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The Effects of Pedicle Screw Adjustments on Neural Spaces in Burst Fracture Surgery

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Study Design. An *in vitro* biomechanical study of experimental burst fractures and a pedicle screw device.

Objectives. To investigate the effects that adjustments of a pedicle screw device have on the neural spaces of the burst fracture.

Summary of Background Data. Decompression of the neural spaces is important for the recovery of neural function after a burst fracture. No studies, experimental or clinical, are available that have attempted to relate the pedicle screw device adjustments to the decompression of the neural spaces.

Methods. Burst fractures were produced at L1 vertebra in nine human lumbar spine specimens. Pedicle screw devices were attached to T12 and L2. Eight device adjustments, consisting of pure translations (distraction or compression), pure extension, and combinations of translation and extension were applied. The dimensional changes in the canal and the superior and inferior intervertebral foramens were measured. Functions of restoration and improvement were determined for the adjustments to evaluate the effects of each adjustment and to determine the optimal adjustment. Analysis of variance was used to find statistically significant differences, with significance set at P values less than 0.05.

Results. Significant differences were observed in the results of the eight adjustments. The most effective adjustments were the combination of 5-mm distraction with 6° extension or 10-mm distraction alone. The worst adjustment was 5 mm of compression.

Conclusions. Restoring compromised neural spaces in a patient with burst fracture is necessary. The choice of a device adjustment was found to be an important factor in the decompression of the neural spaces after the burst fracture. Combined distraction with extension and distraction alone were found to decompress the canal and intervertebral foramens maximally in a burst fracture. [Key words: biomechanics, burst fractures, device adjustments, internal fixator] **Spine 2000;25:1637–1643**

Burst fracture of the thoracolumbar spine is a serious injury, especially when it compromises the neural functions. More than 50% of burst fractures involve neurologic deficit.[2,16,17] Relations between the neural spaces (canal and intervertebral foramen dimensions) and the neurologic dysfunction have been examined. The conclusion is that the decrease in the neural spaces is a major cause of neural dysfunction,[8] and the affect of the decrease differs depending on the type of neural element (*i.e.,* the epiconus, the conus medullaris, and the cauda equina).[2,9] Therefore, to open the neural spaces as much as possible with the hope of restoring neurologic function is the basic and most important goal for surgical management of patients with burst fractures.

Some studies on the restoration of the neural spaces have been performed.[5,6,12,15] In the canal of a patient with burst fracture, the retropulsed bone fragments occupy the canal area and may compress the neural elements. Distraction with or without extension causes ligamentotaxis (pushing of the fragments back into the vertebra), which is considered to be one of the major restoration mechanisms.[6,7,11] In other studies, intervertebral foramen was investigated as a result of spinal posture. Again, distraction improved the space available in the lumbar stenotic foramens.[10,15]

Posterior spinal instrumentation, such as the use of pedicle screw devices, is used widely to apply these restoration displacements. Some new pedicle screw fixation devices (*e.g.,* AO internal fixator rod system) make it possible to apply translation and angulation independently.[1,4,11,13] In general, surgeons use the standard reduction technique for the restoration, approximating an optimal spinal alignment without taking precise measurements.[1,3] Therefore, little is known about the relations between the adjustments of a spinal device and the restoration of the neural spaces.

The purpose of the current study using the cadaveric lumbar spine burst fracture model was twofold: to test the hypothesis that the various adjustments of the pedicle screw device affect the neural spaces differently, and to determine the optimal adjustment that will maximize the neural spaces.

Materials and Methods

Specimen Preparation. Nine fresh human cadaveric thoracolumbar spine specimens were obtained. These were five-vertebrae segments (T11–L3) with an average age of 51 years (range, 21–74 years). The male to female distribution was 6 to 2, with one specimen of unknown gender. Each specimen was radiographed to ensure that it was not injured and had only normal degenerative changes for its age group. Muscle tissue was removed carefully without harming the ligaments and discs. The specimen was double-bagged and frozen at −20 C. At a later date, each specimen was provided with a quick-setting epoxy mount embedding the upper half of T11 vertebra and the lower half of L3, while keeping the L1 vertebra horizontal. Additionally, the T12 and L2 vertebrae were provided

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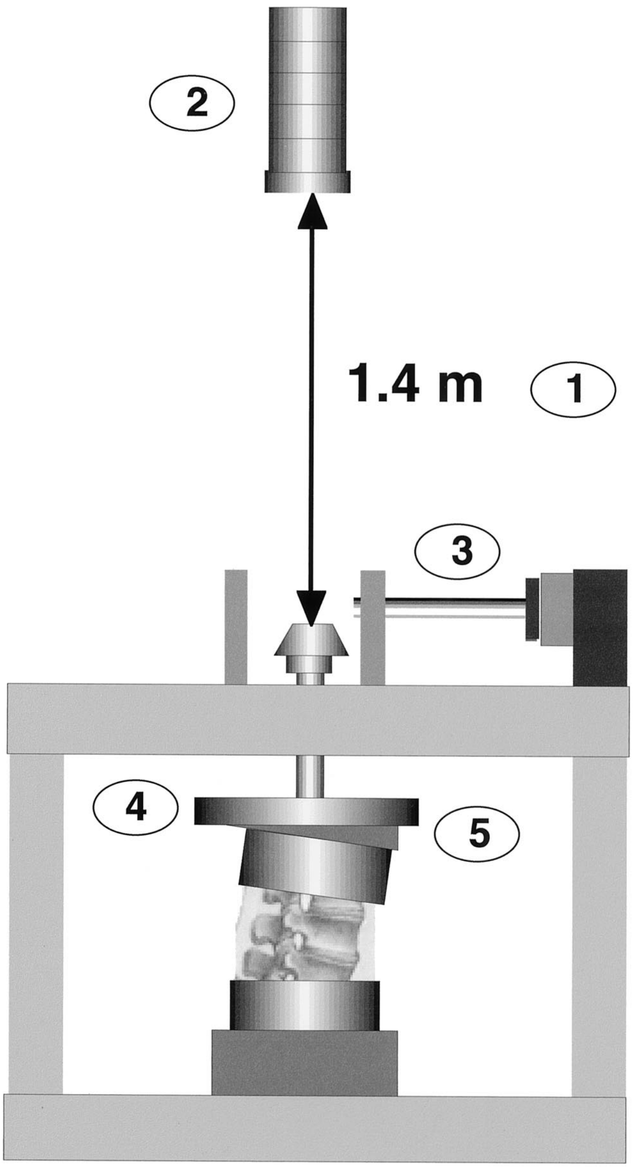

Figure 1. The trauma apparatus. The drop height (**1**) and drop mass (**2**) determined the potential energy delivered to the specimen. The computer-controlled pin (**3**) blocked the second impact of the rebound. The impounder (**4**) transferred the energy to the specimen. An anterior wedge (**5**) put the specimen in slight flexion.

with tight-fitting epoxy collars to protect them during the experimental trauma.

Trauma Production. The trauma apparatus was described earlier.[14] Basically, it had five key features (Figure 1): 1) The drop height could be adjusted, but was fixed at a constant value of 1.4 m in the current study. Thus, the speed at which the mass struck the specimen was always constant at 5.24 m/second. 2) The drop mass was adjustable in increments of 2 kg. 3) A catch pin was released after the mass bounced off the specimen to prevent its impact on the specimen a second time. 4) The impact force of the falling mass was transformed into impact displacement of the specimen's upper mount *via* the impounder. 5) The specimen was slightly flexed by placing an 8° wedge on the superior aspect of the specimen.

The incremental trauma protocol consisted of an initial drop mass of 3.3 kg and an incremental drop mass of 2 kg. Because the drop height always was 1.4 m, the resulting impact energies for the initial and incremental drops were, respectively, 45.3 J and 27.4 J. After the impact, a lateral radiograph was taken and the canal encroachment (defined later) computed. If the resulting canal encroachment was not that desired, then the process was repeated with an additional mass of 2 kg. This process of incremental trauma was continued until the canal encroachment obtained was equal to or greater than that desired. We hoped for the encroachments among the nine specimens to range between 10% and 80% with an average of about 50%. After the burst fracture, the specimen was held in the neutral posture (*i.e.,* there was no external load), and lateral radiograph was taken. This posture was termed burst fracture neutral posture (BFnp).

Dimensions Measured. Before and after the burst fracture, canal and intervertebral foramen dimensions were measured. To measure the spinal canal accurately, a row of small steel balls (1.6 mm in diameter) was attached with crazy glue to the posterior longitudinal ligament and another row to the ligamentum flavum in the midsagittal plane (Figure 2A). An additional row of smaller balls (0.8 mm in diameter) was glued to the soft tissues lining the intervertebral foramens (IVF). The steel balls glued to the soft tissues of the canal and IVF defined the neural spaces available for the dura and the nerve roots, respectively. The balls were optimally spaced so they were neither so close as to touch each other nor so far as to make it difficult to determine the contour of the neural spaces (spinal canal and intervertebral foramens). A lateral radiograph of the specimen was scanned, and the following dimensions were determined by digitizing the images of the steel balls and using custom software:

D_C: diameter of canal (mm)

A_{IVF}: area of intervertebral foramen (mm^2)

H_{IVF}: height of intervertebral foramen (mm)

W_{IVF}: width of, intervertebral foramen (mm),

where D_C was the minimal anteroposterior diameter of the canal; A_{IVF} was the IVF area; H_{IVF} was the maximum dimension within the IVF; and W_{IVF} was the maximum dimension perpendicular to the H_{IVF}. The IVF dimensions were measured for both superior and inferior intervertebral foramens. Therefore, a total of seven dimensions were measured with the intact specimen in neutral posture. These were termed "intact dimensions."

Errors in the Measurements. A typical radiograph was scanned and the D_C, A_{IVF}, H_{IVF}, and W_{IVF} were measured repeatedly 10 times using the aforementioned method. The data were pooled from the 10 trials, and standard deviations were computed for each dimension. The standard deviations (a measure of the error) for the four dimensions, D_C, A_{IVF}, H_{IVF} and W_{IVF}, respectively, were 0.038 mm, 0.201 mm^2, 0.035 mm, and 0.028 mm. Represented as percentages of the corresponding mean values, the errors were 0.41, 0.62, 0.25 and 0.56%, respectively.

Pedicle Screw Device Adjustments. After the final trauma (*i.e.,* the burst fracture) was obtained, the pedicle screw device (AO Internal Fixator, Synthes, Paoli, PA) was applied to the T12 and L2 vertebrae. The eight adjustments consisted of various combinations of distraction–compression and extension

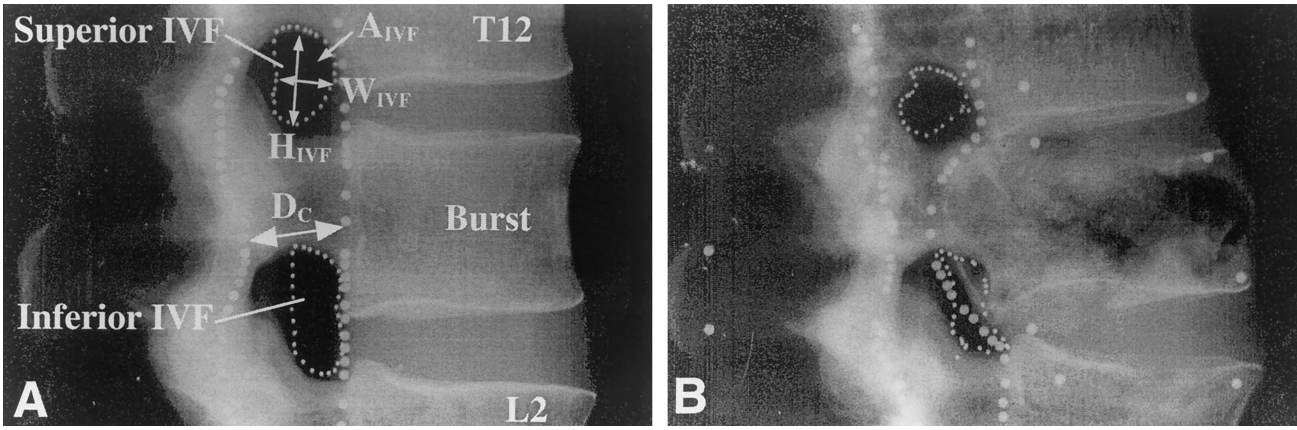

Figure 2. Radiographs of a specimen before **(A)** and after **(B)** burst fracture. The steel balls line the soft canal and the superior and inferior intervertebral foramens. Minimal canal diameter (D_C), and area (A_{IVF}), height (H_{IVF}), and width (W_{IVF}) of the superior and inferior intervertebral foramens are shown.

(Table 1). The first four were either a pure translation (−5 mm, +5 mm, +10 mm) or a pure angulation (−6°). (The sign convention is distraction [+], compression [−], and extension [−]; Figure 3). Adjustment 5 was −5 mm followed by −6°, whereas Adjustment 6 was +5 mm followed by −6°. The final two adjustments were duplicates of Adjustments 5 and 6 except for the order: The −6° was followed by either −5 mm (Adjustment 7) or +5 mm (Adjustment 8).

Lateral radiographs were taken after each adjustment. The dimensions D_C, A_{IVF}, H_{IVF}, and W_{IVF}, defined earlier, were again determined from the lateral radiographs. After Adjustment 8, Adjustment 1 was reapplied to confirm that an individual adjustment did not bias the subsequent adjustment results. The differences between the results of the two Adjustments 1 were within the errors of the measurements.

To assess the status of the neural spaces, three functional parameters (Encroachment, Restoration, and Improvement) were computed. The *encroachment* of each dimension was determined by using the following formula:

$$\text{Encroachment (\%)} = 100 \times (P_{Intact} - BFnp)/P_{Intact},$$

where P_{Intact} and BFnp were, respectively, the dimensions of the intact specimen and after the burst fracture in neutral posture.

The *restoration* was the dimension after an adjustment defined as a percentage of the corresponding intact value. The *improvement* was the increase in the dimension with respect to the corresponding value of the BFnp. For clarity, the following mathematical equations are provided.

$$\text{Restoration (\%)} = 100 \times P_{Adj\#i}/P_{Intact}$$

$$\text{Improvement (\%)} = 100 \times (P_{Adj\#i} - P_{BFnp})/P_{BFnp},$$

where $P_{Adj\#i}$ is a dimension resulting from an adjustment (Adjustment 1 to Adjustment 8).

Statistical Evaluations. Repeated measures analysis of variance (ANOVA) was used to determine significant differences in each of the seven dimensions caused by the eight adjustments with respect to the intact specimen (restoration) and BFnp (improvement). Significance was set at $P < 0.05$.

■ Results

The specimens were traumatized to produce the burst fracture at the L1 vertebra (Figure 2B). All seven dimensions, measured for burst fracture in neutral posture (BFnp), were smaller than the intact specimen (Table 2). The average canal encroachment was 42.6% (range: 9.2–74.7%). The average encroachments for the superior intervertebral foramen A_{IVF}, H_{IVF}, and W_{IVF} were, respectively, 21.4%, 19.4%, and 1.1%. For the inferior intervertebral foramen, the corresponding encroachments were 37.8%, 16.1%, and 16.9% respectively.

How are the canal and intervertebral foramen dimensions restored to their intact values resulting from the eight adjustments? The answers are presented as restorations in Figures 4A to 4D. When an adjustment restored the specific dimension so that the dimension was signif-

Table 1. Eight Adjustments of the Pedicle Screw Device

		Adjustments After Burst Fracture							
	BFnp	1	2	3	4	5	6	7	8
Distraction (+) or compression (−), (mm)	0	−5	5	10	0	−5	5	−5	5
Extension (−), (degree)	0	0	0	0	−6	−6	−6	−6	−6

BFnp = burst fracture specimens in neutral posture.
The first four are single adjustments, whereas the last four are combinations. Adjustments 5 and 6 were identical to the Adjustments 7 and 8, respectively, except that in the latter, the 6° extension was applied first.

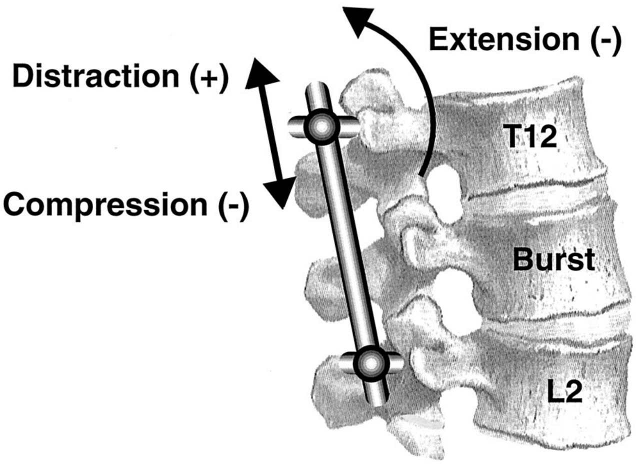

Figure 3. A sketch of the adjustable pedicle screw device and the three vertebrae of the specimen (vertebrae T11 and L3 are not shown). Translation adjustment could be either distraction (+) or compression (−). Angulation adjustment was only extension (−).

icantly not different from its intact value, the result was identified by dollar sign ($) (Figures 4A to 4D). It will be noted that Adjustments 3, 6, and 8 restored all of the intervertebral foramen dimensions, but not the canal diameter (D_C), on a statistical basis. However, on average, these three adjustments restored the D_C to approximately 75% of its intact value. How much did the eight adjustments improve the neural parameters over the BFnp values? The answers are provided in Figures 5A to 5D as the improvement functions. Only Adjustments 3, 6, and 8 improved the canal diameters significantly. It will be noted that the Adjustments 2, 3, 6, and 8 improved the intervertebral foramen area and height, and that Adjustment 1 worsened the A_{IVF} and H_{IVF}. None of the adjustments improved the W_{IVF} over the BFnp values.

■ Discussion

Pedicle screw devices are versatile and used not only to provide fixation for an unstable spine (*e.g.*, after a burst fracture), but also to reduce the canal and intervertebral foramen encroachments and to restore the vertebral spinal alignment. These reductions and restorations are accomplished by adjusting the pedicle device, that is, by applying a combination of distraction–compression (translation) and/or flexion–extension (angulation).

Although the pedicle screw systems are popular spinal instrumentations, little is known about the effects of specific device adjustments on the important parameters that define the neural spaces for the spinal cord and nerve roots. The current authors rationalized that a study of the pedicle screw device adjustments may provide guidelines for the surgeon using such a device in a patient with a burst fracture.

The current model consisted of five-vertebrae fresh cadaveric human thoracolumbar spinal segment. The burst fractures of different severities were produced at L1. The burst fracture severity as defined by the canal encroachment, varied approximately from 9% to 75%. This was by design. By this spread, an attempt was made to represent in the model the wide spectrum of burst fractures observed clinically. Also associated with this spread in severity was the variation in the burst fracture type. Among the nine specimens, Denis Types A (n = 5), B (n = 3), and C (n = 1) were represented. A pedicle screw device (AO Internal Fixator) was chosen that allowed translation (distraction–compression) and angulation (flexion–extension) adjustments to be provided independently. The translation could be adjusted continuously, but the angulation could be adjusted only in steps of 6°. The values of eight adjustments (combinations of translation and angulation) were chosen so as to alter the spinal neural spaces maximally without injuring the specimen. Although the sagittal adjustments in the current model cannot be compared directly to those used clinically, because the clinical adjustments are seldom recorded and have not been published, the authors believe that these adjustments cover the spectrum of adjustments used clinically.

Several interesting results have come from this study. First, it was found that the order of applying translation and angulation in a given set of adjustments does not seem to matter. For example, Adjustment 7 (5 mm compression followed by 6° extension) produced results identical to those of Adjustment 5 (6° extension followed by 5 mm compression). The same was true for the Ad-

Table 2. Average (SD) Values of Seven Neural Space Dimensions

				Adjustments After Burst Fracture							
		Intact	BFnp	1	2	3	4	5	6	7	8
Canal	D_C, (mm)	14.8 (2.0)	8.3 (3.1)	6.6 (2.6)	7.7 (2.8)	10.1 (2.2)	11.3 (1.5)	11.6 (1.7)	9.1 (2.4)	7.9 (2.3)	10.7 (1.8)
Superior	A_{IVF},(mm^2)	96.6 (12.6)	75.9 (14.1)	57.9 (13.4)	67.1 (11.2)	93.3 (14.0)	95.1 (11.6)	101.6 (12.8)	81.2 (11.5)	63.4 (12.6)	94.0 (11.1)
	H_{IVF}, (mm)	15.3 (1.3)	12.3 (1.4)	10.7 (1.4)	11.7 (1.5)	13.9 (1.5)	14.6 (1.4)1	15.3 (1.4)	13.3 (1.4)	11.4 (1.4)	14.6 (1.1)
	W_{IVF}, (mm)	9.0 (0.9)	8.9 (0.9)	8.1 (1.1)	8.8 (1.0)	9.4 (1.0)	9.3 (0.9)	9.3 (0.8)	8.9 (1.1)	8.5 (0.9)	9.3 (1.1)
Inferior	A_{IVF},(mm^2)	96.6 (12.6)	75.9 (14.1)	57.9 (13.4)	67.1 (11.2)	93.3 (14.0)	95.1 (11.6)	101.6 (12.8)	81.2 (11.5)	63.4 (12.6)	94.0 (11.1)
	H_{IVF}, (mm)	15.3 (1.3)	12.3 (1.4)	10.7 (1.4)	11.7 (1.5)	13.9 (1.5)	14.6 (1.4)	15.3 (1.4)	13.3 (1.4)	11.4 (1.4)	14.6 (1.1)
	W_{IVF}, (mm)	9.0 (0.9)	8.9 (0.9)	8.1 (1.1)	8.8 (1.0)	9.4 (1.0)	9.3 (0.9)	9.3 (0.8)	8.9 (1.1)	8.5 (0.9)	9.3 (1.1)

BFnp = burst fracture specimens in neutral posture.
Canal diameter (D_c), and intervertebral foramen area (A_{IVF}), height (H_{IVF}), and width (W_{IVF}) for both superior and inferior foramina were measured when the specimens were intact in neutral posture, and after each adjustment was applied to the burst fracture.

RESTORATIONS

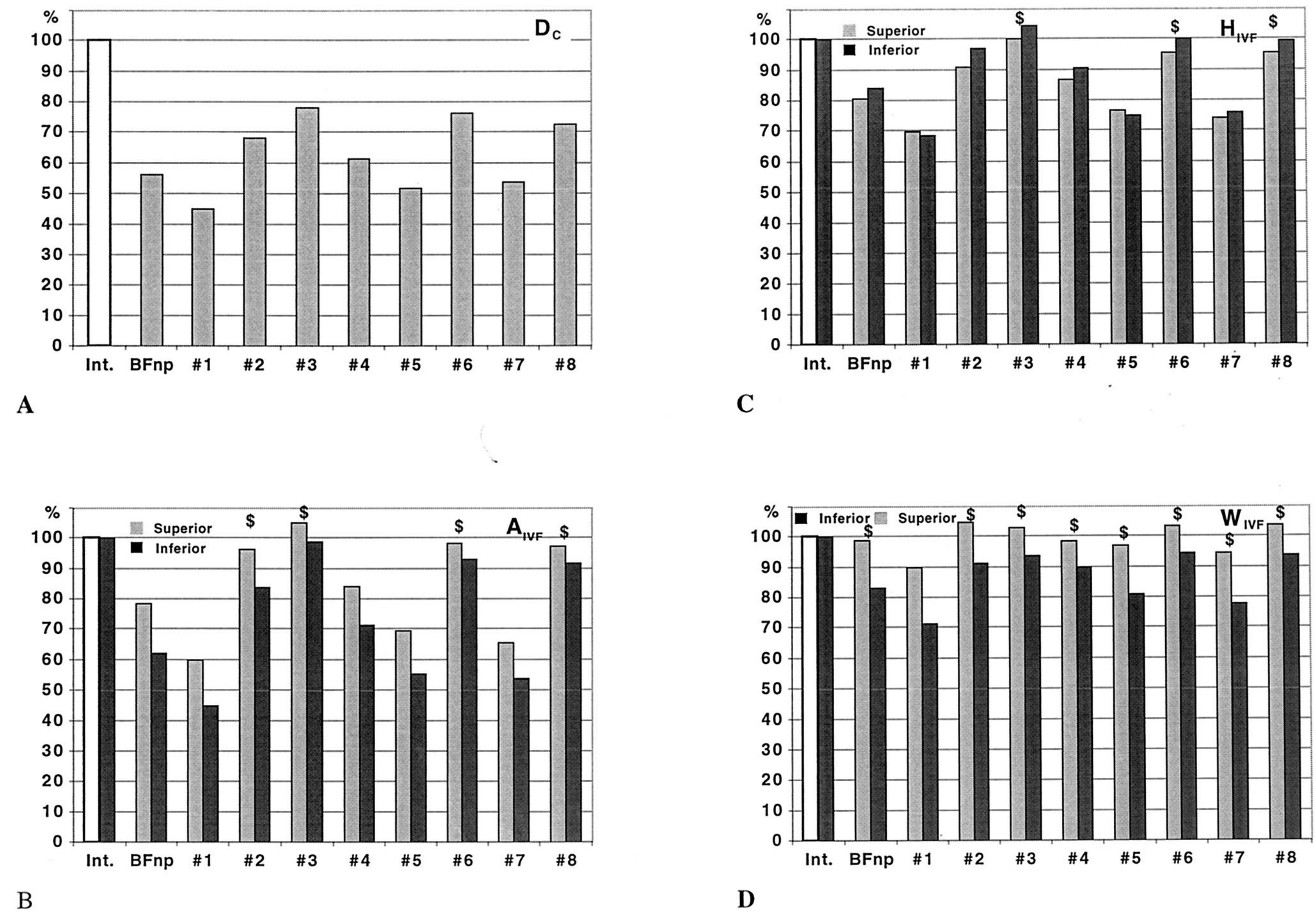

Figure 4. Restorations. The parameters indicate the magnitudes of restoration achieved as percentage of the intact values. **A,** Canal diameter. **B, C,** and **D,** Intervertebral foramen area (A_{IVF}), height (H_{IVF}), and width (W_{IVF}) for both superior and inferior foramens. The adjustment that restored the dimension closest to the intact value is indicated by the dollar sign ($).

justment 8 (5 mm followed by 6° extension) and Adjustment 6 (6° extension followed by 5 mm distraction).

The second important result was that the optimal adjustments (*i.e.,* those that restored the spinal canal and intervertebral foramens as close to the original intact state as possible) were two: Adjustment 3 (+10 mm) and Adjustment 6 (+5 mm followed by −6°). The former was pure distraction, whereas the latter was distraction combined with extension. Both produced nearly identical results. Therefore, depending on the need of the patient, either of the two adjustments may be used to achieve the same maximum improvements in the neural spaces.

In the case of a patient in whom there is a need to restore lordosis, Adjustment 6 may be preferable because it includes 6° of extension. On the other hand, Adjustment 1 (*i.e.,* 5 mm of compression alone) was found to be the worst adjustment. This obviously is to be avoided. It should be mentioned that the optimal adjustments maximized the neural spaces. However, the current study did not provide any information about the stability of the spine. Is an optimal adjustment for neural spaces also an optimal adjustment for spinal stability? The authors plan to answer this question in a future study.

The major limitation of our study is that it was an *in vitro* study. The properties of the muscles and the muscle tone are absent. Also, the weightbearing and the dynamic muscle forces that will be present once the patient is up and performing daily activities also are absent. The precise effects that these *in vivo* loads may have on the neural spaces currently are not known. However, it is reasonable to assume that the maximum neural space restorations for a patient achieved at the time of surgery will lead to the best clinical results. Therefore, the findings from this study can be useful to both the surgeon and the patient.

Another limitation was the choice of the individual components of the adjustments: 5 mm, 10 mm, and 6°.

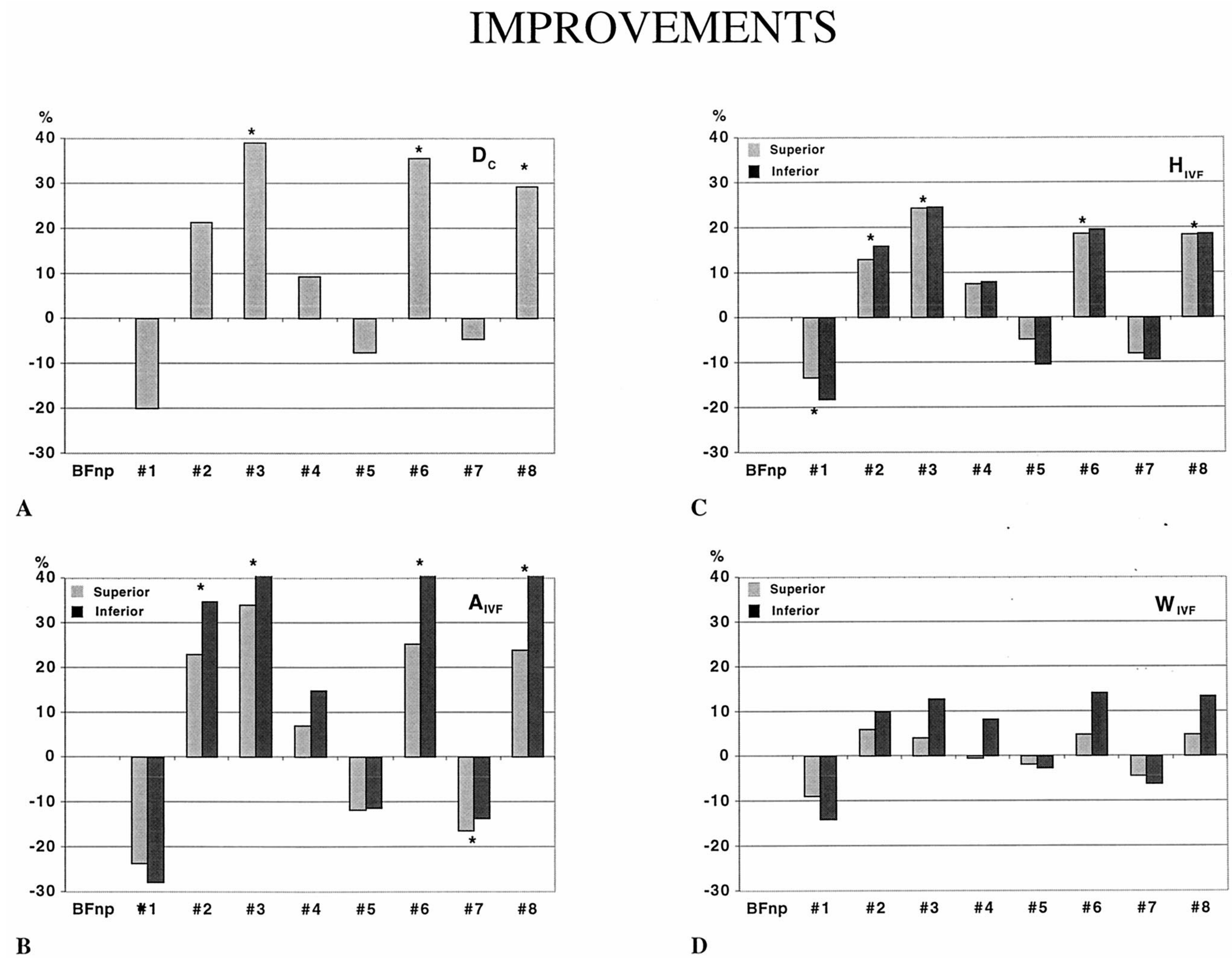

Figure 5. Improvements. The parameters indicate the magnitudes of improvement achieved over the neutral posture burst fracture values. **A,** Canal diameter. **B, C,** and **D,** Intervertebral foramen area (A_{IVF}), height (H_{IVF}), and width (W_{IVF}) for both superior and inferior foramens. The adjustment that improved the dimension over the BFnp is indicated by the asterisk (*).

These values are based on several factors: the literature, the clinical experience of one author, limitation of the device used, and avoidance of injury to the specimen.

Only a limited comparison can be made between the current study results and those of others. To the authors' knowledge, no studies, neither clinical nor experimental, exist in which precise device adjustments were applied and documented. In an early study, three devices were applied to experimentally produced burst fractures.[6] Although no values were given for the device adjustments used, distraction was found to be the most effective in reducing canal encroachment. This is close to Adjustment 3 in the current study. The same specimens and devices were reanalyzed to provide results of vertebral height and lordosis restorations.[18] Again, no device adjustments were provided.

The effects of pure distraction, produced by introducing 5- and 10-mm high wooden discs into disc spaces on the intervertebral foramen areas, were investigated in another experiment, but only in intact spine specimens.[15] As expected, the intervertebral foramen opened.

In a clinical study, the effects of ligamentotaxis on canal encroachment resulting from the use of internal spinal fixator were studied.[11] The authors reported a restoration to 95% of the normal value from an initial canal area 63.7% of the normal. No data were provided concerning the device adjustments made.

As related, no comparable studies are available to confirm the current results, although clinical experience seems to support the findings. It is suggested that in future clinical studies the exact adjustments used in the pedicle screw devices be noted at the time of surgery. This will provide important information for subsequent biomechanical studies that may further explore the subject of the current study.

■ Conclusions

Restoration of neural spaces in a patient with burst fracture is an important clinical goal of a pedicle screw device. Adjustments of the device at the time of surgery can significantly affect the restoration of neural spaces, and consequently, the clinical outcome. Both the 10 mm of distraction and the combination of 5 mm distraction with 6° extension were found to produce the maximum restorations of the canal and intervertebral foramens in a burst fracture.

■ Key Points

- Restoring neural spaces (spinal canal and intervertebral foramen) in a patient is important.
- Different pedicle screw adjustments affect the neural spaces differently.
- Ideal adjustments are a combination of distraction–extension and distraction alone.

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