Kinematics of Progressive Circumferential Ligament Resection (Decompression) in Conjunction With Cervical Disc Arthroplasty in a Spondylotic Spine Model

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Study Design. Benchtop biomechanics study examining kinematic effects of progressive resection in a human cadaveric spine model.

Objective. To determine the effects of posterior longitudinal ligament (PLL) resection, unilateral and bilateral foraminotomy, and laminectomy on cervical intervertebral rotation and translation after cervical disc arthroplasty (CDA).

Summary of Background Data. Although the clinical results after CDA have been studied, there remain unanswered questions regarding the surgical techniques used at the time of device insertion. For example, it is unclear whether a surgeon should retain or resect the PLL and uncinate processes at the time of primary surgical intervention. Further, the effect of a subsequent posterior decompression (foraminotomy or laminectomy) on the stability of a motion segment containing a disc arthroplasty is unknown.

Methods. Three-dimensional intervertebral motion was measured by biplanar videography in human cadaveric spines at C4–C5 or at C5–C6 subjected to a 1.5-Nm moment applied to induce motion in the sagittal plane. Coupled motions were not constrained. After measuring intact spine motion, disc arthroplasty with bilateral ventral foraminotomy was performed without PLL resection. Sequentially, rotations and translations were measured after PLL resection, unilateral foraminotomy, bilateral foraminotomy, and laminectomy.

Results. CDA with bilateral ventral foraminotomy increased sagittal rotation by 0.4° (16%) compared with the intact spine. The addition of PLL resection increased rotation by 0.5° (14% increase). Unilateral and bilateral foraminotomy had negligible effects on sagittal rotation or antero-posterior (AP) translation. Laminectomy resulted in an additional sagittal plane rotation of 2°. The sagittal-plane intervertebral rotation resultant after all interventions was 6°, with 1.5 mm of AP translation occurring only.

Conclusion. Given that a greater degree of motion was seen with PLL resection combined with ventral foraminotomy, we recommend that PLL resection be performed when performing CDA. In our benchtop model, unilateral and bilateral posterior foraminotomies were not associated with the creation of significant sagittal rotational or AP translational instability.

Key words: cervical disc arthroplasty, biomechanics, ProDisc-C, laminectomy, foraminotomy. Spine 2010;35:1676–1683

Cervical disc arthroplasty (CDA) is a promising technology, which allows for motion preservation when combined with discectomy for the relief of radiculopathy and myelopathy. For example, a 2-year follow-up study of the Bryan disc demonstrated 6.7° mean sagittal plane rotation after anterior cervical discectomy and arthroplasty.¹,² The equivalency in pain relief rates of CDA compared with anterior cervical discectomy combined with fusion at 2-year postoperative follow-up has also been reported in several studies as well. For example, a clinical trial comparing the Prestige disc arthroplasty with anterior cervical decompression and fusion noted equivalent rates of neck and arm pain reduction and improvement in visual analog pain scores and short form-36 health survey functional outcomes scores in patients with cervical radiculopathy.³ Recent investigation has also been undertaken examining the clinical results of the ProDisc-C arthroplasty.⁴ In this study, 209 patients were randomized in a one-to-one fashion into anterior discectomy and fusion or CDA. Outcomes compared included neck and arm pain relief rates, postoperative range of motion (ROM), and neurologic success rates. As demonstrated in prior studies with other motion-preserving devices, there were no statistically significant differences in the clinical outcomes between treatment groups. As expected, motion was significantly better in the arthroplasty cohort. In the CDA group whose mean age was 42 years, the average flexion/extension motion after operation was 9° ±(±5°) with 84% of patients maintaining at least 4° of flexion/extension motion at 24 months follow-up.

Although recently published Food and Drug Administration (FDA) trials have commented on postoperative results 2 years after surgical intervention, longer-term follow-up may diminish the positive effects of both motion preservation and neurologic relief. Given
a peak incidence of soft disc herniation in the third and fourth decades of life, implant survivorship 20 to 30 years after arthroplasty will require surveillance in an ambulatory spine practice. Stated otherwise, as surgeons and patients accept motion-preserving options as an adjunct to cervical decompression, the prevalence of arthroplasty will increase in combination with ongoing aging and degeneration.

As new surgical technologies emerge from closely monitored trials to widespread community utilization, one would expect broadening of the target age group and operative treatment of more elderly patients with spondylosis. For example, strict inclusion and exclusion criteria have been followed in the performance of North American clinical trials; hence, these studies have limited their reports to those patients in the age range of 18 to 65 years.2,3 In contrast, Brazilian surgeons have recently reported clinical outcomes in a nonrandomized retrospective series of patients undergoing multilevel arthroplasty.5 In this clinical series, patient age ranged from 18 to 80 years. In the 65- to 80-year-old segment of the population, one might expect advanced spondylosis and high-grade foraminal stenosis. Such high-grade foraminal stenosis might be recalcitrant to ventral foraminotomy alone.

If inadequate ventral foraminotomy has been performed in combination with arthroplasty, it is inevitable that a subset of patients undergoing CDA will awake with functional cervical ROM and persistence of radiating arm pain. When faced with foraminal stenosis and radiculopathy, spine surgeons have relied on intervertebral distraction with anterior discectomy, fusion, and interbody graft interposition as a means of increasing foraminal dimension and reducing nerve root compression. For example, An6 has recommended adding 2 mm to the preoperative disc space height to maximize the foraminal area and nerve root relief during the performance of anterior cervical discectomy with fusion. As “over sizing” of an arthroplasty7 has been reported to decrease ROM across the operative cervical segment, aggressive uncinate process resection combined with arthroplasty has been recommended as a means of ensuring adequate root decompression.8

Recurrent foraminal stenosis with radiculopathy could also occur over time with facet joint osteophyte formation. In this circumstance, the treating physician will be faced with the option of anterior revision decompres-sion (with prosthesis revision or retention) or with posterior foraminotomy. In a similar fashion, should ventral endplate osteophytes form and cause cord compression or should posterior compressive pathologies arise, laminectomy may be required at an arthroplasty-containing segment. Minimal biomechanical data exist to support the safety and kinematic consequences of these interventions combined with disc arthroplasty.

In an effort to study the inevitable combination of disc arthroplasty with posterior decompression, we have undertaken the following study. We hypothesized that incremental combination of ventral foraminotomy, posterior longitudinal ligament (PLL) resection, posterior foraminotomy, and laminectomy would induce segmental instability. Our null hypothesis as formulated contradicts the above, that is, that PLL resection, posterior foraminotomy, and laminectomy would be well tolerated and not induce segmental instability.

Materials and Methods

Specimen Preparation

Eight human cervical spines were obtained from the UC Davis anatomic donor program after protocol approval. Donor histories were screened for the presence of metastatic disease or a prior cervical operative intervention and excluded based on the prior criteria. Radiographs were screened for the absence of metastatic disease or prior surgical intervention. The third cervical and first thoracic vertebrae were embedded in polymethylmethacrylate after placement of screws to augment fixation strength (Figure 1). The average specimen age was 78 years, with a range of 52 to 86 years. Interventions were performed at either C4–C5 or C5–C6, with the operative level chosen for a lesser degree of degenerative change. Because each specimen served as its own control, varying the level tested was expected to have a minimal effect on results.

Experimental Protocol

Specimens were attached to the Instron 5800 using custom grips (Figure 2A). The weight of the human head (5 kg) and the effect of a muscular envelope was simulated with a 50-N preload. Light emitting diode (LED) arrays were rigidly attached to adjacent vertebral bodies using Kirschner wires. The relationships between the LED triplets and specific points on the anterior vertebral bodies were accomplished using a localization technique.9 Specimens were taken through a flexion/extension ROM under load control to ±1.5 Nm (at the mid disc) using a spine ROM device described in previous publications from our laboratory.10 Three complete flexion/extension cycles were performed with data recorded from all motion cycles (Figure 2B). Marker motion was recorded using video cameras (Graflex) and Labview data acquisition systems. Motion was recorded under the following treatments: (a) intact spine (Intact), (b) discectomy, bilateral uncinate process resection and ProDisc-C arthroplasty (bluncr), (c) addition of PLL resection (plll), (d) after posterior left foraminotomy (forl), (e) after posterior bilateral foraminotomy (forbi), and (f) with laminectomy across the arthroplasty segment (lami). To study the effect of disc arthroplasty without and with PLL resection, the disc prosthesis was carefully removed after testing with an intact PLL (treatment b). This was done without removing LED markers or the specimen from the materials testing machine. The PLL was then resected under direct vision, and the disc prosthesis was replaced precisely in its previous location using the keel cut and anterior vertebral body as reference points. Additionally, the differences in the posture (or the rotation and translation offset at the start of each treatment test relative to the intact specimen) of the 2 bodies was also computed. Representative specimens after the sequence of decompressive procedures combined with prosthetic disc arthroplasty are depicted in Figure 1.

Data Analysis

Intervertebral motion was determined during spine loading in terms of rotation and translation data. LED markers affixed to
vertebral bodies were manually identified in initial (stereo) video frames, automatically tracked in subsequent time-sequenced frames, and the 3-dimensional coordinates were determined using SIMI motion analysis software (Untersheisheim, Germany). Marker data were associated with respective vertebral bodies and used to determine relative motion of bony segments with a custom analysis program (MATLAB v.6.0, The Mathworks, Natick, MA). Briefly, global motion (in the calibration cage reference frame) of each bone segment was determined using a least-squares algorithm. Rigid body relations were used to compute relative motion of the upper vertebral body in relation to the lower vertebral body. A local coordinate system was defined on the anterior aspect of C5 using the attached triplet and cross product operations based on vectors defined by LED locations. Care was taken to align the markers with anatomic landmarks such that the orientation of the coordinate system allowed for a direct interpretation of flexion/extension, lateral bending, and axial plane rotations. Relative motion was expressed as rotations (Euler angles; xyz sequence order) and translations of C4 with respect to C5 (C4–C5 disc arthroplasty) or C5 in relation to C6 (C5–C6 arthroplasty) in the anatomic coordinate system. Maximum and minimum rotation and translations were computed from time-dependent data, used to determine the ROM for independent degree of freedom (e.g., rotation in the axial plane), and reported as mean ± standard error of the mean. Rotation and translation differences were analyzed for each independent degree of freedom were analyzed using a repeated-measures analysis of variance and a standard software package (StatView; The SAS Corp., Inc.). Specific mean differences in intervertebral motion after each treatment were determined using Fisher protected least significant difference post hoc comparisons.

Results

The range of intervertebral rotation increased after disc replacement and during the decompression sequence (Figure 3A, Table 1). Disc treatments had a significant effect on the range of sagittal plane rotation \((P < 0.0001)\), but not on coupled lateral bending \((P = 0.110)\) or coupled axial plane rotation \((P = 0.152)\). The average range of sagittal plane rotation across the intact segment was 2.8° before arthroplasty. Bilateral uncinate process resection combined with disc replacement with the ProDisc-C did not result in a significant increase in the range of sagittal plane rotation \((P = 0.268)\). Resection of the PLL resulted in a significant increase in the range of sagittal plane rotation \((P = 0.036)\).
ittal plane rotation ($P = 0.029$). The addition of unilateral foraminotomy and bilateral foraminotomy (50% facet excision) was associated with a significant increase in the range of sagittal plane rotation that exceeded 6° overall ($P < 0.0001$).

The rotation posture increased in the sagittal plane, with specimens assuming a greater degree of extension before testing and relative to the intact position (Figure 3B). The sagittal plane rotation seen began at a position of ~7 degrees of extension relative to the initial neutral spine posture of the intact spine. Subsequent interventions notably increased the relative extension compared with the preceding test. After all interventions had been performed, the resting spine posture effectively was in a position of increased lordosis or extension of 10° relative to the intact spine resting posture.

The range of intervertebral translation increased after disc replacement and during the decompression sequence (Figure 4A, Table 1). Disc treatments had a significant effect on the range of mediolateral ($P < 0.040$), anteroposterior (AP) ($P = 0.004$), and cranio-caudal ($P < 0.0001$) translations. A small (i.e., < 1.0 mm) but significant increase was observed in the range of mediolateral translation after laminectomy compared with the intact specimen ($P = 0.037$), and additionally, in the range of AP translation after foraminotomy ($P = 0.037$) and laminectomy ($P < 0.001$) compared with the intact specimen. The range of cranio-caudal translations significantly increased after single ($P = 0.036$) and bilateral ($P = 0.016$) foraminotomy, as well as laminectomy ($P < 0.0001$) compared with the intact spine, ultimately exceeding 6.0 mm.

Figure 2. Schematic of testing method and representative data computed. C3 and T1 were embedded in polymethylmethacrylate and attached to custom grips (A). Downward displacement of Instron crosshead induced cervical extension whereas vertical crosshead displacement caused cervical flexion. The muscular envelope and weight of the head were simulated by calibrated springs, which provided a 50-N preload. Camera images were recorded to avi files and subsequently processed with SIMI motion analysis software. Three-dimensional motion (rotations and translations) were computed as a function of time during 3 repeated loading periods (B). Consistent kinematic patterns during the 3 loading periods allowed for a simplified analysis of maximum motions during any 1 period.
The translational posture increased as well, particularly, in the craniocaudal direction relative to the intact position (Figure 4B). Although little to no noticeable effect on mediolateral or AP translation was seen with insertion of the ProDisc-C prosthesis, the upper vertebral body anterior cortex was vertically translated 10.0 mm relative to its initial starting position immediately after insertion of the intervertebral prosthesis.

**Discussion**

The objective of this study was to determine the effects of PLL (PLL) resection, unilateral and bilateral foraminotomy, and laminectomy on cervical intervertebral motion after CDA. Differences in intervertebral rotations and translations were observed that depended on the treatment type. Motion generally increased with the application of each treatment, but was ultimately within established anatomic guidelines for clinical instability of the cervical spine.\(^1\)\(^2\)

The implications of cervical decompression in the native human spine have been elucidated with *in vitro* study and clinical case series combining decompression alone or with arthrodesis and internal fixation.\(^1\)\(^3\)\(^4\) The combination of foraminotomy (ventral or posterior or both) and laminectomy with CDA represents uncharted territory from a biomechanical and clinical perspective. Despite an absence of *in vitro* studies, clinical reports are emerging regarding the treatment of complications and after effects of CDA. In these circumstances, clinicians have intervened in human subjects without background *in vitro* experimental evidence to guide decision-making.

In our spondylotic specimens, the range of sagittal plane rotation increased from an intact spine mean of 2.8° to 3.2° after bilateral uncinate resection and CDA. The intact spine sagittal rotation reported is well below those from several previous clinical case reports and *in vitro* studies., although one would suspect that the candidates selected for the FDA IDE clinical studies were younger adults with acute soft disc herniations.\(^1\)\(^3\) In contrast, investigators recently reported on the motion present before replacement with the ProDisc-C prosthesis. In the subset of patients with less than 4 mm of disc space height at the operative disc space, only 3° of intervertebral sagittal plane rotation was present before operative intervention.\(^1\)\(^5\) This finding supports the validity of our spondylotic spine model and testing methods because an *in vivo* model is without doubt the most realistic testing method available.

Resection of the PLL resulted in a minor increase in the range of sagittal rotation (0.5°), with a small reduction in mean AP translation in the motion segments tested with an intervertebral arthroplasty present. Further, the addition of unilateral and bilateral foraminotomy to the motion segments containing an arthroplasty resulted in a mean increase in rotation of 0.3°. Laminectomy combined with the aforementioned interventions produced the greatest contribution to the increase in the range of rotation, with a 57% increase from

### Table 1. Summary of Mean Rotation and Anteroposterior (AP) Translation With Sequence of Testing

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Sagittal Rotation</th>
<th>SEM</th>
<th>Percent Change</th>
<th>C3–T1 Rotation</th>
<th>SEM</th>
<th>Percent Change</th>
<th>AP Translation</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact spine (intact)</td>
<td>2.8</td>
<td>0.3</td>
<td></td>
<td>17.1</td>
<td>3.7</td>
<td></td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Bluncr and Prodisc C (bluncr)</td>
<td>3.2</td>
<td>0.2</td>
<td>16.0</td>
<td>17.4</td>
<td>3.7</td>
<td>2.3</td>
<td>1.2</td>
<td>19.0</td>
</tr>
<tr>
<td>Pll resected (pil)</td>
<td>3.7</td>
<td>0.2</td>
<td>14.0</td>
<td>18.8</td>
<td>5.1</td>
<td>8.1</td>
<td>1.2</td>
<td>−3.8</td>
</tr>
<tr>
<td>Unilateral foraminotomy (forl)</td>
<td>3.9</td>
<td>0.1</td>
<td>5.9</td>
<td>20.0</td>
<td>3.3</td>
<td>6.5</td>
<td>1.3</td>
<td>7.8</td>
</tr>
<tr>
<td>Bilateral foraminotomy (forbl)</td>
<td>4.0</td>
<td>0.3</td>
<td>2.1</td>
<td>20.0</td>
<td>3.1</td>
<td>0.0</td>
<td>1.2</td>
<td>−3.4</td>
</tr>
<tr>
<td>Laminectomy (lami)</td>
<td>6.2</td>
<td>0.5</td>
<td>57.0</td>
<td>22.0</td>
<td>2.9</td>
<td>14.3</td>
<td>1.5</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Minor incremental changes were observed before laminectomy, which produced the largest increase in both rotation and AP translation.
Figure 4. Intervertebral translation increased after disc replacement and during the decompression sequence. Minimal change in AP translation was observed. The range of translation in the craniocaudal direction (A) increased successively, with the maximum range observed after laminectomy (lami). The translational posture (B) increased as well, particularly, in the craniocaudal direction relative to the intact position. **P < 0.05.

3.9° to 6.2°. Similarly, the range of sagittal plane AP translation increased from 1.0 mm in the intact spine to 1.5 mm after laminectomy and bilateral posterior foraminotomy with 50% facet resection. These values fall well within published normative data for asymptomatic human subjects. Further, the resultant mean rotation and translation after all interventions is similar to that reported in clinical FDA trial studies.

The effect of uncovertebral joint resection on motion associated with CDA has recently been elucidated in a cadaveric benchtop model. In this recent publication, the CDA without uncinate resection resulted in a 3.0° increase in flexion/extension rotation compared with the intact spine. Unilateral partial uncinatectomy resulted in a significant increase in flexion/extension motion, and bilateral complete uncinate resection similarly increased flexion/extension with a net change from 8.4° in flexion/extension to a total of 14.0°. Similar effects were seen on axial rotation and lateral bending, although the change in lateral bending ROM did not meet statistical significance. In our study, an increase in sagittal plane rotation of 16% was observed after disc arthroplasty with concomitant bilateral ventral foraminotomy. In contrast to the aforementioned study, we limited our uncinate resection to the posterior one fourth of the uncinate process. This degree of uncinate resection is generally recommended, given the proximity of the vertebral artery and risk of iatrogenic injury with more extensive resection at the midcortical vertebral body level.

Other authors have investigated PLL resection as an independent variable in combination with CDA in a benchtop cadaveric model. In this study, mean specimen age was 68 years; however, despite the advanced specimen age, intact spine flexion/extension rotation was 9°. The rotational range in this study increased to 18° after discectomy and testing without an interbody device or graft. A rotational range similar to that of the intact spine was restored after replacement with the porous coated motion disc arthroplasty. Subsequent testing after resection of the PLL without interbody device placement significantly increased sagittal plane rotation to 24°. In the aforementioned study, sagittal rotation of the tested motion segment was not changed after discectomy, PLL resection, and arthroplasty, nor was it significantly different than the rotation observed in specimens after CDA without PLL resection. Although an increase in the range of sagittal rotation of 0.5° (14% increase in motion) was seen in our study directly attributable to the resection of the PLL, we did not observe the marked increases in motion noted in the previously mentioned study, which exceed the in vivo values reported by Reitman et al.

The safety of cervical disc replacement performed in the setting of previous foraminotomy has been commented on in a recent in vivo retrospective series. Sekhon et al reported their experience with the use of CDA in patients with previous foraminotomy. In their case series, 24 artificial discs were implanted in 15 patients with clinical follow-up for a mean of 24 months. Good results were obtained in all cases in terms of neck and arm pain relief. There was 1 case of segmental hypermobility at the treated level; however, hypermobility was noted before the arthroplasty procedure. The authors concluded that CDA in cases of persistent radiculopathy after posterior foraminotomy was well tolerated and that segmental instability did not arise de novo. Our benchtop cadaveric results confirm these clinical findings. The combination of unilateral foraminotomy limited to 50% facet resection produced only 8° increase in sagittal rotation without substantial change in sagittal plane translation.

During the process of specimen preparation and testing we were unable to successfully implant an arthroplasty device in 2 specimens with advanced facet arthrosis and significant ankylosis of the uncinate processes. Once anterior discectomy was performed and uncinate osteophytes were removed, the entire disc space yawed open and attempts to size an interbody graft was met with progressive hinging of the disc space with an apparent pivot point at the posterior elements. The resultant disc space height was, hence, substantially taller than the tallest disc arthroplasty device available. These effects are likely the result of a posterior shift in the instantaneous axis of rotation as described in previous kinematic
In their benchtop biomechanical model, Chen et al noted a posterior shift in the IAR of ~20 mm, which occurred after discectomy combined with uncinate process resection. These authors advised that any device used to substitute for the intervertebral disc and ventral ligaments should neutralize the tendency toward instability in cervical extension. Should extension instability occur in vivo during preparation of a motion segment for CDA, arthroplasty should be abandoned in favor of anterior fusion with plating.

In our study, we noted a tendency toward increased cervical lordosis at the experimental segment after prosthesis insertion and posterior ligament and bone resection. One must surmise that the instantaneous axis of rotation was shifted anteriorly by device insertion associated with anterior ligament resection and annulotomy. Additionally, in a narrowed disc space with posterior osteophytes, placement of the arthroplasty within the most posterior part of the disc space may not have been achieved, resulting in an anterior shift in the IAR. However, a recent investigation on the effects of single-level and multilevel arthroplasty adjacent to simulated fusion noted a tendency of the spine to “buckle” into a position of progressive lordosis despite precise device insertion. This tendency was summative across multiple segments and most significant at the lowest cervical segment. Other authors have also noted a tendency toward an increase in lordosis at the operative segment after CDA. Anakwenze et al recently reported a net increase in lordotic angle of 3° at the operative segment 2 years after disc arthroplasty with the ProDisc-C prosthesis, an overall cervical lordotic alignment increase of 3.1°, a superior adjacent segment increase in alignment of 1.9°, and a decrease in caudal adjacent segment alignment of 1.8° after CDA. These interesting findings support our observations of an alteration in alignment in our operative segment and overall cervical alignment that accompanies disc arthroplasty and, in our study, posterior ligament and bone resection.

Limitations

Our study was limited to senescent spines with a mean specimen age of 78 years because it was our intent to model the changes that might be seen in an older patient population with a more advanced degree of cervical spondylosis. Although the target population for CDA might be younger in age and without evidence of any facet degenerative changes, we are not unique in presenting biomechanical findings using advanced age specimens for testing. For instance, Onan et al presented excellent data regarding the role of the cervical facet joints in providing coupled axial rotation with lateral bending using an “isolated facet joint method.” In their study, mean specimen age was 66 years, with a specimen age range from 46 to 83. Although our specimen pool represented an older age group of individuals, this is precisely the clinical scenario, which might present years after CDA or in clinical practice if FDA guidelines are not strictly followed. We do not suggest that the study results presented be extrapolated to a clinical patient population without cervical spondylosis. Although the greatest degree of motion may be preserved in young individuals who do not have facet joint degenerative changes, the target population for most large joint arthroplasties, e.g., hip and knee, is generally an older population (similar to our cadaveric population age) than the subset of patients thus far considered candidates for CDA. Additionally, although we were unable to demonstrate gross instability in our cadaveric study in any specimen tested, we purposely limited our resection to 50% of each facet. We believe that clinical instability could have been demonstrated with complete facet resection; however, we do not believe that surgical implantation of an artificial disc would be recommended or performed in this clinical scenario, or that >50% facetectomy be performed after CDA.

Spine specimens were taken through a flexion/extension ROM, a dominant motion required for normal spine function, to analyze functional kinematics in the sagittal plane. However, we did not investigate the other planes of motion, specifically lateral plane bending and axial rotation. The effects of the ProDisc-C on axial rotation and lateral bending have been thoroughly evaluated, however, by Puttlitz et al, who noted preservation of normal axial rotation and lateral bending in addition to normal coupled moments in lateral bending and axial rotation after disc arthroplasty with the ProDisc-C. We are unaware of any established radiographic guidelines for clinical instability of the spine in lateral bending or axial rotation; subsequently, we focused our study on sagittal plane rotation. The measurement of sagittal plane rotation and translation is commonly used as an indicator of spinal instability in clinical practice and has been most extensively studied.

To section the PLL as an independent motion segment treatment, it was necessary to remove the disc prosthesis from the disc space while the entire construct was within the materials testing machine. Although it is possible that the disc prosthesis placement may have been changed compared with its initial resting condition, the authors believe that this effect was minimal because this intervention was done as precisely as possible using both anatomic landmarks (anterior vertebral cortex) and using the keel cut as a rigid posterior endpoint for placement.

Conclusion

In our progressive anterior to posterior resection sequence, bilateral ventral foraminotomy, PLL resection, and ProDisc-C arthroplasty combined with laminectomy and bilateral posterior foraminotomy (50% facet joint resection) did not produce relevant spinal instability. These results parallel those seen in a progressive anterior to posterior and posterior to anterior resection models performed in fresh whole cadaveric specimens. In these studies, significant instability could only be demon-
strated after near complete destruction of all posterior stabilizing ligaments, bilateral facet osteotomy combined with lesioning of the intervertebral disc. Retention of >50% of each facet joint should provide sufficient restraint to catastrophic intervertebral displacement in combination with CDA. Although it is possible that the intervertebral prosthesis (CDA) studied provides additional resistance to excessive rotation and translation, this effect would be difficult to independently study without complete facet resection.

In summary, each decompressive procedure produced minor increases in rotation and translation when compared with the intact spine. The cumulative effect of the aforementioned interventions when combined with laminectomy resulted in a substantial increase in motion. Laminectomy in addition to bilateral foraminotomy and PLL resection increased rotation and translation to 6.2° and 1.5 mm, respectively, values that might be expected in a nonspondylotic arthroplasty setting. The results of this benchtop biomechanical study suggests the need for further study in whole, fresh cadaver models and the exercise of cautious utilization of posterior foraminotomy when necessary for secondary decompression after arthroplasty.

Key Points

- Bilateral posterior foraminotomies and laminectomy did not adversely affect the stability of a cervical disc arthroplasty with the ProDisc-C.
- Minor increases in motion were associated with ventral foraminotomy and posterior longitudinal ligament resection performed in combination with cervical disc arthroplasty.
- Posterior decompression via foraminotomy and laminectomy performed with the ProDisc-C increased mean intervertebral sagittal plane rotation to 6°, consistent with those values seen in nonspondylotic Food and Drug Administration clinical studies.

References