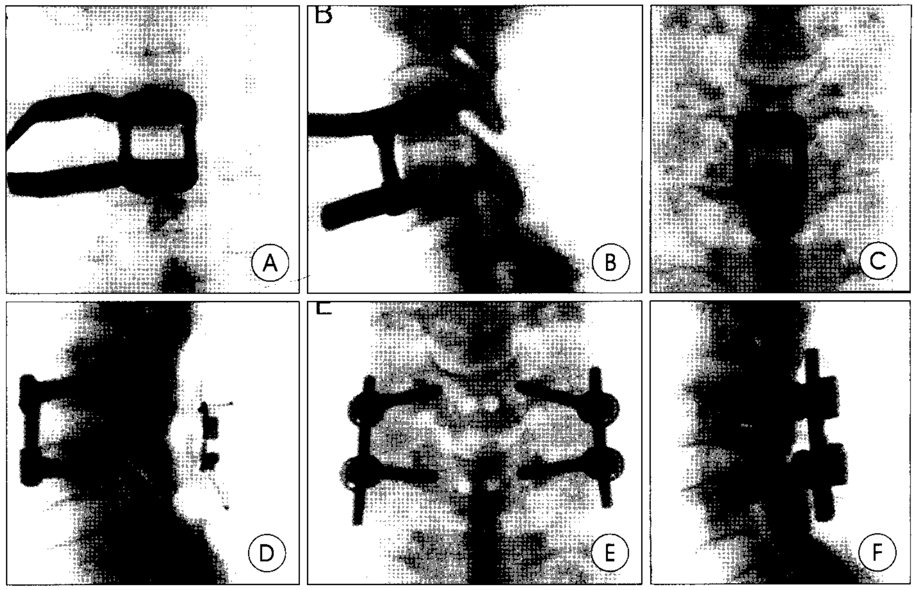

Fig. 1. Radiographic features of three different surgical methods in a simulated bilateral facet dislocation injury created at the level of C5–C6 (anteroposterior and lateral radiographs). A and B: anterior locking plate screw fixation after anterior cervical discectomy and interbody fusion using tricortical iliac graft. C and D: additional posterior simple wiring procedure using Rogers' technique after anterior cervical discectomy and interbody fusion, plating. E and F: additional posterior cervical transpedicular screw rod fixation after anterior cervical discectomy and interbody fusion.

Biomechanical testing

Stability was tested in 6 modes of motion: flexion, extension, right and left lateral bending, and right and left axial rotation. Nondestructive tests were performed under flexion-extension (2.0 Nm), lateral bending (2.0 Nm), and axial rotation (2.0 Nm) with an applied axial preload of 20N. Motions of C5 and C6 were captured by a video-based motion capture system (Qualisys, Sweden) by placing reflective markers on C5 and C6. Each mode of testing was performed 3 times. Only the third result was used in order to stabilize the viscoelastic effect. In each mode of loading, ROM and neutral zone were determined. ROM is defined as the angular deformation in all directions at maximum load, Neutral zone 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 stability, each specimen had three different surgical procedures performed in the following order and 6 modes of motion was tested on the spine (C3-T1) as follows : (1) intact spine, (2) ACDFP after creating bilateral cervical facet dislocation injury(Group 1), (3) ACDFP plus additional Rogers' posterior wiring technique using a Songer's titanium cable (Deputy, AcroMed, Cleveland, OH)(Group 2), (4) posterior transpedicular screw rod fixation using a SUMMIT fixation system (Deputy, AcroMed, Cleveland, OH) after ACDF (Group 3).

Statistical analysis

The average value of ROM and neutral zone for each specimen group was determined and nonparametric statistical methods were employed in order to ascertain the statistically significant differences between the different treatment groups, since there were few specimens and the data could not be assumed to be normally distributed. Paired comparisons were made between different treatment groups by use of the Wilcoxon pairs tests and statistical significance was concluded at the $P<0.05$ level.

Results

The mean $\pm$ SD values of ROM and neutral zone for all specimens are shown in Table 1. The ROM and neutral zone for individual specimens were normalized with respect to that of the intact spine as shown in Figure 2 and 3, respectively.

Flexion mode

The normalized values of ROM (mean $\pm$ SD) were $70\pm59\%$ for Group 1, $29\pm35\%$ for Group 2, and $61\pm84\%$ for Group 3 and normalized values of neutral zone were $68\pm58\%$ for Group 1, $32\pm50\%$ for Group 2, and $62\pm95\%$ for Group 3, respectively. The values of ROM in flexion mode for all three surgical methods were significant lower than that of the intact spine ($p<0.05$) (Fig. 2). The values of neutral zone in flexion mode for all three surgical methods were also lower than that of the intact spine but without statistical significance (Fig. 3). In flexion mode, the Group 2 showed the highest biomechanical stability followed by the Group 3 and the Group 1.

Extension mode

The normalized values of ROM were 74±56% for Group 1, 41±25% for Group 2, and 89±47% for Group 3 and normalized values of neutral zone were 92±77% for Group 1, 63±72% for Group 2, and 72±67% for Group 3, respectively. The values of ROM in extension mode for all three surgical methods were lower than that of the intact spine with statistical significances in the Group 1 and Group 2 ($p<0.05$) (Fig. 2). The values of neutral zone in extension mode for all three surgical methods were also lower than that of the intact spine but without any statistical significance (Fig. 3). In extension mode, the Group 2 showed the highest biomechanical stability followed by the Group 1 and the Group 3.

Lateral bending mode

The normalized values of ROM were 107±68% for Group 1, 89±38% for Group 2, and 28±14% for Group 3 and normalized values of neutral zone were 105±80% for Group 1, 88±76% for Group 2, and 25±14% for Group 3, respectively. The values of ROM in lateral bending mode for the Group 3 and Group 2 were lower than that of the intact spine with a statistical significance in the Group 3 ($p<0.05$). The value of ROM for Group 1 was slightly higher than that of the intact spine (Fig. 2). The values of neutral zone in lateral bending mode for all three surgical methods revealed similar patterns as the values of ROM (Fig. 3). In lateral bending mode, the Group 3 showed much better stability than the other two Groups with a statistical significance ($P<0.05$).

Axial rotation mode

The normalized values of ROM were 96±63% for Group 1, 66±35% for Group 2, and 42±40% for Group 3 and normalized values of neutral zone were 116±90% for Group 1, 87±77% for Group 2, and 40±59% for Group 3, respectively. The values of ROM in axial rotation mode for all three surgical methods were lower than that of the intact spine with statistical significances in the Group 3 and Group 2 ($p<0.05$) (Fig. 2). The values of neutral zone for the Group 3 and Group 2 were lower than that of the intact spine with a statistical significance in the Group 3 ($p<0.05$) and the value of neutral zone for Group 1 was slightly higher

Table 1. Mean and standard deviation ((SD) of range of motion and neutral zone for all treatment groups

Types of Approach	Range of Motion/ Neutral Zone*			
	Flexion	Extension	Lateral Bending	Axial Rotation
Intact	6.71±3.50 / 2.52±2.00	3.70±2.38 / 1.70±1.71	4.52±1.99 / 1.19±0.62	6.27±4.28 / 1.48±1.18
ACDFP	3.58±2.92 / 1.50±2.21	2.06±1.05 / 0.95±0.90	4.10±1.69 / 1.07±0.68	4.41±2.28 / 1.15±0.68
ACDFPW	1.15±0.46 / 0.29±0.27	1.36±1.11 / 0.65±0.84	3.58±1.45 / 0.83±0.57	3.17±1.57 / 0.79±0.53
ACDFTP	2.16±0.61 / 0.51±0.39	2.68±0.60 / 0.63±0.39	1.18±0.56 / 0.23±0.09	1.77±1.90 / 0.32±0.33

* Degrees expressed as means±standard deviation. ACDFP=anterior locking plate screw fixation after ACDF using tricortical iliac graft, Group 1. ACDFPW =additional posterior simple wiring procedure using Rogers' technique after ACDFP, Group 2. ACDFTP=additional posterior cervical transpedicular screw rod fixation after ACDF, Group 3

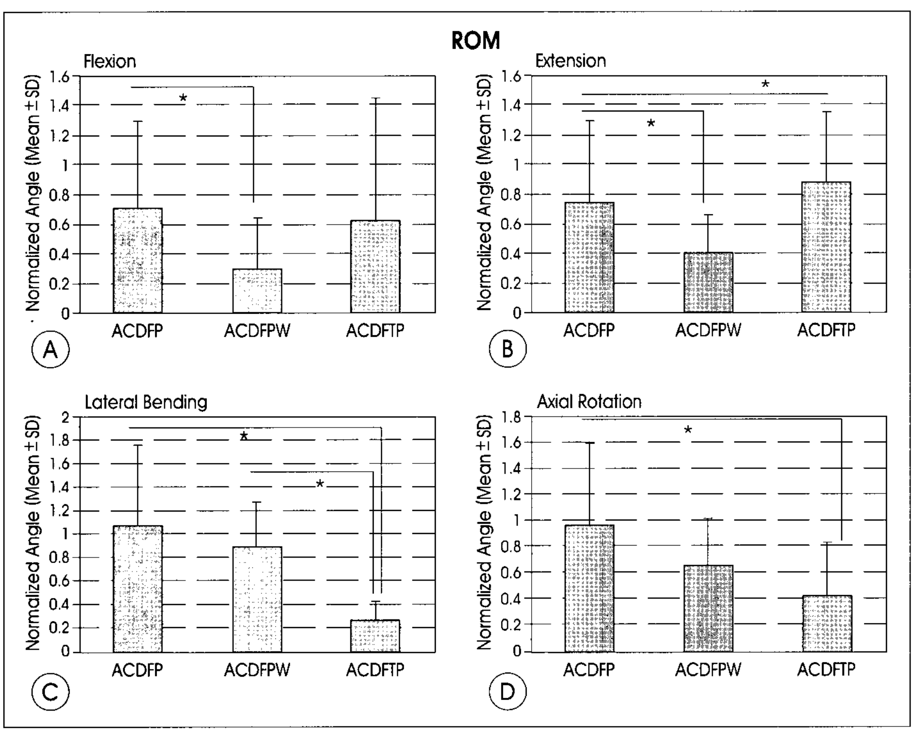

Fig. 2. Mean and standard deviation of normalized range of motion for spine specimens after the anterior cervical discectomy and interbody fusion and plating, the anterior cervical discectomy and interbody fusion and plating plus posterior wiring, the anterior cervical discectomy and interbody fusion plus transpedicular screw rod fixation methods. The significance difference ($P<0.05$) is shown with an asterisk (*).

than that of the intact spine (Fig. 3). In axial rotation mode, the Group 3 showed the highest biomechanical stability followed by the Group 2 and the Group 1.

Discussion

Bilateral facet dislocation injuries of the subaxial cervical spine

Bilateral facet dislocation injuries are highly unstable three-column discoligamentous injuries and are frequently associated with neurological deficits. Overall, 26% of patients with this injury had failed to achieve closed reduction and reduction also could not be maintained in 28% of patients treated with subsequent external immobilization alone[1]. Facet fractures associated with cervical facet dislocation injuries may preclude successful closed reduction[24], but they have been associated with a high rate of arthrodesis with external immobilization alone. Alternatively, discoligamentous disruption without facet fracture is associated with an increased likelihood of failure of external immobilization using a Halo device or Minerva cast in the treatment of these injuries[14]. Recently, numerous studies have shown a high incidence of disc herniation in patients with bilateral cervical facet dislocations[6,11,15,21,26,30]. Therefore, the anterior locking plate screw instrumentations have become popularized in treatment of this injury. Major advantage of this anterior approach is that decompression, reduction, interbody grafting, and instrumental stabilization can be done using the same operative field. Although many biomechanical studies reported that anterior plate screw fixation alone in unstable cervical injuries may not provide adequate stability[9,20,34], reports of clinical series indicate general success with this method of treatment[12,25,27,29]. Alternatively, various different instrumentations for the posterior cervical fixation have been also reported, with excellent results from traditional Rogers' wiring or Bohlman's triple wiring techniques to more modern techniques of posterior instrumentation using lateral mass or transpedicular screws[2,3,7,14,16,32,35]. 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[7,11]. If a large disc herniation is identified in a patient with intact neurological deficits, then anterior decompression, reduction, interbody grafting, and anterior instrumentation have been recommended[31].

Biomechanical comparison for cervical stabilization in bilateral facet dislocation

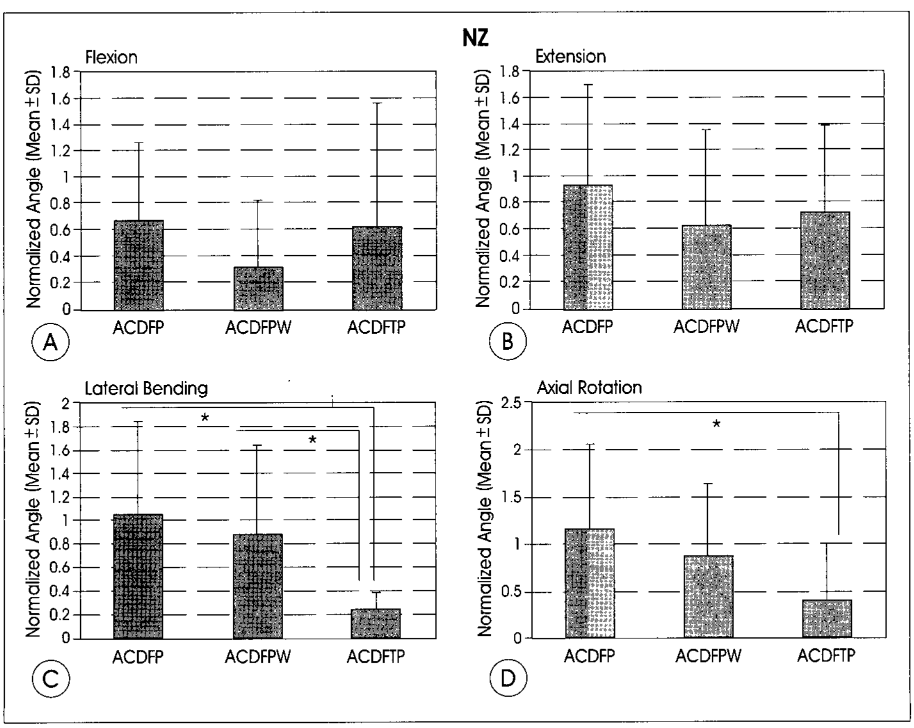

Fig. 3. Mean and standard deviation of normalized neutral zone for spine specimens after the anterior cervical discectomy and interbody fusion and plating, the anterior cervical discectomy and interbody fusion and plating plus posterior wiring, the anterior cervical discectomy and interbody fusion plus transpedicular screw rod fixation methods. The significance difference ($P<0.05$) is shown with an asterisk (*).

In previous biomechanical studies of bilateral cervical facet dislocation injury, Sutterlin et al evaluated the strength of various posterior cervical instrument constructs compared with that of the anterior plate fixation using the Caspar system[34]. They found that an anterior plate with bicortical screw fixation restored flexural stability to only 1/2 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[9]. They also indicated that anterior plate fixations did not provide as sufficient stability as posterior fixation procedures in posterior injury because the cortex of the anterior cervical vertebral bodies is not as strong as that of the posterior bony elements[9,33]. Alternatively, Traynelis et al suggested that anterior plating provided significantly more stability in extension and lateral bending than did posterior wiring after creating a C5 teardrop fracture with posterior ligamentous instability in human cadaveric spines[34]. They reported that the injured/anterior plate-stabilized spines were more stable than the intact specimens in all modes of testing. Unlike previous biomechanical studies, which did not include anterior interbody grafting, in our study, anterior interbody grafting was performed in addition to anterior screw plate fixation. Since 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, can restore disc height and it may increase stability. In this study, the anterior locking plate screw fixation method after ACDF using a tricortical iliac graft showed a higher stability than that of the intact spine in most loading modes except for lateral bending, with statistical significance in flexion and extension modes in ROM. As expected, the additional posterior simple wiring procedure using Rogers' technique after the ACDFP method revealed additional stability in all loading modes and it also provided statistically significant differences in axial rotation of ROM and in flexion of neutral zone to the ACDFP method.

Koh et al suggested that posterior lateral mass screw plating with an anterior interbody graft was biomechanically superior to anterior plating with locked fixation screws for stabilizing the one-level flexion-distraction injury. The posterior lateral mass screw plating showed effective stabilization of the unstable cervical segments in all loading modes whereas the anterior fixation alone was found to be inadequate in stabilizing the cervical spine in the flexion-distraction injury[10]. In their study, anterior plating provided significant stabilization in extension only. In our study, the posterior transpedicular screw rod fixation was tested in comparison with the anterior locking plate screw fixation after ACDF using tricortical iliac graft because the biomechanical advantage of a three-column fixation provided by transpedicular screw rod fixation system stabilizing an unstable cervical spine has proven to be valuable in previous biomechanical study[9]. Cervical pedicle screws demonstrated a significantly higher resistance to pullout forces than did lateral mass screws in another study[17]. Kotani et al reported that the overall stability of transpedicular screw fixation in calf cervical spine was nearly identical to that of the combined anterior plate and posterior triple-wiring for one level fixation in 3-column instability[19]. However, they did not compare the anterior plate fixation with an anterior interbody grafting.

Successful placement of a pedicle screw in the cervical spine requires the accurate identification of the pedicle axis because the transpedicular screw insertion of the cervical spine is associated with apparent risks to major neurovascular structures, including the vertebral artery, nerve root, and spinal cord[2]. Abumi et al, however, reported one vertebral artery injury without neurological complications, 45 screws (6.7%) penetrated the pedicle, and 2 of 45 screws caused radiculopathy in the 180 patients with 669 pedicle screws[4]. In this study, the Group 3 showed higher stability than that of the intact spine in all loading modes with statistical significance, except for extension mode in ROM and flexion and extension modes in neutral zone. The Group 3 also revealed better stability than the Group 1 in bending and axial rotation modes, and better stability than the Group 2 in bending mode for both ROM and neutral zone. However, Group 1 or Group 2 showed a significantly higher stability in extension mode than the Group 3.

Like all cadaveric studies, our study has some limitations. Most of the cadaveric specimens were from the elderly. Our results possibly reveal lower stabilities than those in a young healthy population, because the BMD influences the primary stability of screw fixation. Bilateral cervical facet dislocation injury usually occurs from motor vehicle accidents in the younger age group, who has a high BMD value.

Conclusion

In bilateral facet dislocation of the subaxial cervical spine, posterior transpedicular fixation with an anterior interbody graft demonstrated the most effective biomechanical stabilization followed by the ACDFPW, and the ACDFP method in bilateral cervical facet dislocation at the C5-C6 level. Even though the ACDFP method revealed an low biomechanical stability when compared with the ACDFTP method in the most loading with the exception of extension mode, the use of the anterior locking plate screw fixation after ACDF using a tricortical iliac graft provides a higher biomechanical stability than that of the intact spine in the most loading modes. Therefore, the ACDFP method can provide a relatively effective stabilization in bilateral cervical facet dislocation injury with a brace, though the specific fixation method is determined by the proper clinical and radiological characteristics in each patient.

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