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Enhancing the Stability of Anterior Lumbar Interbody Fusion

A Biomechanical Comparison of Anterior Plate *Versus* Posterior Transpedicular Instrumentation

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Study Design. Biomechanical study using human cadaver spines.

Objective. To assess the stabilizing effect of a supplemental anterior tension band (ATB, Synthes) plate on L5–S1 anterior lumbar interbody fusion (ALIF) using a femoral ring allograft (FRA) under physiologic compressive preloads, and to compare the results with the stability achieved using FRA with supplemental transpedicular instrumentation.

Summary of Background Data. Posterior instrumentation can improve the stability of ALIF cages. Anterior plates have been proposed as an alternative to avoid the additional posterior approach.

Methods. Eight human specimens (L3 to sacrum) were tested in the following sequence: (i) intact, (ii) after anterior insertion of an FRA at L5–S1, (iii) after instrumentation with the ATB plate, and (iv) after removal of the plate and adding transpedicular instrumentation at the same level. Specimens were tested in flexion-extension, lateral bending, and axial rotation. Flexion-extension was tested under 0 N, 400 N, and 800 N compressive follower preload to simulate physiologic compressive preloads on the lumbar spine.

Results. Stand-alone FRAs significantly decreased the range of motion (ROM) in all tested directions ($P < 0.05$); however, the resultant ROM was large in flexion-extension ranging between 6.1 ± 3.1° and 5.1 ± 2.2° under 0 N to 800 N preloads. The ATB plate resulted in a significant additional decrease in flexion-extension ROM under 400 N and 800 N preloads ($P < 0.05$). The flexion-extension ROM with the ATB plate was 4.1 ± 2.3 under 0 N preload and ranged from 3.1 ± 1.8 to 2.4 ± 1.3 under 400 N to 800 N preloads. The plate did not significantly decrease lateral bending or axial rotation ROM compared with stand-alone FRA ($P > 0.05$), but the resultant ROM was 2.7 ± 1.9° and 0.9 ± 0.6°, respectively. Compared with the ATB plate, the transpedicular instrumentation resulted in significantly less ROM in flexion-extension and lateral bending ($P < 0.05$), but not in axial rotation ($P > 0.05$).

Conclusion. The ATB plate can significantly increase the stability of the anterior FRA at L5–S1 level. Although supplemental transpedicular instrumentation results in a more stable biomechanical environment, the resultant ROM with the addition of a plate is small, especially under physiologic preload, suggesting that the plate can sufficiently resist motion. Therefore, clinical assessment of the ATB plate as an alternative to transpedicular instrumentation to enhance ALIF cage stability is considered reasonable.

Key words: anterior lumbar interbody fusion (ALIF), femoral ring allograft (FRA), anterior tension band plate, transpedicular instrumentation. **Spine 2008;33: E38–E43**

The goal of anterior lumbar interbody fusion (ALIF) is to remove the pain generator, restore and maintain intervertebral and foraminal height, restore lumbar lordosis, and provide stability to the painful motion segment.[1] Interbody cages can aid in achieving this goal[2] and obviate the need for large autogenous cortico-cancellous grafts and thus prevent graft resorption and subsidence[3] and donor site morbidity.[4–6] However, biomechanical studies suggest that ALIF cages may not provide adequate stability.[7–10] The initial stability of a stand-alone ALIF cage depends primarily on the compressive forces that are produced by tension on the remaining anulus fibrosus. A recent study showed that the compressive force on the interbody device significantly increased with the larger disc-space distraction magnitude. However, the distraction force reduced in magnitude by more than 20% of peak value in the first 15 minutes due to stress relaxation of the soft tissues.[11] Furthermore, excessive disc-space distraction can change spinal alignment and distract the facet joints that may result in loss of segmental stiffness or hypermobility in extension.[8] External compressive preload has been shown to significantly affect the stabilization provided by stand-alone cages.[12] However, the magnitude of preload across the disc space due to body weight and muscle activity can vary with daily activities, and supplemental stabilization of the ALIF cages has been proposed to provide a more predictable stable environment.[12]

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Transpedicular instrumentation and translaminar facet screws have been reported to significantly increase the stability of ALIF cages in biomechanical studies.[8,13–18] These findings have been confirmed by clinical observations that transpedicular instrumentation can significantly increase fusion rate of ALIF procedures.[19–21] However, this combination requires an additional posterior procedure, resulting in longer operative time, surgical trauma, blood loss, a longer recovery period, and increased potential risk for neural injury.

Several anterior constructs have been proposed to increase the initial stability of ALIF cages and avoid posterior surgery. These constructs vary from anterior crossed screws introduced through the FRA spacer into the adjacent vertebral bodies[22] to anterior plates either integrated in the cage[23] or provided as a separate instrumentation.[24,25] The purpose of this biomechanical study was to assess the stabilizing effect of the supplemental anterior tension band plate (ATB, Synthes, Paoli, PA) on L5–S1 ALIF using a femoral ring allograft (FRA) under physiologic compressive preloads. We hypothesized that (1) the ATB plate would significantly increase the stability of FRA, and (2) the stability achieved with the ATB plate would be comparable with the combination of the FRA with transpedicular instrumentation.

■ Materials and Methods

Specimens and Experimental Setup

Eight fresh frozen human cadaveric lumbar spine specimens from L3 to the sacrum were used. The specimens were from 4 females and 4 males (age: 62.3 ± 8.6 years). They were radiographically screened to confirm the absence of bridging osteophytes and metastatic disease, and thawed at room temperature (20°C), 24 hours before testing. The paravertebral muscles were dissected, while keeping the discs, ligaments, and posterior bony structures intact. Trabecular bone mineral density was measured in each vertebra of all specimens with pQCT scan to ensure that they were not osteoporotic.

The L3 vertebra and the sacrum were anchored in cups using polymethylmethacrilate and pins. The specimen was fixed on a 6-component load cell (Model MC3A-6-250, AMTI Multicomponent transducers, AMTI Inc., Newton, MA) at the caudal end and was free to move in any plane at the proximal end. The anatomic standing position was reproduced, with the L3–L4 disc being horizontal to the floor. A moment was applied to the L3 vertebra by controlling the flow of water into bags attached to 50 cm loading arms fixed to the upper cup. The apparatus allowed for continuous cycling loading of the specimen between specified maximum moment endpoints in flexion-extension, lateral bending, and axial rotation.

The motion of L3, L4, and L5 vertebrae relative to sacrum was measured using an optoelectronic motion measurement system (Optotrak, Northern Digital Inc., Waterloo, Ontario, Canada). In addition, biaxial angle sensors were mounted on each vertebra to allow real-time feedback for the optimization of the preload path. Sequential digital videofuoroscopy images (GE OEC 9800 Plus digital fluoroscopy machine) were obtained over the full range of flexion-extension motion.

Compressive preload was applied to the lumbar spine during the range of motion (ROM) experiments in flexion and extension using the follower load technique described by Patwardhan *et al.*[26] The compressive preload was applied along a path that follows the lordotic curve of the lumbar spine. This allowed the lumbar spine to support physiologic compressive preloads without damage or instability.

The preload was applied using bilateral loading cables attached to the cup holding the L3 vertebra. The cables passed freely through guides anchored to each subjacent body from L4 to the sacrum and were connected to a loading hanger under the specimen. The cable guide mounts allowed anterior-posterior adjustments of the follower load path within a range of about 10 mm. The load path was optimized by adjusting the cable guides to minimize changes in lumbar lordosis when a compressive load of up to 800 N was applied to the specimen beginning in its intermediate flexed posture.[27] Previous data demonstrated that by applying a compressive load along an optimized follower load path the segmental bending moments and shear forces due to the preload application are minimized.[27]

Experimental Protocol

Each specimen was tested in the following sequence: (i) intact, (ii) after insertion of an anterior L5–S1 FRA, (iii) after addition of the ATB plate at L5–S1, (iv) after removal of ATB plate and addition of transpedicular instrumentation (PS) at L5–S1 (Figure 1). After anterior discectomy, FRAs were appropriately sized to reproduce the native disc space. ATB plates and screws (5.5 mm) were used according to the manufacturer's instrumentation protocol. For posterior instrumentation, 45 mm long Titanium polyaxial pedicle screws with diameter of 6.25 mm for L5 and 7 mm for S1, were used. Pilot holes for the screws were undertapped by 1 mm. Contoured rods, to match the lumbosacral lordosis, were placed bilaterally.

In each tested condition, the specimens were subjected to flexion-extension moments that varied from −6 to +8 Nm, lateral bending moment that varied from −6 to +6 Nm, and axial rotation moments that varied from −5 to +5 Nm. These moment values are within the range of moments used in previous biomechanical studies of human lumbar spine segments.[12,25] Flexion-extension was sequentially tested under the application of 0 N, 400 N, and 800 N follower preloads.

Data Analysis

The load-displacement data were collected until 2 reproducible load-displacement loops were obtained. The data were analyzed to obtain the angular ROM at L5–S1 for every loading mode and condition.

The statistical analysis was performed using repeated-measures analysis of variance (Systat Software Inc., Richmond, CA). *Post hoc* tests were performed where indicated by analysis of variance results using Bonferroni correction for multiple comparisons. The following pair-wise comparisons were made: (1) intact spine *versus* stand-alone FRA, (2) stand-alone FRA *versus*" FRA + ATB Plate" construct, and (3) FRA + ATB Plate *versus* "FRA + PLF" constructs. The level of significance was set as Bonferroni-adjusted 1-tailed $P \leq 0.05$.

■ Results

Stand-alone FRA decreased flexion-extension, lateral bending, and axial rotation ROM compared with intact. Flexion-extension ROM was significantly reduced from 9.8 ± 2.7° to 6.1 ± 3.1° under 0 N preload ($P < 0.05$), and from 9.2 ± 3.2° to 6.4 ± 3.2° under 400 N preload

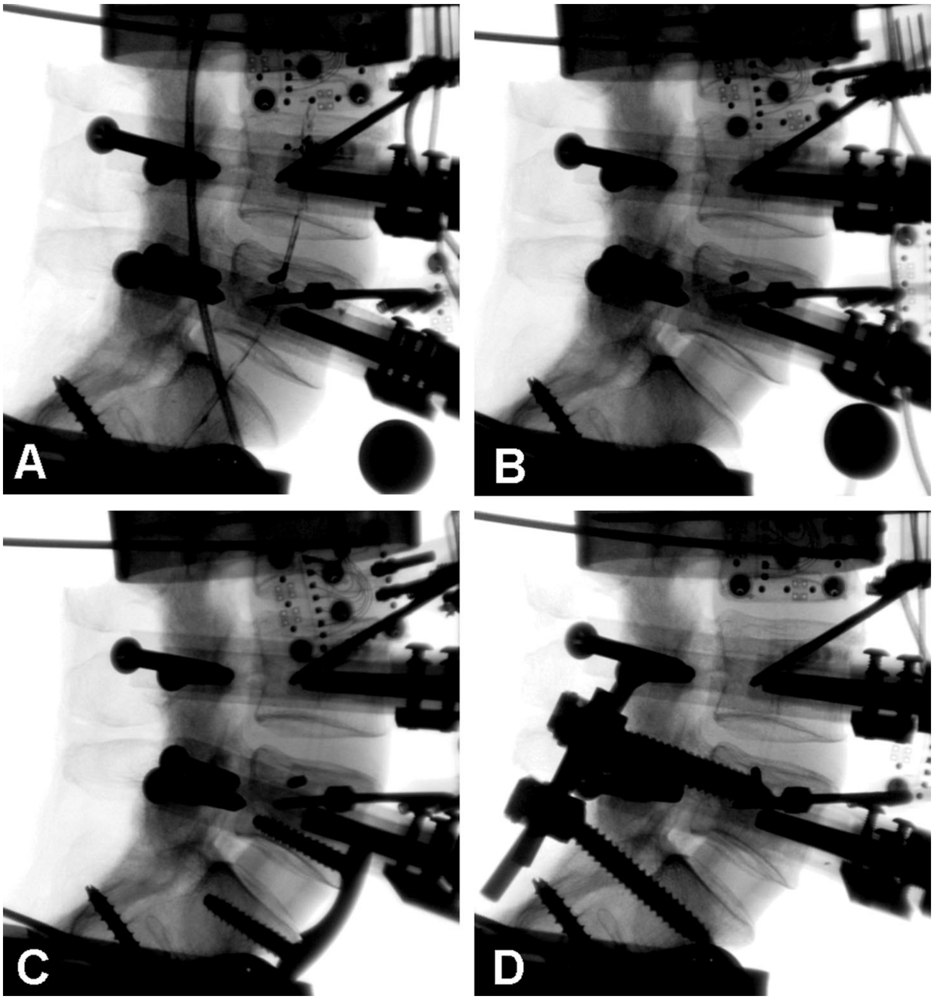

Figure 1. Test sequence: (**A**) intact, (**B**) after insertion of an anterior L5–S1 FRA, (**C**) after addition of the ATB plate at L5–S1, (**D**) after removal of ATB plate and addition of transpedicular instrumentation at L5–S1.

($P < 0.05$) (Figure 2). Under 800 N preload, ROM reduced from 8.1 ± 4.0° to 5.1 ± 2.2°; however, this was not statistically significant ($P > 0.05$). Lateral bending reduced from 5.8 ± 2.6° to 2.8 ± 2.4° ($P < 0.05$), and axial rotation from 3.1 ± 1.5° to 1.2 ± 1.1° ($P < 0.05$) (Figure 3).

Insertion of the ATB plate resulted in an additional reduction in flexion-extension ROM compared with the stand-alone FRA by 30.4% ± 32.9% under 0 N preload, by 45.4% ± 32.8% under 400 N, and by 48.8% ± 19.7% under 800 N preload. The resultant flexion-extension was 4.1 ± 2.3 under 0 N preload, 3.1 ± 1.6

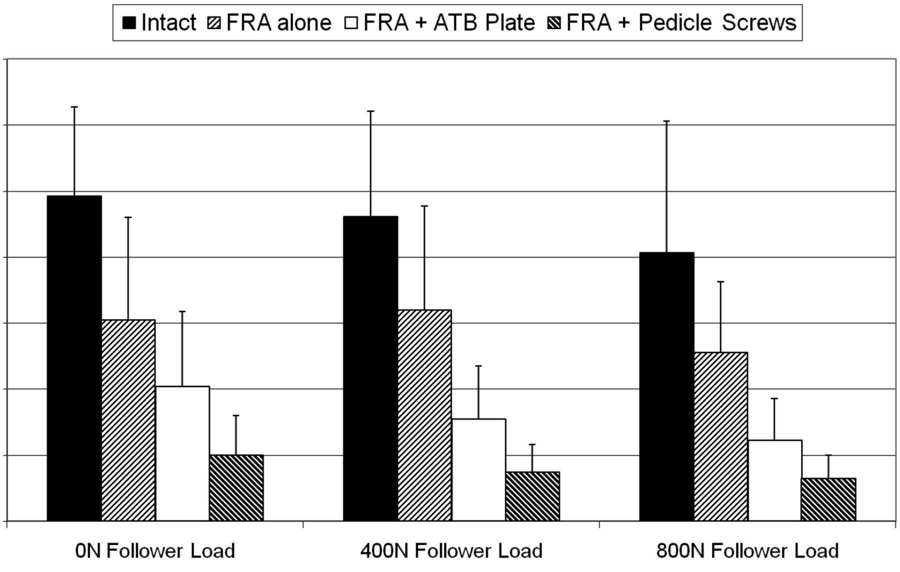

Figure 2. Flexion-extension range of motion (degrees) under 0 N, 400 N, and 800 N preload.

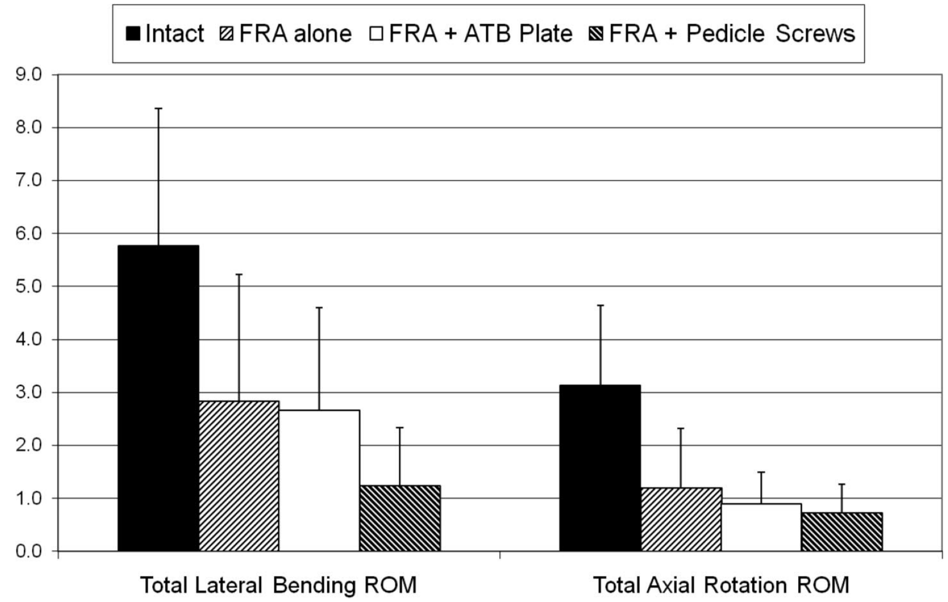

Figure 3. Total lateral bending and axial rotation range of motion (degrees) under 0 N preload.

under 400 N preload and 2.4 ± 1.3 under 800 N preload (Figure 2). The flexion-extension ROM with the combination of ATB plate and FRA was significantly lower than that achieved with the stand-alone FRA under 400 N and 800 N preload ($P < 0.05$) and showed a trend for significance under 0 N ($P = 0.084$). After ATB insertion, total lateral bending ROM reduced to 2.7 ± 1.9 and total axial rotation to 0.9 ± 0.6°; however, the addition of the ATB plate did not significantly reduce the ROM achieved with the stand-alone FRA in lateral bending or rotation ($P > 0.05$) (Figure 3).

The combination of transpedicular instrumentation with FRA resulted in significantly decreased ROM compared with the combination of FRA with the ATB plate in all tested directions. ($P < 0.05$). After supplemental transpedicular instrumentation, ROM in flexion-extension was 2.0 ± 1.2° under 0 N preload, 1.5 ± 0.8° under 400 N and 1.3 ± 0.7° under 800 N preload (Figure 2). ROM in lateral bending was 1.2 ± 1.1° and in axial rotation 0.7 ± 0.6° (Figure 3). Compared with the stand-alone FRA, the addition of transpedicular instrumentation reduced flexion-extension ROM by 65.3% ± 14.3% under 0 N preload ($P < 0.05$), by 75.8% ± 8.4% under 400 N preload ($P < 0.05$), and by 68.0% ± 22.9% under 800 N preload ($P < 0.05$). The additional reduction in lateral bending was 45.2% ± 27.4% ($P < 0.05$), and in axial rotation 31.1% ± 37.5% ($P > 0.05$). Compared with the FRA + ATB Plate construct, the FRA augmented with transpedicular instrumentation additionally decreased ROM in flexion-extension by 47.0% ± 19.6% under 0 N preload ($P < 0.05$), by 47.5% ± 21.5% under 400 N ($P < 0.05$) and by 39.9% ± 27.7% under 800 N preload ($P = 0.062$). The additional reduction in lateral bending was 44.1% ± 24.5% ($P < 0.05$), and in axial rotation 24.4% ± 30.8% ($P < 0.05$). This additional stabilization, although statistically significant, was only 1.5 ± 1.2° in lateral bending and 0.2 ± 0.1° in axial rotation.

■ Discussion

The purpose of this study was to determine the effectiveness of the ATB plate to enhance stability of an anterior cage, and to compare it with the standard combination of anterior cage with transpedicular screw-rod instrumentation. The effects of tested instrumentation were assessed under different preload magnitudes to simulate physiologic conditions. Schultz tabulated the internal compressive force on the lumbar spine during different physical tasks, using data from a number of studies.[28] The average compressive force ranged from 440 N in relaxed, upright standing position to 1400 N in a relaxed standing position with the trunk flexed 30°. These forces were shown to increase substantially when subjects held a weight in the hands while in the static standing posture, with further increases during dynamic lifting.[29] However, as the patients' activities are restricted in the immediate postoperative period, we chose to apply 400 to 800 N preload in this study. Patwardhan *et al* showed that compressive preloads of these magnitudes significantly affected the stability of stand-alone anterior lumbar interbody cages in flexion and extension.[12] It was therefore relevant to investigate the additional stability achieved with the anterior plate or the transpedicular fixation in the presence of physiologic preload. However, the effect of preload was tested only in flexion-extension. With the current experimental setting, the loading cables pass through the lateral sides of the vertebral bodies, and therefore can only be optimized for motion in the sagittal plane. Application of preload in lateral bending and axial rotation using the same cables would result in moments in the opposite direction of those applied for the motion, thus opposing free mobility.

This study demonstrated that stand-alone FRA resulted in significant reduction in the ROM in all tested directions ($P < 0.05$), reflecting that adequate pretension of the remaining anulus while simultaneously avoiding excessive lateral anular resection, can significantly enhance cage stability. However, the resultant motion in flexion-extension was 6.1 ± 3.1° under 0 N preload, and remained at 5.1 ± 2.2° even under 800 N preload. The ATB plate provided additional stability and decreased the ROM of the instrumented segment. This additional stabilization increased with the application of preload and became significant in flexion-extension under physiologic preload ranging from 400 to 800 N. Although the resultant flexion-extension ROM was still 4.1 ± 2.3 under 0 N preload, this is unlikely to reflect *in vivo* conditions, as the weight of the body and the muscle tone impose external preload on the lumbar spine in all activities of daily living. One can therefore assume that the range of 3.1 ± 1.6° to 2.3 ± 1.4° that was recorded under 400 N and 800 N preload is more close to what could be expected *in vivo*. Testing lateral bending and axial rotation under follower preload was not possible as described above; however, ROM was in the range of 2.7 ± 1.9° for lateral bending and 0.9 ± 0.6° for axial rotation. Theoretically, an even lower ROM may be anticipated *in vivo* under physiologic preload.

Previous biomechanical studies have demonstrated that anterior plates or screws can enhance the stability of ALIF cages. Glazer *et al* reported that in human lumbar cadaveric spines, anterolateral instrumentation can enhance stability of femoral ring interbody spacers.[13,10] Similarly, Kuzhupilly *et al* reported significant improvement of the stability of FRA spacers in extension when anterior crossed screws were inserted through the FRA into the adjacent vertebral bodies.[22] However, previous comparisons of anterior constructs with posterior instrumentation have reached to various conclusions, reflecting different testing protocols, and methodologies on reporting the results. Cain *et al* reported that an anterior plate incorporated in an anterior interbody cage achieved similar stability as the combination of the cage alone (without the plate) with transpedicular screws.[23] In that study, a complete anterior discectomy was performed before cage insertion negating the pretension effect of the lateral anulus. Gerber *et al* concluded that a triangular anterior plate was equivalent to pedicle screws in enhancing the stability of cylindrical threaded cages in flexion-extension, axial rotation, and anteroposterior shearing, but not in lateral bending.[24] In that study, comparisons were not made with intact but to the destabilized spine after discectomy and bilateral facetectomy. Therefore, the unphysiologically increased ROM after destabilization may have masked the differences between the tested instrumentation. Furthermore, direct comparisons of the anterior plate to pedicle screw-rods revealed that the plate did not significantly reduce the ROM compared with stand-alone cages; however, pedicle screw-rods significantly reduced ROM compared with stand-alone cages.[24]

The same ATB plate that was tested in the current study has been previously tested by Beaubien *et al*, who reported that the plate significantly reduced ROM compared with anterior cage alone in flexion-extension and axial rotation, but not in lateral bending.[25] In that study, the plate reduced ROM compared with pedicle screw-rods to a similar degree in axial torsion, to a marginally lower degree in flexion-extension, and to a much lower degree in lateral bending. However, only 3 spine specimens were used, and they were sectioned into 7 lumbar motion segments, each comprising of 2 adjacent vertebrae. We consider there are at least 2 potential issues with the use of single functional segmental units. First, there is a likelihood of introducing boundary artifacts when fixing 1 vertebra and applying loads to the only other mobile vertebra in a single functional spinal unit model; and second, as some ligaments span multiple segments, isolating a single functional spinal unit may introduce anatomic artifacts in the experimental model. Furthermore, that study did not use compressive preload, which has been reported to improve the stability of stand-alone anterior cages.[12]

Posterior instrumentation has been proven to be effective in enhancing the stability of anterior cages in biomechanical[8,13–18] and clinical studies.[19–21] Holte *et al* reported a fusion rate of 98% when FRAs were combined with posterior spinal instrumentation compared with 75% with stand-alone FRAs.[20] A recent study using thin-section computed tomography revealed an even higher difference, with the stand-alone ALIF cages achieving a fusion rate of 51% compared with 89% when combined with transpedicular instrumentation.[21] Our findings suggest that transpedicular fixation remains the biomechanical gold standard to enhance stability of ALIF cages. Transpedicular instrumentation resulted in a significant further reduction in ROM compared with the ATB plate. The resultant ROM in flexion-extension was 1.3 ± 0.7° under 800 N preload, and even without preload it remained 2.0 ± 1.2°.

Posterior surgery, however, adds considerably to the morbidity of the procedure, as it entails a separate posterior approach with its attendant extensive muscle stripping, blood loss, operative time, longer recovery period, and potential neural and facet injury. Laminar facet screws can be implanted using less invasive techniques thus reducing the morbidity of posterior surgery; however, thin-section computed tomography studies have shown that translaminar facet screws resulted in significantly lower fusion rates compared with transpedicular instrumentation when used to enhance ALIF cage stability.[21] Therefore, we chose to compare the ATB with transpedicular instrumentation in the current biomechanical study. Whether the additional stability provided by transpedicular instrumentation will be of clinical importance, especially in the face of the additional morbidity of a posterior approach, is a question than can be addressed only by clinical studies with adequate follow-up.

This study has some limitations. The effect of preload was tested only in flexion-extension for reason described above, and only assumptions of similar stabilizing effect of preload in lateral bending and axial rotation can be made. Furthermore, this study only looked at the immediate stability after instrumentation using preloads and moments within the physiologic range. Further biomechanical investigation examining both load to failure and prolonged, cyclic loading to simulate long-term clinical use would help elucidate the longevity of the plate *versus* transpedicular fixation.

■ Conclusion

The ATB plate can significantly increase the stability of the anterior FRA at L5–S1 level. The resultant ROM with the addition of a plate is small, especially under physiologic preload, suggesting that the plate can sufficiently resist motion. Transpedicular instrumentation results in a more stable biomechanical environment compared with ATB plate when combined with the FRA; however, necessitates an additional posterior approach for implantation. Therefore, clinical assessment of the ATB plate as an alternative to transpedicular instrumentation to enhance ALIF cage stability is considered reasonable, especially in the context of the additional morbidity associated with the additional posterior approach.

■ Key Points

- Stand-alone ALIF cages at L5–S1 can significantly reduce ROM; however, the resultant motion still remains high, even under external preload.
- The ATB plate can significantly enhance the stability of FRA in flexion-extension; the resultant ROM is small, especially under physiologic preload.
- Compared with the ATB plate, transpedicular fixation achieves significantly less ROM in flexion-extension and lateral bending, but not in axial rotation.
- The ATB plate can enhance anterior cage stability while avoiding an additional posterior approach.

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