The Spine Journal 15 (2015) 1077–1082

Basic Science

Stability of transforaminal lumbar interbody fusion in the setting of retained facets and posterior fixation using transfacet or standard pedicle screws

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Received 31 August 2012; revised 17 May 2013; accepted 29 June 2013

Abstract

BACKGROUND CONTEXT: The transforaminal lumbar interbody fusion (TLIF) technique supplements posterior instrumented lumbar spine fusion and has been tested with different types of screw fixation for stabilization. Transforaminal lumbar interbody fusion is usually placed through a unilateral foraminal approach after unilateral facetectomy, although extraforaminal entry allows the facet to be spared.

PURPOSE: To characterize the biomechanics of L4–L5 lumbar motion segments instrumented with bilateral transfacet pedicle screw (TFPS) fixation versus bilateral pedicle screw-rod (PSR) fixation in the setting of intact facets and native disc or after discectomy and extraforaminal placement of a TLIF technology graft.

STUDY DESIGN: Human cadaveric lumbar spine segments were biomechanically tested in vitro to provide a nonpaired comparison of four configurations of posterior and interbody instrumentation.

METHODS: Fourteen human cadaveric spine specimens (T12–S1) underwent standard pure moment flexibility tests with intact L4–L5 disc and facets. Seven were studied with intact discs, after TFPS fixation, and then with TLIF and TFPS fixation. The others were studied with intact discs, after PSR fixation, and then combined with extraforaminally placed TLIF. Loads were applied about anatomic axes to induce flexion-extension, lateral bending, and axial rotation. Three-dimensional specimen motion in response to applied loads during flexibility tests was determined. A nonpaired comparison of the four configurations of posterior and interbody instrumentation was made.

RESULTS: Transfacet pedicle screw and PSR, with or without TLIF, significantly reduced range of motion during all directions of loading. Transfacet pedicle screw provided greater stability than

FDA device/drug status: Approved (FacetFuse, PedFuse, TLIFT).

Author disclosures: ***KRC:*** Royalties: SpineFrontier, Inc. (E); Stock Ownership: SpineFrontier, Inc. (E); Trips/Travel: SpineFrontier, Inc (E); Board of Directors: SpineFrontier, Inc. (E). ***MTR:*** Nothing to disclose. ***PMR:*** Trips/Travel: SpineFrontier, Inc. (A). ***AGUN:*** Nothing to disclose. ***AN:*** Nothing to disclose. ***JPG:*** Consulting: Tans 1 (B); Trips/Travel: SpineFrontier, Inc./Tans 1 (B); Scientific Advisory Board: SpineFrontier, Inc. (D). ***RDS:*** Advisory Board: SpineFrontier (None). ***NRC:*** Grant: The LES Society (E, Paid directly to institution/employer); Support for travel to meetings for the study or other purposes: SpineFrontier, Inc. (A); Research Support (Investigator Salary, Staff/Materials): Medtronic (F, Paid directly to institution/employer), The LES Society (F, Paid directly to institution/employer), SI Bone (D, Paid directly to institution/employer), Lanx (D, Paid directly to institution/employer), Spartek, Inc. (D, Paid directly to institution/employer), Synthes (E, Paid directly to institution/employer); Grants: NIH (G, Paid directly to institution/employer); Fellowship Support: Synthesis (E, Paid directly to institution/employer).

The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

Funding for this work was received from The LES Society.

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1529-9430/$ - see front matter
http://dx.doi.org/10.1016/j.spinee.2013.06.103

PSR in all directions of motion except lateral bending. In flexion, TFPS was more stable than PSR ($p=.042$). A TLIF device provided less stability than the intact disc in constructs with TFPS and PSR.

CONCLUSIONS: These results suggest that fixation at L4–L5 with TFPS is a promising alternative to PSR, with or without TLIF. A TLIF device was less stable than the native disc with both methods of instrumentation presumably because of a fulcrum effect from a relatively small footplate. Additional interbody support may be considered for improved biomechanics with TLIF.

Keywords: Transforaminal lumbar interbody fusion; Transfacet pedicle screws; LES; Less Exposure Surgery; Facet

Introduction

Instability because of degenerative disc or facet disease and spondylolisthesis is frequently seen at the L4–L5 and L5–S1 levels, which may require fusion to achieve stability and relieve symptoms. Technologies such as facet screws are seeing more popularity because of their ability to aid ‘‘less-exposure’’ surgeries, which aim to reduce blood loss, postoperative pain, hospital stays, narcotic usage, and time before recovery and return to activities of daily living [1–5].

Transforaminal lumbar interbody fusion (TLIF) was developed for maintaining intervertebral height and to provide a scaffold for fusion. It is intended to be used with supplemental spinal fixation systems for use in the lumbar spine, such as screw fixation. Transforaminal lumbar interbody fusion is usually placed through a unilateral foraminal approach after unilateral facetectomy, although extraforaminal entry allows the facet to be spared.

Transfacet pedicle screw (TFPS) fixation and pedicle screw-rod (PSR) fixation have been demonstrated to have biomechanically similar stability after repetitive cycling [6] in the presence of an anterior lumbar interbody fusion device, but data are lacking on TFPS compared with PSR fixation with and without a TLIF.

The objective of this study was to determine if TFPS and PSR fixation provide better stability with an intact disc or after removing the disc and placing a TLIF device and to compare the stabilizing potential of TFPS to that of PSR.

Methods

Specimen preparation

Fourteen fresh human cadaveric lumbar spine segments from T12 to S1 were used. The mean age was 53.1 (±11.0) years, and there were 4 men and 10 women. Dual-energy X-ray absorptiometry scans were performed on the L4 vertebra of each specimen to assess bone mineral density and to ensure they were not osteoporotic. Specimens were carefully cleaned of muscular tissue while keeping all the ligaments, the joint capsules, and the discs intact. For testing, the sacrum was reinforced with household wood screws, embedded in a block of polymethylmethacrylate or fast-curing resin (Smooth-Cast 300Q, Smooth-On, Inc., Easton, PA, USA), and attached to the base of the testing apparatus. The T12 vertebra was embedded in a cylindrical metal fixture for the application of loads.

One group of seven specimens was studied in the intact condition, after TFPS fixation (FacetFuse; SpineFrontier, Inc., Beverly, MA, USA) and TLIF (T-LIFT; SpineFrontier, Inc.; TFPS fixation still in place) (Fig. 1, Left). The second group of seven specimens was studied in the intact condition, after PSR fixation (PedFuse; SpineFrontier, Inc.) and TLIF (PSR fixation still in place) (Fig. 1, Right). Figure 2 (Left and Right) demonstrate TFPS in situ as an example of our facet fixation technique. Transfacet pedicle screw diameter was 5.0 mm, and length was 40 mm. Holes were prepared using an awl, and a 3.5-mm cannulated drill bit, followed by tapping before screw insertion. Pedicle screw diameter was 5.0 mm, and length was 40 mm. Holes were prepared using a tapered awl, followed by a pedicle finder/probe, and tapping before screw insertion. Top-locking PSRs were 5.5 mm in diameter and were secured using a locking cap. Transforaminal lumbar interbody fusion graft length was 25 mm, and height was 8 to 12 mm. For TLIF placement, a complete discectomy was performed using rongeurs and curettes from an extraforaminal approach, sparing both facet joints. The TLIF cages were sized to fit snugly within the disc space. The bulleted design allowed the disc space to self-distract as the TLIF cage was inserted. To test the effects of retained facets, we chose an extraforaminal approach; however, the final TLIF placement was identical to a transfacet approach.

Biomechanical testing

The specimens were studied using standard pure moment flexibility tests. For these tests, an apparatus was used in which a system of cables and pulleys imparts nondestructive nonconstraining torques in conjunction with a standard servohydraulic test system (MTS, Minneapolis, MN, USA), as we have described previously [7]. This type of loading is distributed evenly to each motion segment, regardless of the distance from the point of loading [8]. Loads of 7.5 Nm maximum were applied about the appropriate

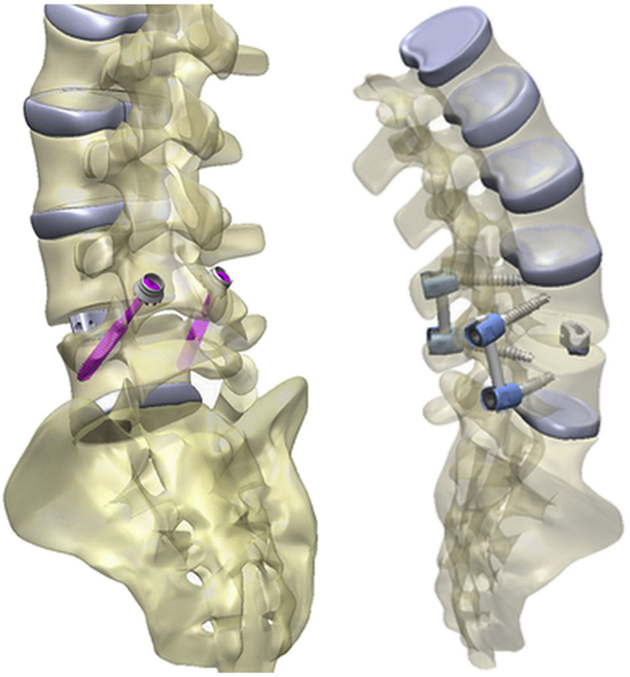

Fig. 1. Posterolateral representations of the L4–L5 region with (Left) transfacet pedicle screw or (Right) pedicle screws-rods in place with a transforaminal lumbar interbody fusion cage.

anatomic axes to induce three different types of motion: flexion-extension, lateral bending, and axial rotation.

Three-dimensional specimen motion in response to the applied loads during flexibility tests was determined using the Optotrak 3020 system (Northern Digital, Waterloo, Ontario, Canada). This system measures stereophotogrammetrically the three-dimensional displacement of infrared-emitting markers rigidly attached in a noncollinear arrangement to each vertebra. Custom software converts the marker coordinates to angles about each of the anatomic axes in terms of the motion segment's own coordinate system [9]. Spinal angles were calculated using a technique that provides the most appropriate results for describing three-dimensional spinal motion [10]. Fluoroscopy was used to ensure correct positioning of the TLIF grafts and screws.

Data analysis

From the raw data, three parameters were generated from the quasistatic load-deformation data: angular range of motion (ROM), lax zone (LZ, zone of ligamentous laxity), and stiff zone (SZ, zone of ligamentous stretching). The LZ and SZ are components of the ROM and represent the low-stiffness and high-stiffness portions of the typically biphasic load-deformation curve, respectively [11]. To mitigate the effect of interspecimen variability, before statistical analysis, data were normalized by dividing the LZ, SZ, or ROM in each instrumented condition by the LZ, SZ, or ROM for that specimen in its intact condition. Lax zone, SZ, and ROM for flexion, extension, lateral bending (average right and left), and axial rotation (average right and left) were statistically analyzed using one-way analysis of variance, followed by Holm-Sidak tests, to determine whether outcome measures were significantly different among the various conditions of instrumentation, and p values less than .05 were considered significant.

Results

Both TFPS and PSR, with or without TLIF in place, significantly reduced mobility compared with normal during all the directions of loading (Fig. 3, Table 1). Transfacet pedicle screw allowed smaller ROM and LZ than PSRs during flexion and extension, both with and without TLIF, and allowed greater ROM and LZ than PSR during lateral bending. These differences were statistically significant during flexion and extension for ROM (with intact disc or TLIF) and for LZ (with intact disc) (Table 2, $p<.05$). During extension and axial rotation (with intact disc), PSR allowed significantly greater SZ than TFPS. The change in LZ,

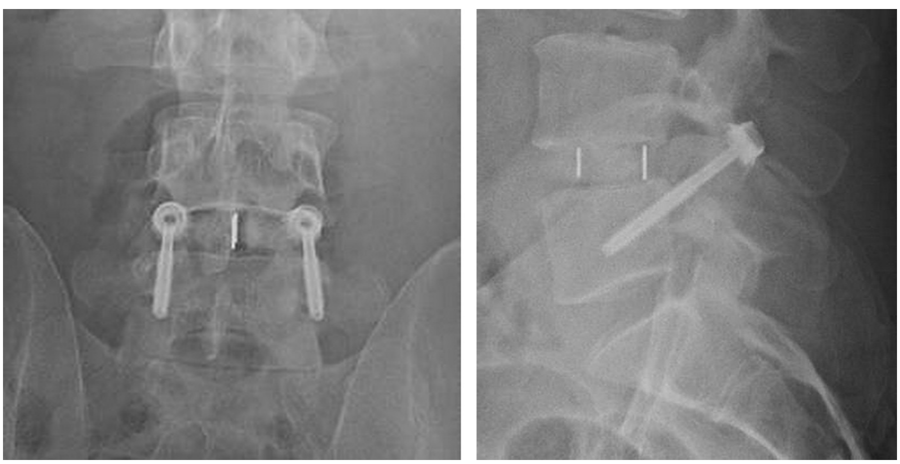

Fig. 2. Anteroposterior (Left) and lateral (Right) views of FacetFuse in situ.

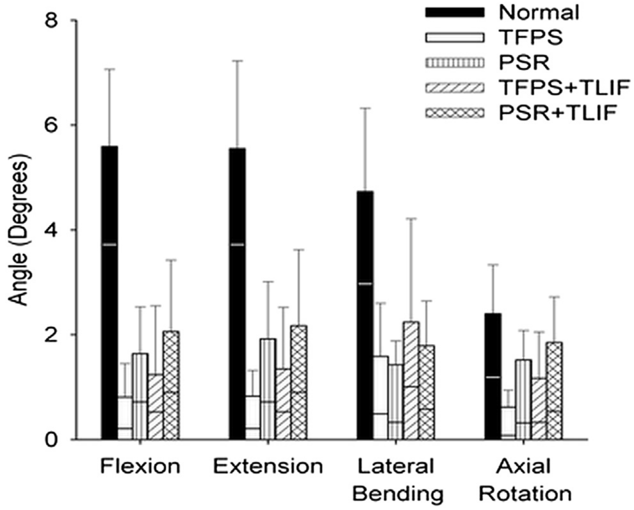

Fig. 3. Mean angular motion for intact and instrumented configurations with transfacet pedicle screws (TFPSs) or pedicle screws-rods (PSRs), with and without transforaminal lumbar interbody fusion. Values for lateral bending and axial rotation are average right/left. Full columns represent range of motion (ROM). The portion of each column above the horizontal dividing line represents stiff zone; the portion below each dividing line represents lax zone. Error bars show standard deviation of the ROM.

SZ, or ROM with the addition of a TLIF was not statistically significant for either type of screw (p>.05).

Discussion

The potential benefits of TLIF to maintain intervertebral height and add anterior column support seem intuitive but need further biomechanical testing to truly understand its effects. Moskovitz [12] have described the indications and technique for TLIF. Their description details the anterior column, back muscle, and ligament support provided by TLIF. The fact that during TLIF there is no need to expose or manipulate the dura as it is a unilateral approach is highlighted; yet, it still provides the benefits of 360° fusion. Normal lumbar lordosis is maintained and the normal anatomy of the motion segment is restored as has been previously described in their study and others [13]. In this study, we have compared the stability of an intact native disc with TLIF stabilized with TFPS or PSR, hence further testing the benefits of TLIF as promoted by the previously mentioned authors.

As aforementioned, earlier tests have been performed on screw fixation methods for stabilization with TLIF. Harris et al. [13] found that in biomechanical testing TLIF with bilateral pedicle screws, this construct most closely mimicked the L4–L5 segmental flexibility of the intact spine compared with unilateral translaminar facet screws and unilateral PSRs. Slucky et al. [14] compared stability of TLIF constructs augmented by bilateral or unilateral pedicle screw fixations and a new unilateral pedicle screw fixation concept with contralateral facet screws. They reported that all TLIF permutations with posterior instrumentation decreased ROM and increased segmental stiffness and that the technique of contralateral facet screw placement provided the same surgical advantage of unilateral pedicle screw with comparable stability with TLIF with bilateral pedicle screws. In this study, we were not able to recreate the increased stability of TLIF with TFPS and/or PSR compared with a native disc. However, our results do support the use of PSR for posterior stabilization, and we have taken this one step further to demonstrate the role of TFPS to increasing stability in flexion-extension compared with PSR.

Table 1
Normalized mean (dimensionless ratio to intact±1 standard deviation) ROM, LZ, and SZ at L4–L5 for configurations with TFPS and PSR and with and without TLIF

Motion	TFPS	PSR	TFPS+TLIF	PSR+TLIF
Flexion				
ROM	0.12±0.06	0.33±0.17	0.19±0.14	0.42±0.28
SZ	0.31±0.23	0.58±0.29	0.35±0.27	0.75±0.48
Extension				
ROM	0.14±0.05	0.38±0.19	0.22±0.13	0.44±0.27
SZ	0.34±0.16	0.75±0.32	0.45±0.22	0.79±0.44
Flexion-extension				
LZ	0.05±0.03	0.22±0.18	0.11±0.12	0.27±0.22
Lateral bending				
ROM	0.39±0.33	0.33±0.11	0.49±0.34	0.41±0.20
LZ	0.20±0.21	0.10±0.12	0.31±0.35	0.21±0.18
SZ	0.68±0.47	0.65±0.13	0.73±0.43	0.74±0.29
Axial rotation				
ROM	0.33±0.15	0.56±0.13	0.61±0.39	0.69±0.23
LZ	0.09±0.07	0.25±0.20	0.38±0.47	0.39±0.23
SZ	0.49±0.24	0.92±0.16	0.76±0.34	1.02±0.26

ROM, range of motion; TFPS, transfacet pedicle screw; PSR, pedicle screw-rod; TLIF, transforaminal lumbar interbody fusion; LZ, lax zone; SZ, stiff zone.

Table 2
p Values from comparisons of normalized values for configurations with TFPS and PSR and with and without TLIF

Parameter and loading mode	PSR vs. TFPS	PSR+TLIF vs. TFPS+TLIF
ROM		
Flexion	**.042**	**.025**
Extension	**.018**	**.036**
Lateral bending	.716	.716
Axial rotation	.064	.064
LZ		
Flexion-extension	**.046**	.060
Lateral bending	.447	.447
Axial rotation	.173	.173
SZ		
Flexion	.876	.876
Extension	**.019**	.050
Lateral bending	.960	.960
Axial rotation	**.005**	.074

TLIF, transforaminal lumbar interbody fusion; TFPS, transfacet pedicle screw; PSR, pedicle screw-rod; ROM, range of motion; LZ, lax zone; SZ, stiff zone.

Numbers in bold indicate statistical significance.

The ability of TLIF to limit surgical trauma was defended by Schleicher et al. in 2008 [15]. They performed biomechanical comparisons of different posterior stabilization methods for TLIF, finding that bilateral pedicle screw augmentation offered more stability than unilateral ones in most test modes. They had compared the native motion segment with TLIF with bilateral and ipsilateral constructs, TLIF and ipsilateral pedicle screws plus contralateral translaminar facet screws, and TLIF and ipsilateral pedicle screws plus contralateral lumbar facet interference screws. Our results have supported these findings of increased stability of TLIF with PSR and have also demonstrated that use of TLIF with TFPS offers equivalent stability.

Others have examined the stability offered by a clamping lumbar interspinous anchor for TLIF demonstrating equivalent limitations of flexion and extension during biomechanical testing between interspinous anchors and PSRs [16] but inferior stability during lateral bending. This option has been suggested as an alternative to bilateral PSRs for supplemental posterior fixation. Here, we have suggested another alternative to PSR in the form of TFPS for supplemental posterior fixation with or without TLIF, with the advantage that stability is equivalent to PSR in modes other than flexion and extension.

Finally, Sim et al. [17] have biomechanically compared the stability of the fused and adjacent segments with PLIF and TLIF both accompanied by bilateral pedicle screw fixation. They reported that with posterolateral fusions, both PLIF and TLIF have comparable biomechanical properties at the adjacent segments, further speaking to the role of TLIF. The comparison between PLIF and TLIF was not made in this study but could be the subject of future research evaluating TFPS and PSR with both interbody fusion techniques to determine if their biomechanics remain equivalent under these conditions.

We found only one reported clinical use of TFPS in the literature to date [18]. This technique description describes the successful placement of TFPS in two patients to achieve lumbar fusion. The next obvious step would be to perform clinical studies detailing the clinical advantages and disadvantages of TFPS and provide more clinically relevant discussion about the ability of TFPS to present a reasonable alternative to PSR for posterior fixation.

One potential weakness of our study was that we placed the instrumentation first before placing the TLIF. However, we thought this method made the cage fit more snugly and did not change the cage height used had we placed the screws first. There were no cases in which we saw reason to be concerned with the fit of the TLIF. Placement of a TLIF through an extraforaminal approach is a new option that has the benefit of preserving the facets and, as such, was the reason for this approach used in this study.

Data from this study have illustrated increased instability of the segment after removal of the native disc and placement of a TLIF device regardless of the posterior instrumentation technique. We postulate that this is because of the relatively small footplate of the TLIF compared with the disc space such that there is a fulcrum effect (the interbody acting as a pivot about which the vertebra can turn). It therefore seems that additional interbody stabilizers such as bone graft or a larger footplate would be needed for greater stability to ensure solid fusion.

The data also show increased stability with TFPSs versus PSRs during flexion-extension, both with and without TLIF in place. This finding was somewhat surprising because the larger moment arm with pedicle screws should be able to resist flexion-extension more easily. The reason that stability is increased with TFPS may be because the joint is pinned; so, there is less ability for it to move under small loads. With screw-rod linkage for PSR, however, there is more chance for restoration of the natural anatomic spacing of the spinal segments. It may be that with larger loads, PSR may perform better. The effect of decreased stability with TFPSs versus PSRs (without TLIF) during lateral bending has been shown during similar comparative studies in the cervical spine [19]. Based on results from the present study, the addition of a TLIF does not seem to change this behavior, suggesting that fixation at L4–L5 with TFPSs is a promising alternative to PSRs, with or without the use of a TLIF.

Finally, it is important to note that TLIF in this study was performed without disruption of either facet. The reason for sparing the facet was that we sought to study the stability offered strictly by the TLIF device without considering the contribution to stability of the facets. Clinically, placement of a TLIF device through an extraforaminal approach is feasible, making these results particularly relevant to such a procedure. Obviously, bilateral placement of TFPS is not possible after unilateral facetectomy is performed. Further study is needed to elucidate the biomechanical effect of removal of one facet together with TLIF wedge placement and unilateral posterior instrumentation.

Conclusions

Our results suggest that fixation at L4–L5 with TFPS is a promising alternative to PSR, with or without TLIF. The TLIF device was less stable than the native disc with both methods of instrumentation presumably because of a fulcrum effect from a relatively small footplate. Additional interbody support may be considered for improved biomechanics with TLIF.

Acknowledgment

The authors gratefully acknowledge the assistance of Dr V. Cumming, LES Society, in researching, drafting, and editing the manuscript.

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