Kinetic analysis of anterior cervical discectomy and fusion supplemented with transarticular facet screws

Laboratory investigation

VINCENT C. TRAYNELIS, M.D., 1 JONATHAN SHERMAN, M.D., 2 ERIC NOITMEIER, M.D., 3 VANEEET SINGH, M.S., 4 KIRK MCGILVRAY, PH.D., 5 CHRISTIAN M. PUTTLITZ, PH.D., 5 AND PATRICK DEVIN LEAHY, PH.D. 5

1Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois; 2KeiperSpine, PC, Eugene, Oregon; 3Department of Neurological Surgery, Mayo Clinic, Jacksonville, Florida; 4Medtronic Spinal and Biologics, Memphis, Tennessee; and 5Department of Mechanical Engineering and School of Biomedical Engineering, Colorado State University, Fort Collins, Colorado

Object. The clinical success rates of anterior cervical discectomy and fusion (ACDF) procedures are substantially reduced as more cervical levels are included in the fusion procedure. One method that has been proposed as an adjunctive technique for multilevel ACDF is the placement of screws across the facet joints (“transfacet screws”). However, the biomechanical stability imparted by transfacet screw placement (either unilaterally or bilaterally) has not been reported. Therefore, the purpose of this study was to determine the acute stability conferred by implementation of unilateral and bilateral transfacet screws to an ACDF construct.

Methods. Eight C2–T1 fresh-frozen human cadaveric spines (3 female and 5 male; mean age 50 years) were tested. Three different instrumentation variants were performed on cadaveric cervical spines across C4–7: 1) ACDF with an intervertebral spacer and standard plate/screw instrumentation; 2) ACDF with an intervertebral spacer and standard plate/screw instrumentation with unilateral facet screw placement; and 3) ACDF with an intervertebral spacer and standard plate/screw instrumentation with bilateral facet screw placement. Kinetic ranges of motion in flexion-extension, lateral bending, and axial rotation at 1.5 Nm were captured after each of these procedures and were statistically analyzed for significance.

Results. All 3 fixation scenarios produced statistically significant reductions (p < 0.05) in all 3 bending planes compared with the intact condition. The addition of a unilateral facet screw to the ACDF construct produced significant reductions at the C4–5 and C6–7 levels in lateral bending and axial rotation but not in flexion-extension motion. Bilateral facet screw fixation did not produce any statistically significant decreases in flexion-extension motion compared with unilateral facet screw fixation. However, in lateral bending, significant reductions at the C4–5 and C5–6 levels were observed with the addition of a second facet screw. The untreated, adjacent levels (C2–3, C3–4, and C7–1) did not demonstrate significant differences in range of motion.

Conclusions. The data demonstrated that adjunctive unilateral facet screw fixation to an ACDF construct provides significant gains in stability and should be considered a potential option for increasing the likelihood for obtaining a successful arthrodesis for multilevel ACDF procedures.

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Key Words • facet screws • ACDF • kinetics • fusion • cervical spine

A nterior cervical discectomy and fusion (ACDF) is a safe and effective means of treating clinically significant degenerative cervical disc disease. Some patients may not experience fusion with time, and although not all of these patients will be symptomatic, the development of a solid arthrodesis is associated with an optimal outcome. Fusion rates for a construct consisting of allograft and an anterior plate at 1 level have been reported to be 96%–97%. 7,11 These rates are reduced with the inclusion of additional levels to the fusion procedure, with 2- and 3-level fusion success rates reported to be 82%–95% and 63%–83%, respectively. 7,12,18 Overall, it is widely accepted that reduction in motion at the fusion site, which is most frequently accomplished with instrumentation, generally decreases the risk of nonunion. However, imparting adequate rigidity to a

Abbreviations used in this paper: ACDF = anterior cervical discectomy and fusion; ROM = range of motion.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
multilevel ACDF construct to achieve a successful fusion in the relatively mobile cervical spine is challenging. Almost all ACDF procedures use both intervertebral disc spacers (allografts or synthetic biomaterial) and anterior plates with screw fixation. Adjunctive posterior fixation has been proposed as a means to provide additional support and rigidity to the healing fusion mass; however, this method generally requires a second open surgery and the patient suffers from morbidity associated with posterior spinal procedures, such as postoperative pain, risk of infection, and devitalization of the cervical musculature. Another supplemental posterior instrumentation technique that involves a more minimally invasive approach uses screws placed across the facet joints ("transfacet screws"). This method has been advocated as an alternative to lateral mass screw/rod fixation in the cervical spine.\(^2,3,11,20\) Transfacet screws have an inherent mechanical advantage over lateral mass trajectories in that they obtain purchase in 4 cortices, and it has been reported that transfacet screws provide greater pullout strength than cervical lateral mass fixation.\(^14\) Data accumulated following the successful use of transfacet screws in preliminary clinical series support the use of this fixation modality as a supplemental stabilization technique for ACDF constructs with plates and interdiscal spacers.\(^7\) However, the biomechanical stability provided by transfacet screws in this setting has not been rigorously addressed. Additionally, it is unknown whether there is a difference in the stabilization provided by unilateral (as opposed to bilateral) transfacet screw fixation. The objective of the current study was to determine the degree of acute stability afforded by augmenting a standard ACDF construct with either unilateral or bilateral transfacet screws using a cadaveric cervical spine model.

**Methods**

Eight C2–T1 fresh-frozen human cadaveric spines (3 female and 5 male; mean age 50 years) were used in this study. Biplanar radiographs were examined to ensure that the spines were free from severe significant degeneration, osteophytes, or congenital fusions. The musculature was excised from the spines with care taken to preserve the ligaments and intervertebral discs. Saline spray was used at 15-minute intervals during preparation and testing to maintain soft-tissue hydration. The superior aspects of C-2 and the inferior endplate of T-1 were potted in polymethylmethacrylate to add stability to the test setup. Self-tapping screws were drilled into the bone at the potting sites to increase purchase within the polymethylmethacrylate. The T-1 potting material was rigidly fixed to a 6–degrees of freedom load cell (model MC3A-6 with a 5kN/110-Nm load capacity, AMTI) to measure reaction forces and moments. These force and moment data were recorded by using a custom-written code (version 8.0.1, Labview, National Instruments) at 60 Hz. Reflective triads were inserted into each vertebral body such that intervertebral rotations could be measured by a 3-camera near-infrared stereophotogrammetric system at 60 Hz (model Eagle 4, Motion Analysis). Using a series of controlled experiments we have determined the spatial resolution of this system to be 0.2 mm, with an associated angular resolution of 0.3° after computation of the intervertebral Euler angles.

A pure-moment loading apparatus was used to actuate the spine through its physiological range of motion (ROM).\(^4,19\) This system consisted of a driveshaft attached to the C-2 potting material to enable the application of pure-moments. An axially sliding joint and 2 universal joints in the driveshaft enabled free motion in the off-axis directions. The loading apparatus was configured to apply moments in the axial rotation, lateral bending, or flexion and extension bending planes. These bending directions were randomly ordered for each specimen. Moments were applied to C-2 using a sinusoidal waveform with a peak of ± 1.5 Nm.\(^8,16\) A force-feedback stepper motor rotated the driveshaft at a quasi-static rate (2.8/sec) until the specified peak torque was attained. Seven cycles were applied per loading condition to achieve the requisite preconditioning. Data from the final cycle were used in the data analysis.

All surgical procedures were performed by American Board of Neurological Surgery–certified surgeons who had significant clinical experience using this technique. The following 4 experimental conditions were investigated:

1) Intact. The native cervical spine was tested without alteration to provide a normative data baseline.

2) Multilevel ACDF (C4–5, C5–6, and C6–7). The anterior longitudinal ligament was sectioned followed by excision of the anterior annulus and removal of the disc. Appropriately sized polyetheretherketone spacers (Medtronic Spinal and Biologics) were implanted. A 3-level anterior cervical plate (Medtronic, Spinal and Biologics) was placed across the treated levels using fixed-angle screws (4.0 mm in diameter, 14 mm in length) at the caudal level and variable angle screws (4.0 mm in diameter, 14 mm in length) at all other levels.

3) Multilevel ACDF with unilateral transarticular fixation. The ACDF construct described above was augmented with unilateral (left side) transfacet screw (3.5 mm in diameter, 12 mm in length; Medtronic, Spinal and Biologics) fixation at C4–5, C5–6, and C6–7 placed across each of the anteriorly treated levels. The bony entry point for the transfacet screw was consistently maintained as the middle of the lateral mass, with a straight parasagittal trajectory oriented perpendicular to the facet joint surface. The position and trajectory were verified with biplanar digital radiographs.

4) Multilevel ACDF with bilateral transarticular fixation. The ACDF construct described above was augmented with bilateral transfacet fixation by adding identical facet screws to the right side across each of the anteriorly treated motion segments (Fig. 1). The same entry point and trajectory for the transfacet screws as described above were used for these bilateral specimens.

Intervertebral rotations (Euler angles) were calculated from the stereophotogrammetric data using a custom-written code (version 7.11.0.584, Matlab, MathWorks). Total ROM across the entire construct (C4–7) was compared between the 4 treatment groups. Range of motion was also evaluated for each experimental level (C4–5, C5–6, and
Facet screw biomechanics

C6–7) as well as for the adjacent cervical levels above and below the construct (C2–3, C3–4, and C7–T1). Each motion segment was also analyzed separately. Statistical differences between the groups were assessed with a 1-way ANOVA where a p value $\leq$ 0.05 was considered significant (version 3.1, SigmaStat, Systat Software, Inc.).

Results

Overall, all fixation scenarios produced statistically significant reductions ($p < 0.05$) in all 3 bending planes compared with the intact condition (Figs. 2–4). Specifically, the average reduction in ROM due to ACDF over the entire operated construct (C4–7) with respect to the intact condition was 78.7%, 70.8%, and 73.0% in flexion-extension, lateral bending, and axial rotation bending planes, respectively. Intersegmental reductions in ROM for all 3 fixation variants at the C4–5, C5–6, and C6–7 levels were also statistically significant compared with the intact condition for all bending planes.

The addition of unilateral facet screw fixation to the ACDF construct produced varying kinetic results. Flexion-extension ROM with the addition of a unilateral facet screw did not produce statistically significant reductions in ROM at the C4–5 and C6–7 levels (Fig. 2). However, both lateral bending (Fig. 3) and axial rotation (Fig. 4) ROMs were significantly reduced at the C4–5 and C6–7 levels with unilateral facet screw augmentation. The central fixation level (C5–6) did not experience a significant ROM reduction in lateral bending ($p = 0.39$) or axial rotation ($p = 0.26$) with the addition of a unilateral facet screw.

Bilateral facet screw fixation also produced varying alterations in ROM reductions over unilateral facet screw fixation. Specifically, bilateral facet screw fixation did not produce any statistically significant decreases in sagittal plane motion at any level. However, in lateral bending, significant reductions at the C4–5 and C5–6 levels were observed but not at the C6–7 level ($p = 0.33$). In axial rotation, the addition of bilateral facet screws to the ACDF preparation produced only a significant reduction at the C5–6 level compared with unilateral screw fixation; however, the C4–5 ($p = 0.14$) and C6–7 ($p = 0.19$) reductions were minimal compared with ACDF with a unilateral facet screw. Interestingly, while unilateral facet screw fixation did not significantly reduce motion at the C5–6 level in lateral bending and axial rotation compared with ACDF alone, the addition of a second facet screw (that is, bilateral fixation) did significantly reduce motion at these levels and planes of motion compared with ACDF alone.

![Fig. 1. Bilateral facet fixation (yellow dashed circles) at the C4–5, C5–6, and C6–7 levels.](image)

![Fig. 2. Total sagittal plane (flexion-extension) ROMs for the 3 operated levels with associated p values given for each model comparison. The data indicate that motion was progressively reduced with each treatment variant. Data shown are means with 1 standard deviation error bars.](image)
Fig. 3. Total lateral bending ROMs for the 3 operated levels with associated p values given for each model comparison. The data indicate that motion was progressively reduced with each treatment variant. Data shown are means with 1 standard deviation error bars.

Fig. 4. Total axial rotation ROMs for the 3 operated levels with associated p values given for each model comparison. The data indicate that motion was progressively reduced with each treatment variant. Data shown are means with 1 standard deviation error bars.
Finally, it was observed that the untreated, adjacent levels (C2–3, C3–4, and C7–T1) did not demonstrate significant differences in ROM in any bending plane between the treatment groups and the intact condition (Fig. 5).

**Discussion**

It is well established that the increased stability provided by internal fixation exerts a positive effect on the promotion of arthrodesis. While ACDF has proven to be a highly successful 1-level procedure, the extension of this technique to 3 (or more) levels may result in a significant reduction in the rate of arthrodesis. This is most likely due to the relatively mobile nature of the subaxial cervical spine. There have been a number of adjuvant methods proposed in an effort to improve on multilevel ACDF fusion rates, many of which are based on limiting motion. In this study we investigated whether transfacet screw fixation with ACDF effectively resulted in reductions in cervical spine motion.

Overall, the data indicate that the addition of unilateral facet screw fixation to a 3-level ACDF construct resulted in significant stability gains (that is, reductions in ROM) at the caudal and cephalad levels in lateral bending and axial rotation. This finding seems to support the argument that the anterior plating construct provides rigidity in the plane in which it is oriented (that is, the sagittal plane), but does not provide equivalent support to loads off of this axis (that is, in the lateral bending and axial rotation planes). The addition of posteriorly located unilateral facet screws enhances the anterior plate’s stability in these planes by providing secondary (remote) points of fixation. This stabilizing effect is more pronounced at the termini of the construct because these levels are adjacent to mobile segments and are inherently experiencing heightened stresses.

The addition of 2 facet screws to each level (bilateral facet fixation) to the ACDF construct generally demonstrated modest reductions in ROM compared with adjunctive unilateral facet screw fixation to anterior plating. While statistical significance was achieved at certain construct levels under specific loading conditions, the absolute value of these ROM reductions was relatively small compared with the gains made by adding a single facet screw to the ACDF construct (unilateral fixation). The failure of the facet screw(s) to substantially reduce lateral bending motion at the C6–7 level may be related to the relatively small size of the C-7 facet and/or the relative amount of inherent lateral bending motion that is typically afforded at this segment.

The use of transfacet screws provides some decided clinical advantages. The C-7 lateral mass is typically thinner and more elongated than the lateral masses at other cervical levels, which can limit the placement of lateral mass screws at C-7. Cervical transfacet screws have been shown to be a viable alternative to lateral mass screws when incorporating the C-7 level.10

There are some clinical points regarding percutaneous transfacet screw placement that warrant attention. Cervical transfacet screws require a near-perpendicular trajectory to the facet joint. This can present a challenge at levels superior to C-5 due to the occiput impeding the downward trajectory required for placement of a cervical transfacet screw perpendicularly across the joint. Forward flexion of the head can usually eliminate this occipital hindrance in these cases; however, this may lead to the patient’s spine being fused in a kyphotic position and can limit the use of cervical transfacet screws in pa-
tients undergoing posterior cervical fusion alone. On the other hand, patients undergoing cervical transfacet screw placement as an adjunct to an anterior construct can have their head flexed during this procedure with no resulting kyphosis across the instrumental levels due to the maintenance of proper alignment provided at these levels by the anterior cervical plate.

To demonstrate efficacy of the transfacet approach, we present a clinical case of percutaneous fixation using transfacet screws. A 45-year-old woman had symptomatic C4–5 and C5–6 degenerative disc disease. She smoked more than 20 cigarettes per day and did not want to have an autograft harvested or wear a cervical orthosis. She was treated with C4–5 and C5–6 anterior decompression and fusion with allograft and instrumentation. Under the same anesthesia session, transfacet screws were placed using a percutaneous approach (Fig. 6). The screw position and trajectory were verified using intraoperative fluoroscopy. Postoperatively, the patient went on to develop a solid arthrodesis across the treated segments without complication.

As with any ex vivo investigation, the results of this study should be carefully viewed within the context of the investigation’s limitations. The data presented herein represent the acute, immediately postoperative behavior of these constructs. Of course, once implanted in vivo, the hardware will be subjected to repeated (cyclic) loading, which can affect not only the material behavior of the implants but the degree of purchase at the screw-bone interface. Therefore, the results of this study, while conclusive that adjunctive facet fixation in the cervical spine produces significant acute stability gains, are not capable of providing predictive information on the long-term effectiveness of these constructs. While the constructs were tested in the 3 primary rotational planes, compressive forces and/or off-axis (combined) bending are common in vivo loading regimens. The former were not considered in this study because no consistent procedure exists for applying compression that mimics physiological muscle action. All currently developed methods of applying compression, whether using a follower load concept or not, produce offset moments and/or shear forces. In addition, it is well known that the center of rotation shifts in a helical manner as the cervical spine moves throughout its range of motion. Since a contemporary compression apparatus cannot replicate either of these muscle action or center of rotation alteration effects, we feel that the adoption of compression in this study would have only confounded the resultant data and not served to have enhanced the comparative nature of this investigation.

Conclusions

Our data demonstrated that adjunctive unilateral facet screw fixation to an ACDF construct provides significant gains in stability and should be considered a potential option for increasing the likelihood for obtaining a successful arthrodesis.

Disclosure

Dr. Traynelis is a consultant for, patent holder with, and received clinical or research support for this study from Medtronic. He reports that his institution receives fellowship support from Globus. Dr. Sherman is a consultant for Medtronic and Spine Wave. Dr. Nottmeier is a consultant for Medtronic Navigation and receives royalties from Globus for the XTEND anterior cervical plate. Mr. Singh is an employee of Medtronic. Dr. Puttlitz is a consultant for Medtronic Spinal and Biologics.

Author contributions to the study and manuscript preparation include the following. Conception and design: Puttlitz, Traynelis, Sherman, Nottmeier, Singh. Acquisition of data: Puttlitz, Sherman, McGilvray, Leahy. Analysis and interpretation of data: Puttlitz, Traynelis, McGilvray, Leahy. Drafting the article: Puttlitz, Traynelis, Sherman, Nottmeier, Singh, McGilvray. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Puttlitz. Statistical analysis: McGilvray, Leahy. Administrative/technical/material support: McGilvray. Study supervision: Puttlitz.

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Facet screw biomechanics