SPINE Volume 35, Number 26S, pp S361–S367
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Biomechanical Analysis and Review of Lateral Lumbar Fusion Constructs

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Study Design. Biomechanical study and the review of literature on lumbar interbody fusion constructs.

Objective. To demonstrate the comparative stabilizing effects of lateral interbody fusion with various supplemental internal fixation options.

Summary of Background Data. Lumbar interbody fusion procedures are regularly performed using anterior, posterior, and more recently, lateral approaches. The biomechanical profile of each is determined by the extent of resection of local supportive structures, implant size and orientation, and the type of supplemental internal fixation used.

Methods. Pure moment flexibility testing was performed using a custom-built 6 degree-of-freedom system to apply a moment of ±7.5 Nm in each motion plane, while motion segment kinematics were evaluated using an optoelectronic motion system. Constructs tested included the intact spine, stand-alone extreme lateral interbody implant, interbody implant with lateral plate, unilateral and bilateral pedicle screw fixation. These results were evaluated against those from literature-reported biomechanical studies of other lumbar interbody constructs.

Results. All conditions demonstrated a statistically significant reduction in range of motion (ROM) as a percentage of intact. In flexion-extension, ROM was 31.6% stand-alone, 32.5% lateral fixation, and 20.4% and 13.0% unilateral and bilateral pedicle screw fixation, respectively. In lateral bending, the trend was similar with greater reduction with lateral fixation than in flexion-extension; ROM was 32.5% stand-alone, 15.9% lateral fixation, and 21.6% and 14.4% unilateral and bilateral pedicle screw fixation. ROM was greatest in axial rotation; 69.4% stand-alone, 53.4% lateral fixation, and 51.3% and 41.7% unilateral and bilateral pedicle screw fixation, respectively.

Conclusion. The extreme lateral interbody construct provided the largest stand-alone reduction in ROM compared with literature-reported ALIF and TLIF constructs. Supplemental bilateral pedicle screw-based fixation provided the overall greatest reduction in ROM, similar among all interbody approach techniques. Lateral fixation and unilateral pedicle screw fixation provided intermediate reductions in ROM. Clinically, surgeons may evaluate these comparative results to choose fixation options commensurate with the stability requirements of individual patients.

Key words: lumbar interbody fusion, range of motion, extreme lateral, stability, XLIF. **Spine 2010;35:S361–S367**

Lumbar spine fusions, often combined with direct or indirect neurologic decompression, are commonly performed to treat patients with persistent symptoms of neurologic pain due to spinal instability, spondylosis, or spinal deformities such as scoliosis and spondylolisthesis and who are refractory to nonoperative measures. Lumbar spine surgery has been compared with other elective orthopedic procedures such as total knee and total hip replacement, and patients were found to have better clinical quality of life outcomes comparing pre- and postoperative indexes with various procedures.[1] Although the posterolateral gutter remains the most common site for fusion, it is increasingly common to perform an anterior column (interbody) fusion to increase stability and the likelihood of fusion.[2,3] Several operative approaches are commonly used to access the anterior column for fusion, including posterior, transforaminal, anterior, and more recently, lateral transpsoas.

Posterior approaches for lumbar spine surgery allow for placement of anterior (*i.e.*, interbody) and posterior instrumentation through a single incision, though with a relatively small working window, risk to neural structures,[4–6] and damage to posterior musculature.[7,8] Anterior approaches provide a broad exposure of the anterior column and use techniques familiar to most surgeons, but complications associated with the approach (*e.g.*, vascular[9,10] and reproductive[11,12]) as well as a high risk of vascular injury during revision procedures lessen the value of anterior approach benefits, especially at lumbar levels above L5–S1. The lateral transpsoas approach minimizes the vascular and neural complications associated with anterior and posterior procedures, respectively. It is considered a minimally disruptive approach, and advanced neuromonitoring techniques are required to avoid lumbar plexus injuries.[13,14] From a biomechanical perspective, the lateral approach allows an abundant amount of disc to be removed, and placement of a large, stable interbody implant, retaining the anterior longitu-

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Acknowledgment date: August 24, 2010. First revision date: September 29, 2010. Second revision date: October 15, 2010. Acceptance date: October 15, 2010.

The device(s)/drug(s) is/are FDA-approved or approved by corresponding national agency for this indication.

Corporate/Industry funds were received in support of this work. One or more of the author (s) has/have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript: *e.g.*, honoraria, gifts, consultancies, royalties, stocks, stock options, decision making position.

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dinal ligament and annulus, and providing a large fusion surface area.[13–15]

Despite the differences among surgical approaches, the techniques employed on reaching the intervertebral disc are similar for all interbody fusion procedures. This typically involves removal of intervertebral disc material and preparation of the graft bed, followed by insertion of an interbody implant (spacer) into the newly formed space to restore the appropriate disc height and alignment and to carry the loads of the anterior column, along with bone graft for eventual fusion and long-term stabilization. Supplemental internal fixation, such as pedicle screws/rods or plates, may then be placed to increase the stability of the construct and assist the fusion process. Bilateral pedicle screw and rod systems are considered the standard for providing the most rigidity in instrumented fusion constructs.[16] However, alternative fixation options are available that may minimize the exposure necessary for supplemental internal fixation. Use of unilateral pedicle screw fixation has been reported with good success[17–21]; as has anterior/lateral plate fixation,[22–24] which allows for single-approach anterior and lateral procedures.

The objective of this biomechanical study and literature review was to demonstrate the stability of anterior column reconstruction through the less invasive lateral approach technique and the additional comparative stabilizing effects of various internal fixation options.

■ Materials and Methods

A literature review of lumbar biomechanical/kinematic studies on lumbar interbody fusion constructs was conducted using the published literature database PubMed/MEDLINE. Only articles pertaining to biomechanical analysis of plate and/or pedicle screw fixation systems on lumbar interbody fusion constructs were considered. Specifically, articles focused on interbody implant design, position, and alternative fixation options were excluded from the review.

Previously reported XLIF-specific biomechanical testing results[25] were reviewed, and additional testing was performed for comparison. Both series of results were evaluated relative to the published literature on other interbody fusion techniques.

XLIF Construct Testing

Levels L1–L5 were dissected from 10 fresh-frozen cadaveric specimens (average age, 53.2 years; range, 25–72). Anterior-posterior and lateral radiographs were used to confirm that specimens were free of deformity or excessive degeneration. Bone density was assessed by dual-energy radiograph absorptiometry (Discovery C, Hologic Inc., Bedford, MA), with average bone mineral density (BMD) of 0.83 ± 0.12 g/cm^2 (range, 0.67–1.04 g/cm^2). In some cases, the bone may be considered osteoporotic and this should be considered when evaluating the results. The caudal and cephalad ends of each specimen were mounted in polymethylmethacrylate (PMMA), positioned with the L3–L4 level horizontal. After testing the intact spine, the following conditions were tested at the L3–L4 level: (1) XLIF "stand-alone" (lateral discectomy and XLIF interbody implant alone without supplemental fixation), (2) XLIF supplemented with a lateral plate, (3) XLIF supplemented with ipsilateral unilateral pedicle screws, and (4) XLIF supplemented with bilateral pedicle screws. The ipsilateral side was defined as the side from which the lateral approach was made. A discectomy was performed to remove sufficient disc material and prepare the endplates similar to clinical practice. The CoRoent XL (NuVasive, Inc., San Diego, CA) XLIF cage is 18-mm wide in the anterior-posterior direction and made from polyetheretherketone. Interbody sizing was based on the anatomy to determine height and lateral length, and was performed by surgeons experienced with lateral approach surgery taking care not to damage the endplates. Insertion of the large footprint cage causes caudal-cephalad distraction of the intervertebral space; producing tension in the longitudinal ligaments and remaining annulus. Endplate preservation is therefore important in achieving initial stability. Pedicle screws and lateral plate bolts were placed with the aid of fluoroscopy before testing without any additional spine ligament resection. The order of construct assembly was reversed for half the specimens to minimize bias due to the order of testing.

Pure moment flexibility testing was performed on a custom-built, LabVIEW (National Instruments, Austin, TX) controlled, servomotor actuated 6 degree-of-freedom spine testing system (Figures 1A, B), applying unconstrained moments of ±7.5 Nm about each axis (flexion-extension, lateral bending, and axial rotation) for 3 cycles, with the final cycle used in data analysis. The axial load was maintained at 0 N. These parameters are consistent with the literature.[26,27] A detailed summary

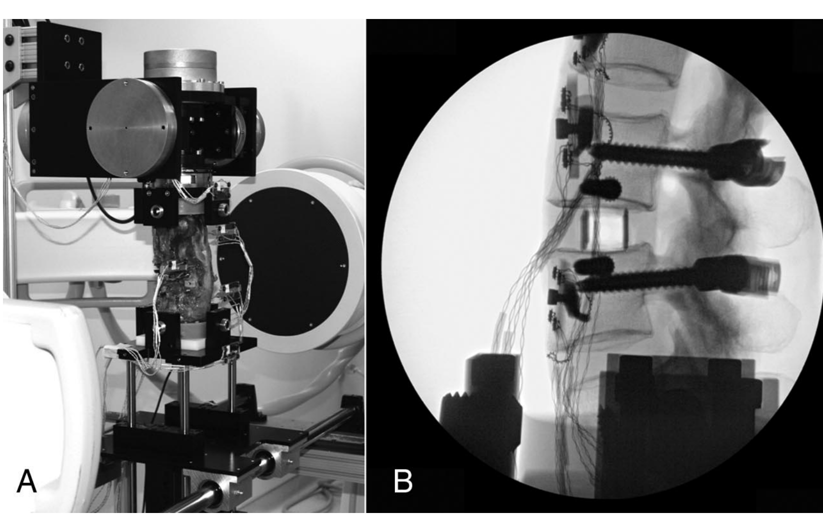

Figure 1. **A**, photograph of custom 6 degree-of-freedom spine testing apparatus with servomotors for flexion-extension, lateral bending and axial rotation. Lumbar spine from L1 to L5 in position between C-arm with infra-red LED markers on each vertebral body. **B**, radiographic image of specimen with XLIF interbody implant in place and supplemental fixation in place for additional stabilization.

Table 1. Summary of Average ROM as a Percentage of the Intact Spine With Standard Deviations for Each Tested Condition

Test Condition	Flexion-Extension	Lateral Bending	Axial Rotation
Stand-alone	31.6% ± 10.7%	32.5% ± 13.8%	69.4% ± 16.2%
Lateral plate	32.5% ± 10.8%	15.9% ± 4.1%	53.4% ± 11.8%
Unilateral PS	20.4% ± 6.1%	21.6% ± 6.8%	51.3% ± 13.1%
Bilateral PS	13.0% ± 4.3%	14.4% ± 5.3%	41.7% ± 14.8%

ROM indicates range of motion; PS, pedicle screw.

Table 2. Summary of the Bess *et al*[25] Results, With Average ROM as a Percentage of the Intact Spine With Standard Deviations for Each Tested Condition

Test Condition	Flexion-Extension	Lateral Bending	Axial Rotation
Stand-alone	45.8% ± 12.8%	41.8% ± 15.8%	66.3% ± 20.3%
Lateral plate	40.0% ± 14.0%	24.2% ± 9.2%	50.7% ± 24.7%
Unilateral PS	26.8% ± 9.8%	27.8% ± 11.8%	47.3% ± 21.3%
Bilateral PS	22.5% ± 4.5%	16.1% ± 4.1%	43.1% ± 15.1%

ROM indicates range of motion; PS, pedicle screw.

of the reviewed literature is available on the electronic supplement (Supplemental Digital Content, online only, available at: http://links.lww.com/BRS/A494). The kinematics of each motion segment were obtained using an optoelectronic motion system (Optotrak Certus, Northern Digital Inc., Waterloo, Ontario, Canada) with infrared light-emitting diode marker arrays attached to each vertebral level.

The means and standard deviations for the range of motion (ROM) at the index level were calculated for each test condition and loading direction, and pair-wise comparisons were made using repeated-measures analysis of variance and the Holm-Sidak test, with a level of significance of $P < 0.05$. Comparisons were initially performed with all conditions included. Subsequent analyses were performed with the intact data excluded from the analysis to facilitate comparisons between the various fixation methods evaluated.

■ Results

The ROM results for the current study were expressed as a percentage of the intact spine ROM and summarized (Table 1). All conditions were found to be statistically less than the ROM observed in the intact spine ($P = 0.007$).

Comparing the results of the stand-alone interbody condition with the various fixation conditions revealed that all 3 fixation conditions had significantly greater reductions in ROM than stand-alone in lateral bending ($P = 0.002$) and axial rotation ($P = 0.0002$). In flexion-extension, pedicle screw fixation (unilateral or bilateral) demonstrated the greatest reduction in ROM ($P = 0.00001$), while ROM with lateral plate fixation was not statistically different from that in the stand-alone condition ($P = 0.628$).

Comparing the 3 fixation conditions revealed further differences: in flexion-extension, pedicle screw fixation demonstrated more reduction in ROM than lateral plate fixation ($P < 0.05$), bilateral greater than unilateral ($P = 0.002$). In lateral bending, neither unilateral ($P = 0.098$) nor bilateral ($P = 0.593$) pedicle screw fixation demonstrated significantly different ROM than lateral plate fixation; however, bilateral pedicle screw fixation did demonstrate a greater reduction in ROM than unilateral ($P = 0.045$). Finally, in axial rotation, ROM with unilateral screw fixation was not significantly different than lateral plate fixation ($P = 0.518$). Bilateral screw fixation exhibited significantly less ROM than lateral plate fixation ($P = 0.004$) and unilateral pedicle screw fixation ($P = 0.013$).

The results of the previously reported study from Bess *et al*[25] were summarized as a means to compare 2 similarly conducted studies (Table 2). Despite the slight numerical differences between the current study and the Bess *et al*[25] study, the trends are similar, with similar ranking of ROM for the various constructs (Figures 2A–C).

■ Discussion

The published literature abounds with reports of biomechanical testing of fusion constructs. For the purposes of this study, the scope of review was narrowed to studies relating specifically to interbody fusion and the kinematic effects of various internal fixation supplements.

Beaubien *et al*[28] compared stand-alone ALIF with freeze-dried femoral ring allograft (FRA) and anterior plate, pedicle screws, or translaminar screws. The authors evaluated 3 human lumbar spines from L1 to the

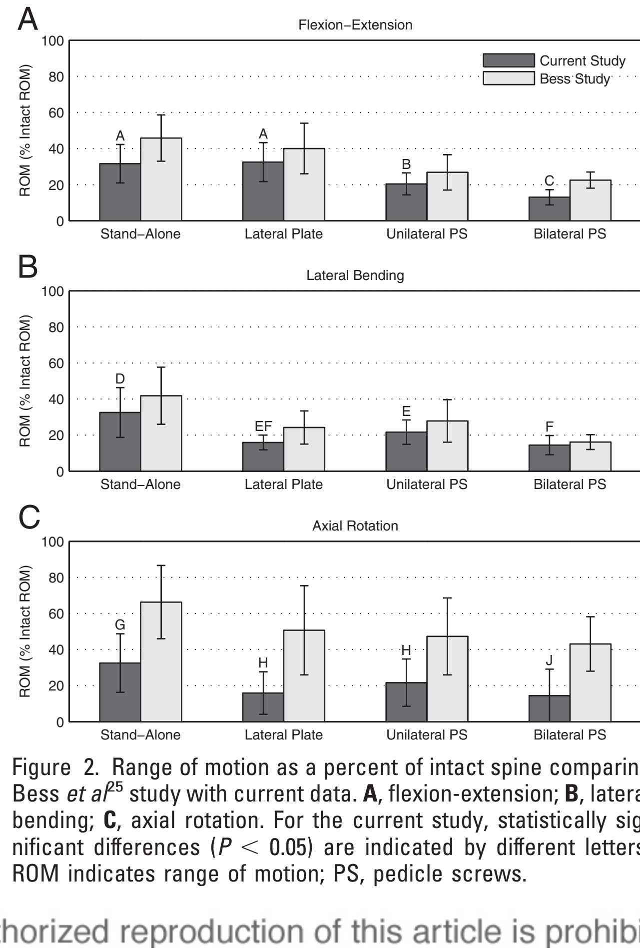

Figure 2. Range of motion as a percent of intact spine comparing Bess *et al*[25] study with current data. **A**, flexion-extension; **B**, lateral bending; **C**, axial rotation. For the current study, statistically significant differences ($P < 0.05$) are indicated by different letters. ROM indicates range of motion; PS, pedicle screws.

sacrum and divided each spine into 3 individual, functional spine units (L1–L2, L3–L4, and L5–S1). Each functional level was instrumented, and ROM data were collected. All instrumented constructs demonstrated significantly decreased ROM compared with intact spines. ALIF with anterior plate significantly reduced the ROM compared with stand-alone ALIF in extension and axial rotation, but did not statistically reduce the ROM in lateral bending. Pedicle screws and translaminar facet screws provided a significantly greater reduction in ROM than ALIF and ALIF with anterior plate in all planes.

Slucky *et al*[16] examined TLIF biomechanics associated with unilateral pedicle screw fixation, bilateral pedicle screw fixation, and unilateral pedicle screw fixation combined with a contralateral facet screw. Seven fresh-frozen human lumbar spines were tested in random construct order in flexion-extension, lateral bending, and axial rotation using ± 5 Nm pure moments and 50 N of compressive load; each specimen was tested from L2–L5 with the operated level at L3–L4. Compared with the intact spine, all TLIF constructs with posterior instrumentation resulted in reduced segmental ROM and increased stiffness at the operated level. Bilateral pedicle screw fixation and unilateral pedicle screw fixation combined with a contralateral facet screw reduced the ROM and increased stiffness significantly more than unilateral pedicle screw fixation.

Harris *et al*[29] also examined TLIF biomechanics comparing the intact spine to stand-alone interbody TLIF implant (obliquely placed carbon-fiber cage), TLIF implant plus facet screw, TLIF implant plus unilateral pedicle screw fixation, and TLIF implant plus bilateral pedicle screw fixation. Five fresh-frozen human lumbar spines were tested in flexion-extension, lateral bending, and axial rotation using ± 5 Nm pure moments and 50 N of compressive load; each specimen included T12–S1 with L4–L5 the operated level. TLIF reconstruction with a solitary cage significantly increased segmental ROM at L4–L5 in axial rotation. A unilateral translaminar facet screw had minimal stabilizing effect at L4–L5 while unilateral pedicle screws further increased stiffness at the L4–L5 segment. TLIF with bilateral pedicle screws was found to most closely approximate the L4–L5 segmental ROM of the intact spine and did not demonstrate as much stability as the current data and other studies.[16,25,28]

Tsantrizos *et al*[30] compared the effect of different stand-alone ALIF cage constructs and cage-related features on initial segmental stability. They found that none of the cage constructs reduced neutral zone (NZ; defined as the difference between the original position and the displacement of the spine after the load force is removed); cages did reduce ROM in all loading directions, but the residual ROM indicated micromotion at the cage-endplate interface. Cylindrical cages had the largest NZ increase in flexion-extension and lateral bending. Differences between cage designs were attributed to the cage-endplate geometry mismatch, where cage dimensions, height, and angle were determined to be significant factors in initial stability.

A study by Niemeyer *et al*[31] compared the stability of both TLIF and ALIF constructs. Six L1–L5 cadaveric specimens were tested under the following conditions: (1) intact spine, (2) stand-alone TLIF or ALIF cage at L2–L3, (3) stand-alone cage at L2–L3 with bilateral pedicle screw stabilization, (4) stand-alone ALIF or TLIF cage (whichever was not used in step 2) at L3–L4 leaving the L2–L3 segment as in step 3, (5) cage at L3–L4 stabilized with bilateral pedicle screws, leaving L2–L3 instrumented as described in step 2. Pure moment, multidirectional flexibility testing at 7.5 Nm with no axial load was performed. The ALIF constructs were more stable than TLIF in all loading directions. Significant differences ($P < 0.05$) were found between the 2 stand-alone interbody techniques in flexion-extension and lateral bending, and with the addition of pedicle screw fixation significant differences were detected in flexion-extension and axial rotation.

Less biomechanical data have been published on interbody reconstruction performed through a lateral approach. Heth *et al*[32] evaluated the mechanical stability of stand-alone, titanium-threaded interbody fusion cages placed either anteriorly or laterally across the disc space. Fourteen human cadaveric lumbar spines were instrumented at the L4–L5 interspace. Seven spines were instrumented anteriorly with 2 adjacent cages, and 7 spines were instrumented laterally with only 1 cage, which was placed transversely across the disc space. Compared with the intact spine, anterior discectomy destabilized the L4–L5 motion segment in flexion and axial rotation, whereas lateral discectomy did not significantly increase the angular ROM. Anterior and lateral cages restored angular ROM to that of the intact segment; however, the ROM was not significantly less than values obtained for the intact spine. There was no statistical difference in stability imparted by the anterior and laterally placed interbody cages.

Le Huec *et al*[33] evaluated the biomechanics of a laterally placed threaded interbody fusion cage in 8 lumbar functional spinal units with 2 additional fixation options: a lateral plate and a lateral plate locked to the cage. The laterally placed cage provided a decrease in the ROM compared with the intact spine in flexion-extension but not in lateral bending or axial rotation. The reduction in ROM observed with the plate (both independent and coupled) was significantly reduced relative to the intact spine in all 3 motion planes (flexion-extension, lateral bending, and axial rotation). Coupling the plate to the laterally-placed cage did not significantly affect the ROM results.

Tencer *et al*[34] evaluated the biomechanics of bilateral anterior and single transverse cage placement in the lumbar spine. A single lateral cage performed similar to 1 or 2 anterior cages, with the exception that laterally placed cages demonstrated greater stiffness in axial rotation.

Ploumis *et al*[35] compared the stability of multiple approaches (TLIF, anterior ALIF, lateral ALIF) in 2 groups of 6 motion segments using unconstrained, multidirectional moments to 5 Nm. The TLIF group was tested intact and after TLIF cage insertion stabilized with bilateral pedicle screws. The ALIF group was tested intact, after ALIF cage inserted through a lateral approach, after cutting of the anterior longitudinal ligament, and after a resized cage was placed anteriorly. Bilateral pedicle screw fixation was used with all ALIF cage conditions, and the fixation was adjusted for the anterior ALIF condition. ROM and NZ parameters were evaluated. The lateral ALIF, anterior ALIF, and TLIF conditions provided significantly less ROM than intact ($P < 0.05$). No statistical difference was detected between the TLIF and lateral ALIF groups. The anterior ALIF approach had similar stability to the lateral approach in flexion-extension and lateral bending ($P > 0.05$), but greater ROM in axial rotation. Resection of the ALL significantly increased ROM over the lateral ALIF in flexion-extension and axial rotation. This investigation showed that bilateral pedicle screw fixation provided notable stability to anterior and lateral ALIF and TLIF interbody constructs.

Kim *et al*[36] evaluated the stability of human cadaveric lumbar spine constructs using FRA interbody reconstruction performed via a traditional ALIF approach or a lateral approach. Specimens were instrumented at the L3–L4 and L4–L5 levels and were evaluated in 4 conditions: (1) intact spine, (2) destabilization by anterior or lateral discectomy, (3) stand-alone interbody reconstruction (anterior or laterally placed FRA), and (4) interbody reconstruction supplemented with additional fixation (lateral interbody reconstruction was supplemented with lateral plate fixation, and ALIF was supplemented with posterior transpedicular fixation). The segmental ROM and the NZ were measured in flexion-extension, lateral bending, and axial rotation. Values were normalized to the intact spine. The ROM and NZ were increased in all dimensions after lateral and anterior discectomy. There was no difference in the ROM or NZ between the lateral and the anteriorly destabilized spine. The stand-alone lateral interbody and ALIF implants restored the ROM and NZ to intact spine values. There was no significant difference in the ROM or NZ between stand-alone lateral interbody and ALIF implants. Compared with the intact spine, supplemental instrumentation significantly reduced the ROM and NZ in all loading modes (except for the NZ in lateral bending) in both groups. Lateral interbody reconstruction supplemented with a lateral plate demonstrated significantly reduced ROM in flexion and lateral bending compared with stand-alone lateral interbody. All ALIF/pedicle screw values for the ROM and NZ were significantly lower than the values for stand-alone ALIF. In flexion-extension and lateral bending, the ALIF/pedicle screw constructs also demonstrated lower ROM and NZ values than lateral interbody/lateral plate constructs.

Bess *et al*[25] used a human cadaver model to compare lumbar spine kinematics of a laterally placed polyetheretherketone interbody device (CoRoent XL; NuVasive, Inc.) used as a stand-alone construct with various instrumented constructs. Seven fresh-frozen, human cadaveric lumbar spine specimens were potted at L1 and L5. All specimens underwent nondestructive testing in 3 physiologic directions: flexion-extension, lateral bending, and axial rotation using a hybrid protocol.[37] The L3–L4 interspace was evaluated in 5 conditions: (1) intact spine, (2) lateral discectomy and stand-alone lateral interbody device (XLIF), (3) XLIF supplemented by a lateral plate, (4) XLIF supplemented by unilateral pedicle screws, and (5) XLIF supplemented by bilateral pedicle screws. Testing was performed using a custom, multiaxis spine simulator. Intervertebral motion was evaluated using an optoelectronic motion measurement system. Intact specimens were precycled for 30 cycles at ±5 Nm moment in flexion-extension. The ROM cycles were also conducted using 50 N axial compression preload.

Bess *et al*[25] study and the current data reveal that the extreme lateral interbody implant, with or without supplemental fixation, provides significantly decreased ROM in all loading modes compared with intact specimens. Further analysis demonstrated that bilateral constructs had significantly decreased ROM for flexion-extension and lateral bending compared with XLIF alone, plated, and with unilateral fixation. The greatest reduction in ROM was observed with lateral bending and flexion-extension in all treatments.

Differences in testing methodology make it difficult to draw exact comparisons among biomechanical study results. However, trends in outcomes are telling and are summarized in Figures 3A–C. The XLIF data from the current study and Bess *et al*[25] was combined using an average weighted by the total number of specimens in each study. This is compared with historical values for ALIF (Beaubien *et al*[28]) and TLIF (Slucky *et al*[16]). When normalized to the intact motion, stand-alone XLIF demonstrated greater stability than stand-alone ALIF in flexion-extension and lateral bending. The greatest difference between stand-alone ALIF and stand-alone XLIF was noted in flexion-extension. In the case of XLIF, the anterior longitudinal ligament and annulus are preserved which not only limits extension motion, but tensioning of the ligaments and annulus by distraction from the XLIF interbody cage provides substantial initial stability. Minimal differences were demonstrated between the groups if supplemental fixation was added to XLIF, ALIF, or TLIF. Bilateral fixation combined with anterior column support provided the greatest biomechanical reduction in ROM. Finally, comparing the reported changes in axial rotation, TLIF with unilateral pedicle screw fixation provided the least reduction in motion. Bilateral fixation (with either pedicle screw or interlaminar facet screws) combined with ALIF demonstrated the greatest reduction in ROM, followed by XLIF and bilateral pedicle screw fixation.

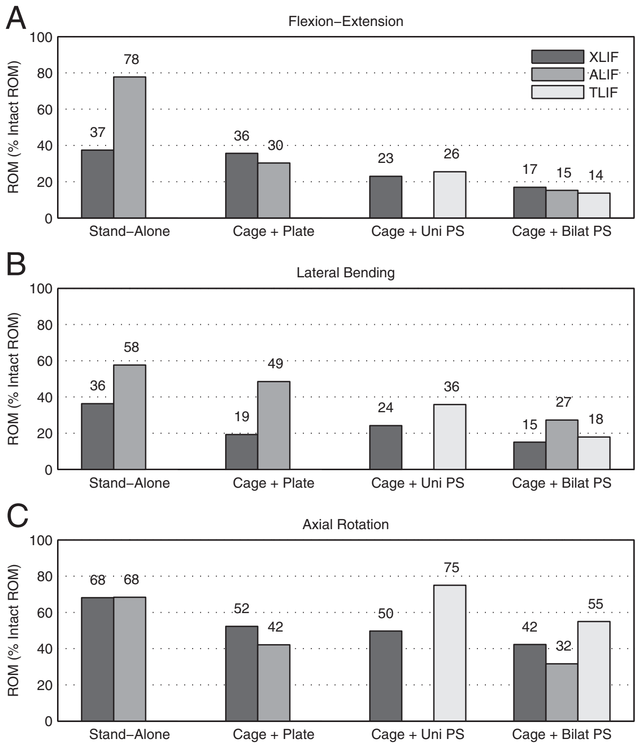

Figure 3. %ROM relative to intact spine for (**A**) flexion-extension, (**B**) lateral bending, and (**C**) axial rotation comparing ALIF (Beaubien *et al*[28]), TLIF (Slucky *et al*[16]), and XLIF (Current study and Bess *et al*[25]). ROM indicates range of motion; Uni, unilateral; PS, pedicle screws.

The current XLIF study has limitations that are shared with most other cadaveric biomechanics studies. The sample size was limited to 10, with specimens of variable bone density and preexisting intervertebral motion. These factors make the results more difficult to interpret; however, they are representative of patient populations. The pure moment loading applied to the specimens in order to measure ROM is typical of physiologic levels, but does not include the stabilizing effect of surrounding musculature, which may alter the results. Importantly, unconstrained moments can be applied in a repeatable manner independent of specimen size, and hence provide a practical method for biomechanical testing of spines. Finally, the nondestructive test methods described provide an appreciation of the immediately postoperative stability of the construct, and do not take into consideration the biologic changes that will occur *in vivo*.

■ Conclusion

Lateral interbody fusion using an appropriately designed and sized implant that spans the lumbar vertebrae (ring apophysis) provides immediate segmental stability in the lumbar spine. Compared with historical data, the segmental reduction in ROM provided by the laterally placed interbody implant exceeds that of stand-alone ALIF and TLIF. Based on results from the current study, the lateral interbody implant significantly decreases ROM compared with the intact lumbar spine; likely due to the strong stabilizing effect of the anterior longitudinal ligament. Lateral interbody implants supplemented with internal fixation further reduce ROM when compared with intact spines and stand-alone lateral implants. Bilateral pedicle screw–supplemented constructs demonstrated the greatest reduction in ROM. While no *in vivo* studies have defined the optimum rigidity for lumbar fusion, these data suggest that with lateral-approach interbody fusion, surgeons have supplemental internal fixation alternatives that achieve stabilization demands, depending on the desired degree of rigidity for the operative level commensurate with the biomechanical requirements of the patient.

■ Key Points

- The extreme lateral interbody fusion technique facilitates completion of a full, large discectomy, and lateral placement of a large interbody implant across the ring apophysis of the lumbar vertebrae, while maintaining the anterior longitudinal ligament. The size and placement of the implant and retention of inherent stabilizing structures make this a uniquely stable interbody construct.
- The additional reduction in range of motion with various supplemental internal fixation options is presented to facilitate clinical decision making.
- In comparison with literature-reported results from other studies on interbody construct biomechanics, the lateral interbody implant provides the largest reduction in range of motion in a stand-alone construct. The stability of the interbody construct with supplemental bilateral posterior fixation is similar to that following other interbody techniques (ALIF and TLIF).

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