Original Article

# Transforaminal lumbar interbody fusion with a silicon nitride cage demonstrates early radiographic fusion

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**Background:** Degeneration of the lumbar spine is common in aging adults and reflects a significant morbidity burden in this population. In selected patients that prove unresponsive to non-surgical treatment, posterior lumbar fusion (PLF) surgery, with or without adjunctive transforaminal lumbar interbody fusion (TLIF) can relieve pain and improve function. We describe here the radiographic fusion rates for PLF versus TLIF, using an intervertebral spinal cage made of silicon nitride ceramic (chemical formula $Si_3N_4$).

**Methods:** This retrospective cohort analysis enrolled 99 patients from August 2013 to January 2017; 17 had undergone PLF at 24 levels, while 82 had undergone TLIF at 104 levels. All operations were performed by a single surgeon at one institution. Radiographic and clinical outcomes were compared between PLF and TLIF at 2 and 6 weeks and then at 3, 6, 12, and 24 months.

**Results:** TLIF patients fused at higher rates compared to PLF at the 3-month (38.5% *vs.* 8.3%, P=0.006), 6-month (78.7% *vs.* 35.0%, P<0.001) and 12-month time periods (97.9% *vs.* 81.3%, P=0.018), with no difference at 24 months (100% *vs.* 94.4%, P=0.102). Index level segmental motion was significantly less and intervertebral disc height was improved in TLIF over PLF at all follow up intervals. Foraminal height was only greater in early follow up periods (2 weeks, 6 weeks and 3 months). TLIF patients experienced lover rates of PI-LL mismatch which was maintained across long term follow-up. Pelvic tilt was lower following TLIF compared to PLF, with no differences in complication rates between study groups.

**Conclusions:** Our retrospective series demonstrated that TLIF performed with silicon nitride interbody cages led to earlier radiographic fusion, greater restoration of disc and foraminal height, increased segmental rigidity and improved sagittal alignment when compared to PLF alone.

**Keywords:** Degenerative disc disease; spondylolisthesis; spinal stenosis; posterolateral fusion (PLF); transforaminal lumbar interbody fusion (TLIF); silicon nitride ($Si_3N_4$)

Submitted Nov 10, 2021. Accepted for publication Jan 14, 2022.
doi: 10.21037/jss-21-115
**View this article at:** https://dx.doi.org/10.21037/jss-21-115

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## Introduction

Low back pain is the number one cause of adult disability worldwide (1), with significant implications on healthcare costs and lost employment productivity in the United States (2). Back pain results commonly from degenerative disc disease, spinal stenosis, spondylolisthesis or a combination of these conditions (3,4). As a first line treatment, nonsurgical measures may be effective in relieving back pain, but patients with severe or recalcitrant symptoms may require spinal decompression surgery with segmental fusion (5). Spinal fusion techniques include posterolateral fusion (PLF), a term referring to the fusion of two or more lumbar vertebral bodies by placing bone graft along the sides of the vertebral bodies. This is completed in conjunction with screws and rods to provide immediate stability of the operative levels and encourage bone healing. In transforaminal lumbar interbody fusion (TLIF), pedicle screws and rods are used for spinal fixation, with bone graft placed in the intervertebral disc space and lateral gutters posteriorly (6). Although TLIF involves more surgery, it combines a PLF and interbody fusion which has theoretical advantages outlined below.

While both PLF and TLIF are effective in treating back and radicular pain from degenerative lumbar spinal pathology (6-8), TLIF may have improved radiographic fusion rates when compared to PLF alone (9). Other authors disagree; stating that the addition of an interbody fusion in TLIF does not necessarily improve clinical outcomes (3,8). In theory, the placement of interbody bone graft in TLIF has the advantage of fusing the axial, load bearing axis, with restoration of the disc space assisted by an interbody cage (3,8). Practically, patient pain scores, disability scores, fusion rates and complication rates may not differ between PLF and TLIF (10). It has been suggested that TLIF may be associated with increases in operative time, blood loss and higher costs, although other studies have shown similar readmission rates, pain outcomes and blood loss (11). To summarize, the superiority of TLIF or PLF alone in instrumented lumbar fusion remains unclear.

It is possible that the material properties of the interbody cage may affect fusion rates. One biomaterial, silicon nitride ($Si_3N_4$) ceramic has demonstrated to be a safe and effective interbody implant for lumbar spinal fusion (12). Surface bioactivity of $Si_3N_4$ has been shown to have enhanced osteoconductive and osteoinductive properties as well as resistance to bacterial adhesion; these material attributes have been well described in several studies (13-18). We hypothesized that TLIF performed with $Si_3N_4$ cages may show superior outcomes to PLF, specifically earlier fusion, improved disc and foraminal heights with no increase in complication rates. We present the following article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-21-115/rc).

## Methods

We retrospectively evaluated two cohorts of patients who underwent spinal fusion by a single spine surgeon from August 2013 to January 2017. A total of 99 patients were included (17 PLF and 82 TLIF + PLF). Patient accountability is shown in *Figure 1*. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Parkview Institutional Review Board (No. PRC17-1009 TLIF) on January 31st, 2018 and there was no written consent required for patients due to the retrospective nature of the study. Inclusion criteria included the following: (I) age ≥18 years; (II) lumbar degenerative disease with or without spondylolisthesis; (III) failure of ≥6 weeks of non-surgical treatments; (IV) PLF or TLIF performed 1 or 2 levels. Exclusion criteria included: (I) corpectomy; (II) non-instrumented PLF; (III) history of lumbar trauma, neoplasm, or infection. Patient indications for PLF *vs.* TLIF were identical, and they were used at the discretion of the primary surgeon. Interbody spacers were made of $Si_3N_4$ (SINTX Technologies; Salt Lake City, UT, USA). A standard TLIF technique was performed using shaver blades, curettes, and pituitaries for the discectomy.

Patient data were collected through an electronic medical record system [Centricity Picture Archiving and Communication System (PACS)], and stored on an encrypted server. Data were collected preoperatively, intraoperatively, and at scheduled follow-up visits at 2 weeks, 6 weeks, 3 months, 6 months, 1 year, and 2+ years after surgery. Because of scheduling variability in the patient follow-up windows, time to surgery was also collected for each patient's return visit. Anterior-posterior, lateral, flexion and extension radiographs were obtained at each follow-up interval for each patient. All radiographic measurements were obtained by the measurement tools in PACS, and stored on a secure server. Radiographs were examined for evidence of: (I) bony bridging; (II) osseous integration of the implant; (III) index surgical level segmental motion; (IV) disc height; (V) foraminal height; (VI) lumbar lordosis (LL);

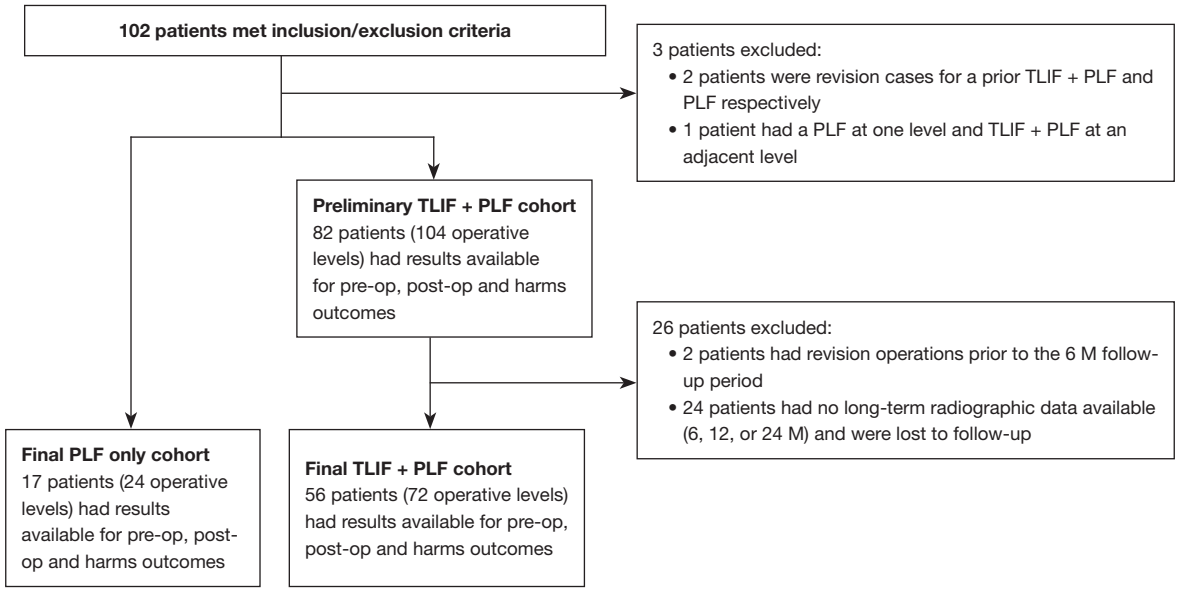


**Figure 1** Patient accountability of the study cohort for long term radiograph interpretation. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion; M, month.

(VII) pelvic incidence (PI); and (VIII) pelvic tilt.

Bony bridging was graded on anterior-posterior and lateral radiographs using the Lenke 5-point modified intertransverse fusion scale, where 1= solid bridging bilaterally, 2= solid bridging unilaterally with questionable bridging contralaterally, 3= questionable bridging bilaterally, 4= questionable bridging unilaterally with no bridging contralaterally, 5= no bridging bilaterally (19). Osseous integration of the $Si_3N_4$ implant was graded as "positive" if bridging cancellous bone was visible between fused segments, with no peri-implant radiolucency. For the TLIF patients, fusion was considered to be achieved with either a Lenke score of 1 or 2, or confirmation of osseous integration of the $Si_3N_4$ cage.

Index level segmental motion was calculated as the absolute value of the difference on flexion and extension radiographs of the Cobb angle. The Cobb angle was measured, using the measurement tool in PACS, at the intersection of the two lines perpendicular to the two lines drawn along the lower endplate of the superior vertebral body and the upper endplate of the inferior vertebral body. Disc height was measured preoperative and at each post-operative timepoint to assess for implant subsidence. Disc height was measured as the distance between the middle of the bottom surface of the upper vertebra and the middle of the top surface of the lower vertebra. Foraminal height was measured as the maximal diameter of the neural foramen identified on the lateral X-ray view.

LL was measured on lateral radiographs as the angle between the line perpendicular to the superior endplate of S1 and the line perpendicular to the inferior endplate of T12. For the purposes of this text, "lumbar lordosis" and "global lordosis" are equivalent. PI was measured as the angle between two lines: (I) the line perpendicular to the top surface of S1 and (II) the line connecting the center of the femoral head and the midpoint of the top surface of S1. To evaluate restoration of spinal alignment parameters, we calculated the absolute values of the change of LL and of the change of PI, from the preoperative visit to first early follow-up and from the first early to last long-term follow-up. Mismatch between PI and LL (PI-LL mismatch) was calculated as the absolute value of the difference between the PI and LL.

### *Statistical analysis*

Statistical analyses were performed using MedCalc Ver. 20.011-64 bit (Ostend, Belgium). Ordinal data were analyzed using Student's *t*-tests whereas nominal results used proportionality assessments including Chi-squared and Fisher's exact tests. Significance was set at P values of $<0.05$. Patients who didn't follow up at a given interval were not included in analysis at that time interval. All 99 patients who met inclusion/exclusion criteria were included at all follow-up intervals that data were available.

## Results

One hundred and two patients met inclusion/exclusion criteria; of these, baseline and early post-operative data were available for 99 patients (17 in the PLF group and 82 in the TLIF group) as outlined in *Figure 1*. Radiographs at 2 weeks, 6 weeks, 3 months and 6 months, 1 year, and >2-year follow-up were available for 56 patient in the TLIF cohort (72 operative levels), and 17 patients in the PLF group (24 operative levels), such that complete long-term follow-up data was available for 73 patients.

Baseline demographic characteristics and comorbidities are shown in *Table 1*. The PLF group was slightly older (62.4 *vs.* 54.8 years, P=0.02) with a lower incidence of prior lumbar interventions (5.9% *vs.* 33.9%, P=0.02) than the TLIF group. The L4/5 fusion level was the most common operative level, with no difference in the distribution of fusion levels between groups. The cohort of patients who had long-term radiographic data had similar distributions of baseline characteristics. Bone graft was commonly utilized intraoperatively with a heterogenous distribution of graft choice between groups. Almost all patients had iliac crest autograft in combination with some form of allograft or bone void filler added to the autograft.

### *Radiographic outcomes*

*Tables 2,3* show radiographic outcomes for the study groups, including average follow-up duration for patients with long-term follow up. There were no differences in the pre-op disc height between groups (6.67 mm PLF *vs.* 7.73 mm, P=0.20). At every post-operative interval there was a significant improvement in disc height in the TLIF group compared to PLF alone. The change in disc height between pre-operative radiographs and each follow-up timepoint was also compared between groups *Figure 2*. The TLIF group experienced on average 4 mm gain in disc height postoperatively that was maintained over all follow-up intervals.

There were no pre-operative differences in foraminal height between study groups (14.58 mm PLF *vs.* 13.45 mm TLIF, P=0.37). The TLIF group showed a significant improvement in average foraminal height of ~3 mm at 2 weeks, 6 weeks and 3 months compared to PLF. However, at 6, 12, and 24 months of follow-up, this difference resolved such that foraminal height was similar between study groups.

There was no statistically significant difference in intertransverse fusion scores at any timepoint between TLIF and PLF. The mean intertransverse fusion score was less than 2 at the 12-month interval, indicating radiographic fusion, on average, by 12 months in either group. Composite fusion scores (which added the finding of osseous integration of the interbody cage to intertransverse fusion scores) are shown in *Figure 3*. Composite fusion scores showed improved fusion in the TLIF *vs.* PLF group at 3, 6 and 12 months; this difference resolved itself at the 24-month follow up, when >90% of PLF patients and 100% TLIF patients had achieved spinal fusion.

Index level segmental motion data was available at 3 months, and at the subsequent follow up intervals. Comparing Cobb angles derived from flexion and extension radiographs (*Figure 4*), TLIF patients had significantly less segmental motion than PLF patients at 6-months, and subsequent follow up intervals. On average, the TLIF group had one degree less segmental motion at all long term follow up points, with an average <2 degrees segmental motion at the 12- and 24-month intervals.

### *Global and segmental lordosis*

The two groups differed pre-operatively with respect to global lordosis, with TLIF patients having greater global lordosis compared to PLF (54.76° *vs.* 47.44°, P=0.049). There was no decrease in global lordosis for the TLIF patients after surgery, while the PLF group was more variable, with some patients showing a loss of 5 degrees while others a gain of 2 degrees in lordosis at various follow up intervals (*Figure 5*). Pre-operatively there was no difference in segmental lordosis between TLIF and the PLF alone groups (20.04° *vs.* 17.65°, P=0.224). At every additional follow-up interval there was a significantly greater segmental lordosis observed in the TLIF group compared to the PLF group (*Figure 6*).

### *Spinal alignment*

PI and pelvic tilt were measured pre-operatively, and at each follow-up visit. There was no difference in PI between TLIF and PLF groups pre-operatively or at any time point after surgery. Pelvic tilt was consistently less in the TLIF group compared to the PLF alone group across all follow up intervals. At 24 months there was >5 degrees difference between groups with an average pelvic tilt (PT) of 25.9° and 20.1° for TLIF *vs.* PLF respectively. There was no observed preoperative difference in PI-LL mismatch, but greater

**Table 1** Demographics, comorbidities, indications, and operative details for patients at enrollment

| Patient characteristics | PLF | | TLIF | | P value |
|---|---|---|---|---|---|
| | N | Mean ± SD or % | N | Mean ± SD or % | |
| Demographics | | | | | |
| Age (years) | 17 | 62.4±10.1 | 56 | 54.8±12 | 0.02 |
| Female (%) | 5 | 29.40 | 26 | 46.40 | 0.22 |
| Average body mass index (kg/m$^2$) | 17 | 32.4±4 | 56 | 31.1±5.1 | 0.34 |
| Comorbidities (%) | | | | | |
| Tobacco use | 5 | 29.40 | 17 | 30.40 | 0.94 |
| Diabetes mellitus | 5 | 29.40 | 11 | 19.60 | 0.40 |
| Osteoporosis | 1 | 5.90 | 1 | 1.80 | 0.37 |
| Osteopenia | 0 | 0.00 | 3 | 5.40 | 0.33 |
| Hypertension | 13 | 76.50 | 33 | 58.90 | 0.19 |
| Other comorbidities | 4 | 23.50 | 18 | 32.10 | 0.50 |
| Prior lumbar interventions | 1 | 5.90 | 19 | 33.90 | 0.02 |
| Pre-operative radiographic parameters | | | | | |
| Segmental lordosis (°) | 23 | 17.65±10.05 | 71 | 20.04±7.44 | 0.22 |
| Global lordosis (°) | 16 | 47.44±10.63 | 55 | 54.76±13.41 | 0.049 |
| Pelvic incidence (°) | 15 | 53.53±9.17 | 52 | 52.65±12.01 | 0.79 |
| PI-LL mismatch | 15 | 10.27±7.2 | 52 | 7.96±6.1 | 0.22 |
| Pelvic tilt (°) | 15 | 23.73±7.77 | 51 | 18.76±6.94 | 0.02 |
| Disc height (mm) | 24 | 6.67±4.58 | 71 | 7.73±3.04 | 0.2 |
| Foraminal height (mm) | 24 | 14.58±5.09 | 71 | 13.45±5.44 | 0.37 |
| Operative details (%) | | | | | |
| 1-level fusion | 10 | 41.70 | 40 | 55.60 | 0.24 |
| 2-level fusion | 14 | 58.30 | 32 | 44.40 | 0.24 |
| L1/L2 fusion level | 1 | 4.20 | 0 | 0.00 | 0.08 |
| L2/L3 fusion level | 1 | 4.20 | 1 | 1.40 | 0.41 |
| L3/L4 fusion level | 5 | 20.80 | 8 | 11.10 | 0.23 |
| L4/L5 fusion level | 12 | 50.00 | 33 | 45.80 | 0.72 |
| L5/S1 fusion level | 5 | 20.80 | 30 | 41.70 | 0.07 |

PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion; PI, pelvic incidence; LL, lumbar lordosis.

mismatch rates in the PLF group at both early and late follow up timepoints (*Figure 7*).

### *Complications*

Perioperative complications were compared between groups at outlined in *Figure 4*. Dural tears were the most common complication in this series, with 10 patients in the TLIF group, and 2 in the PLF group (TLIF 12.2%, PLF 11.8%, P=0.96). Other complications similarly did not differ between groups. Five of the 82 TLIF patients required hardware revision; none among the PLF group.

**Table 2** Early radiographic results for patients with long term follow-up

| Patient characteristics | PLF | | TLIF | | P value |
|---|---|---|---|---|---|
| | N | Mean ± SD or % | N | Mean ± SD or % | |
| 2-week follow up | | | | | |
| Average follow up (weeks) | 24 | 1.92±0.44 | 72 | 2.02±0.43 | 0.338 |
| Segmental lordosis (°) | 24 | 15.96±9.27 | 72 | 22.85±5.39 | 0 |
| Global lordosis (°) | 17 | 42.47±12.08 | 56 | 54.86±10.98 | 0 |
| Pelvic incidence (°) | 12 | 56.00±8.26 | 46 | 53.24±10.73 | 0.412 |
| PI-LL mismatch | 12 | 14.50±16.18 | 45 | 7.49±5.67 | 0.018 |
| Pelvic tilt (°) | 12 | 27.83±7.17 | 46 | 21.02±6.62 | 0.028 |
| Disc height (mm) | 24 | 7.79±4.79 | 72 | 12.42±2.24 | 0 |
| Δ in disc height from pre-op (mm) | 24 | 1.13±2.19 | 71 | 4.66±2.74 | 0 |
| Foraminal height (mm) | 24 | 14.58±4.67 | 72 | 16.47±3.70 | 0.046 |
| Δ in foraminal height (mm) | 24 | 0±2.99 | 71 | 3.00±4.01 | 0.001 |
| 3-month follow up | | | | | |
| Average follow up (weeks) | 24 | 12.48±1.61 | 65 | 12.18±1.33 | 0.389 |
| Segmental lordosis (°) | 24 | 18.29±9.32 | 65 | 22.75±4.87 | 0.004 |
| Global lordosis (°) | 17 | 47.53±11.07 | 51 | 56.69±10.51 | 0.003 |
| Pelvic incidence (°) | 16 | 53.94±9.31 | 36 | 51.14±11.24 | 0.388 |
| PI-LL mismatch | 16 | 11.13±11.26 | 36 | 7.25±4.16 | 0.074 |
| Pelvic tilt (°) | 16 | 24.56±6.47 | 36 | 19.83±5.88 | 0.012 |
| Disc height (mm) | 24 | 7.92±4.79 | 65 | 12.32±2.40 | 0 |
| Δ in disc height from pre-op (mm) | 24 | 1.25±2.07 | 64 | 4.52±3.01 | 0 |
| Foraminal height (mm) | 24 | 13.92±4.33 | 65 | 16.37±3.90 | 0.012 |
| Δ in foraminal height (mm) | 24 | –0.67±3.50 | 64 | 3.05±3.63 | 0 |
| Δ cobb angle (°) | 18 | 2.22±1.96 | 58 | 2.17±2.15 | 0.930 |
| Intertransverse fusion grade [1–5] | 24 | 4.46±0.88 | 64 | 4.38±1.03 | 0.737 |
| Osseous integration (1= yes; 2= no) | NA | NA | 65 | 1.62±0.49 | NA |
| Fusion (%) | 24 | 8.30 | 64 | 38.50 | 0.006 |

Δ, change in. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion; PI, pelvic incidence; LL, lumbar lordosis.

Two revision operations were done because of vertebral body endplate fracture and implant subsidence, one revision operation for persistent radiculopathy at the operated level, one revision operation for a broken S1 screw and one revision for pseudoarthrosis at 8 months which progressed to fusion at the 24-month follow up visit. One hematoma in the PLF group resolved after similar treatment.

## Discussion

The aim of this retrospective study was to compare fusion rates, relevant radiographic variables, and complication rates for patients undergoing PLF versus TLIF; the latter patients had a $Si_3N_4$ cage implanted for the intervertebral component of the surgery. Most studies comparing PLF to TLIF leave the choice of fusion technique to surgeon

**Table 3** Late radiographic results for patients with long term follow-up

| Patient characteristics | PLF | | TLIF | | P value |
|---|---|---|---|---|---|
| | N | Mean ± SD or % | N | Mean ± SD or % | |
| 6-month follow up | | | | | |
| Average follow up (weeks) | 20 | 24.99±2.81 | 61 | 25.19±1.98 | 0.731 |
| Segmental lordosis (°) | 20 | 16.10±10.24 | 58 | 21.98±5.43 | 0.002 |
| Global lordosis (°) | 14 | 46.29±11.39 | 45 | 56.71±11.00 | 0.003 |
| Pelvic incidence (°) | 12 | 55.25±8.50 | 40 | 51.58±10.02 | 0.256 |
| PI-LL mismatch | 12 | 10.25±11.27 | 40 | 7.80±4.98 | 0.284 |
| Pelvic tilt (°) | 12 | 23.83±7.80 | 40 | 19.38±6.31 | 0.048 |
| Disc height (mm) | 20 | 7.35±4.50 | 61 | 12.11±2.30 | 0 |
| Δ in disc height from pre-op (mm) | 20 | 0.80±2.33 | 60 | 4.37±3.05 | 0 |
| Foraminal height (mm) | 20 | 14.55±3.97 | 61 | 16.23±4.06 | 0.110 |
| Δ in foraminal height (mm) | 20 | −0.05±3.75 | 60 | 2.53±4.30 | 0.019 |
| Δ cobb angle (°) | 18 | 3.33±2.20 | 58 | 2.26±1.88 | 0.046 |
| Intertransverse fusion grade [1–5] | 20 | 2.95±1.36 | 61 | 2.92±1.36 | 0.932 |
| Osseous integration (1= yes; 2= no) | NA | NA | 61 | 1.21±0.41 | NA |
| Fusion (%) | 20 | 35.00 | 61 | 78.70 | 0 |
| 12-month follow up | | | | | |
| Average follow up (weeks) | 16 | 55.54±9.73 | 48 | 56.57±11.43 | 0.758 |
| Segmental lordosis (°) | 15 | 15.47±10.13 | 48 | 21.10±6.00 | 0.010 |
| Global lordosis (°) | 11 | 48.55±13.42 | 38 | 59.18±10.46 | 0.008 |
| Pelvic incidence (°) | 11 | 54.55±6.71 | 31 | 52.94±11.25 | 0.659 |
| PI-LL mismatch | 10 | 12.90±13.92 | 31 | 9.29±4.88 | 0.219 |
| Pelvic tilt (°) | 11 | 23.45±8.17 | 31 | 18.84±5.71 | 0.047 |
| Disc height (mm) | 16 | 6.75±4.88 | 48 | 11.75±2.28 | 0 |
| Δ in disc height from pre-op (mm) | 16 | 1.25±1.88 | 47 | 4.09±3.11 | 0.001 |
| Foraminal height (mm) | 16 | 13.88±4.47 | 48 | 15.71±3.45 | 0.094 |
| Δ in foraminal height (mm) | 16 | −0.63±1.96 | 47 | 1.87±4.08 | 0.022 |
| Δ cobb angle (°) | 13 | 2.85±2.27 | 48 | 1.69±1.49 | 0.031 |
| Intertransverse fusion grade [1–5] | 16 | 1.81±1.11 | 48 | 1.56±0.85 | 0.350 |
| Osseous integration (1= yes; 2= no) | NA | NA | 48 | 1.02±0.14 | NA |
| Fusion (%) | 16 | 81.30 | 48 | 97.90 | 0.018 |
| 24-month follow up | | | | | |
| Average follow up (weeks) | 18 | 182.37±172.61 | 48 | 136.66±34.55 | 0.083 |
| Segmental lordosis (°) | 18 | 16.94±8.30 | 48 | 21.85±5.82 | 0.009 |
| Global lordosis (°) | 12 | 43.42±12.12 | 35 | 57.86±8.93 | 0 |
| Pelvic incidence (°) | 11 | 55.18±10.97 | 33 | 53.61±7.92 | 0.609 |

**Table 3** (*continued*)

**Table 3** (*continued*)

| Patient characteristics | PLF | | TLIF | | P value |
|---|---|---|---|---|---|
| | N | Mean ± SD or % | N | Mean ± SD or % | |
| PI-LL mismatch | 11 | 13.45±13.49 | 33 | 8.64±5.11 | 0.090 |
| Pelvic tilt (°) | 11 | 25.91±11.07 | 33 | 20.12±6.05 | 0.033 |
| Disc height (mm) | 18 | 7.78±5.68 | 48 | 12.31±1.89 | 0 |
| Δ in disc height from pre-op (mm) | 18 | 1.50±3.65 | 48 | 4.38±2.74 | 0.001 |
| Foraminal height (mm) | 18 | 14.33±4.37 | 48 | 15.85±3.07 | 0.117 |
| Δ in foraminal height (mm) | 18 | 0.44±4.73 | 48 | 1.35±3.82 | 0.423 |
| Δ cobb angle (°) | 16 | 2.44±2.61 | 42 | 1.38±1.36 | 0.048 |
| Intertransverse fusion grade [1–5] | 18 | 1.33±0.77 | 48 | 1.31±0.75 | 0.924 |
| Osseous integration (1= yes; 2= no) | NA | NA | 48 | 1.00±0 | NA |
| Fusion (%) | 18 | 94.40 | 48 | 100.00 | 0.102 |

Δ, change in. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion; PI, pelvic incidence; LL, lumbar lordosis.

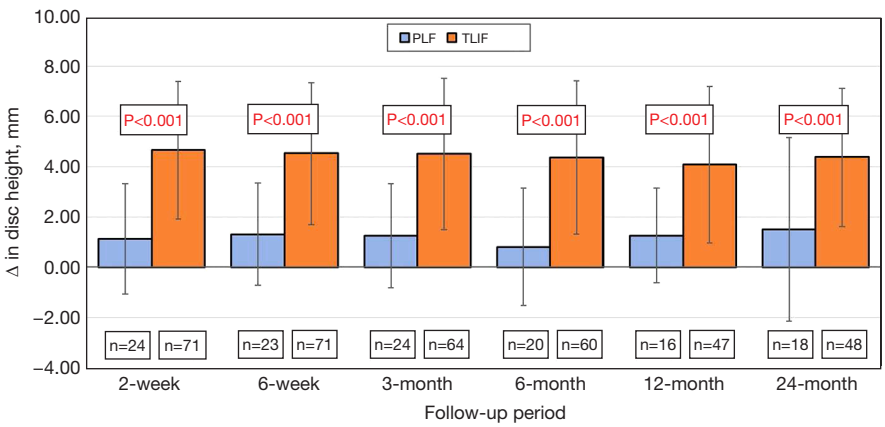


**Figure 2** Change in disc height from pre-op to follow-up intervals in the TLIF and PLF cohorts. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion.

discretion and judgment; as such, there is limited evidence to support one operation over another (20,21). Høy *et al.* randomized patients to TLIF with a tantalum cage *vs.* PLF with a follow-up interval of 2 years and found no difference in SF-36 or DPQ pain scores, length of stay or complication rate (7). A recent non-inferiority randomized controlled-trial by Kersten *et al.* compared TLIF with a $Si_3N_4$ cage to utilization of a PEEK cage. They reported no difference in RMDQ, SF-36 or ODI scores, complication rates as well as no differences in radiographic fusion between groups (22).

Similar to other studies, we relied on plain radiographs of operative levels, in combination with clinical findings to assess lumbar fusion (23). When compared to other imaging modalities such as fine-cut computed tomography, plain X-rays are advantageous in terms of lower cost, ease of use, lower radiation exposure, and the documented accuracy and reproducibility of plain radiographs in this regard (24-27).

Our data showed earlier radiographic fusion at 3, 6 and 12 months of TLIF over PLF, this advantage persisted even at 24 months even though the difference was not statistically significant (100% TLIF, 94.4% PLF). Studies have shown the influence of modifiable and non-modifiable risk factors related to bone quality and healing (diabetes, smoking, obesity, osteoporosis, female sex, age) as well as bone graft

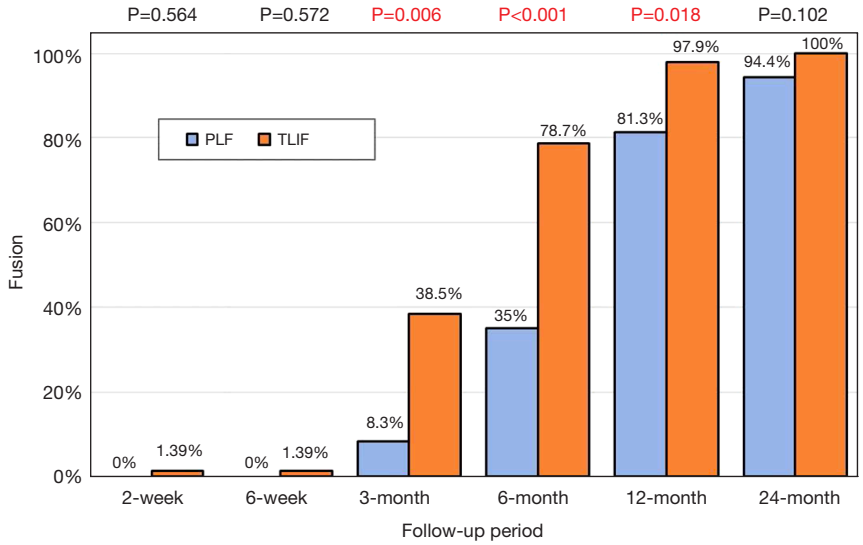


**Figure 3** Composite fusion results for TLIF and PLF groups for patients with long-term follow-up. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion.

utilization in affecting fusion and reoperation rates (28-32); these factors were comparable between study groups, except for greater patient age in the PLF group. There is a well understood age related decline in bone mineral density, and despite age differences between our groups there was no appreciable difference in osteopenia/osteoporosis rates.

With the axial support of a structural interbody cage in TLIF, it is not surprising that we found greater disc height restoration (4 mm average) maintained through the 2-year follow-up point in the TLIF group versus the PLF group. Foraminal height was significantly greater in the TLIF group, but this difference resolved itself at 6, 12, or 24 months between study groups. Tallarico *et al.* compared mechanical loading of normal harvested cadaveric spine specimens to specimens following a TLIF procedure. This biomechanical study demonstrated that TLIF specimens had a 1.5–2 mm gain in neuroforaminal height, with elimination of foraminal stenosis on flexion and extension compared to non-surgical spine specimens. Additionally, they noted that the greatest decompression was achieved with posterior positioning of the interbody cage compared to anterior cage placement (33). While the present study did not measure radicular leg pain, foraminal height is an accepted surrogate for nerve root decompression and corresponding pain relief (34). Likewise, disc height is correlated with the restoration of lumbar lordosis and overall sagittal balance (35).

In the present study, the TLIF patients had greater construct rigidity with an average of 1° less segmental motion on flexion-extension radiographs at each follow-up interval (*Figure 4*). Previous reports have used Cobb angle measurements on flexion-extension radiographs, stating that a difference of <2° to suggest fusion (36-38), with >4° difference associated with pseudoarthrosis (39,40). Our TLIF group showed <2° of segmental motion at both 12 and 24 months, indicating spinal stability and successful fusion.

Sagittal balance is a key factor in understanding the development of degenerative spinal pathology, and improvement in this variable may reduce the risk of adjacent segment disease after spinal fusion (41). In the present study, segmental and global lordosis values were improved at all follow-up time periods for the TLIF group while the PLF group had more variable segmental and global lordosis. Additionally, the TLIF group demonstrated lower pelvic tilt measurements compared to PLF patients. Increased pelvic tilt has been identified as an independent risk factor for post-operative pain following lumbosacral fusion (42-44). Lazennec *et al.* followed lumbosacral fusion patients (mean follow-up 2.8 years) and identified patients without post fusion pain had a PT of 13.9° compared to those with pain had a PT of 26.2° (42). As outlined in *Table 3*, our results demonstrated at 24-month the PT of the two groups differed by >5 degrees, with an average PT of 25.91 in the PLF group and 20.12 in the TLIF group (P=0.033).

Instrumented surgical fusion for degenerative spinal pathology is not without risk. Previous reports of TLIF

| Description | N | PLF | N | TLIF | P value |
|---|---|---|---|---|---|
| Post-operative infection | 0 | 0.0% | 1 | 1.2% | 0.65 |
| Iliac crest pain | 0 | 0.0% | 2 | 3.0% | 0.47 |
| Revision surgery | 0 | 0.0% | 5 | 6.1% | 0.42 |
| Incidental durotomy | 2 | 11.8% | 10 | 12.2% | 0.96 |
| Oher complications | 1 | 5.9% | 11 | 13.4% | 0.39 |
| **Other complication details** | | | | | |
| PLF | Lumbar hematoma requiring L4 and L5 laminectomy | | | | |
| TLIF | Fracture of L5 endplate with cage migration | | | | |
| | Dural tear requiring additional laminectomy | | | | |
| | Adjacent level TLIF for new facet cyst | | | | |
| | Endplate fracture at L5 | | | | |
| | Delayed superficial infection at 96 weeks | | | | |
| | Broken S1 screw | | | | |
| | Asymmetric disc collapse | | | | |
| | Residual radiculopathy requiring L4/5 decompression | | | | |
| | Post-operative hematoma | | | | |
| | L3/L4 pseudoarthrosis | | | | |
| | Incidental durotomy requiring irrigation and debridement | | | | |
| **Flexion/extension Δ cobb angle results** | | | | | |
| **Follow up period** | **N** | **PLF** | **N** | **TLIF** | **P value** |
| 3 months | 18 | 2.22±1.96 | 58 | 2.17±2.15 | 0.93 |
| 6 months | 18 | 3.33±2.20 | 58 | 2.26±1.88 | 0.046 |
| 12 months | 13 | 2.85±2.27 | 48 | 1.69±1.49 | 0.03 |
| 24 months | 16 | 2.44±2.61 | 42 | 1.38±1.36 | 0.046 |

**Figure 4** Peri-operative complications and Δ cobb angle results. Δ, change in. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion.

and PLF surgery have shown that complications such as nerve injury, dural tears, implant or bone graft migration, infection, implant subsidence and failure of fusion can manifest (45). A metanalysis of 990 patients undergoing TLIF or PLF reported a >50% overall lower complication rate following TLIF compared to PLF (46). In our study population, five of 82 TLIF patients required revision surgery after the index procedure, and two experienced implant subsidence. No patients in the PLF group required further hardware revision. While silicon nitride is stiffer than both titanium and PEEK, the material modulus is unrelated to the risk of implant subsidence (47). No clinical studies have demonstrated higher rates of subsidence as well. $Si_3N_4$ cages offer specific benefits in terms of ease of radiographic imaging, as well as accelerated bone healing and resistance to bacterial infection (48). These advantages have been validated in a number of *in vitro* as well as large scale clinical studies (49,50).

Given the small patient population outlined in our study, multicenter registries and metanalyses may offer more accurate insights into complication rates given their larger sample populations. A recent metanalysis by Levin *et al.* concluded there was no difference between TLIF and PLF patients for post-operative infection rate (3.3%

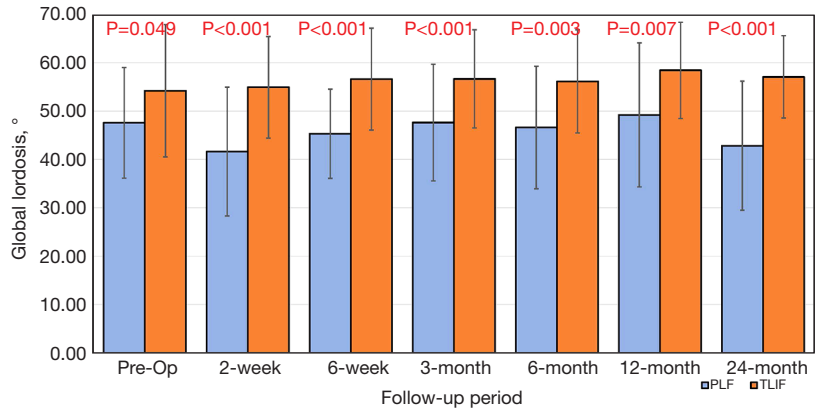


**Figure 5** Global lordosis outcomes for patients with long term follow-up. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion.

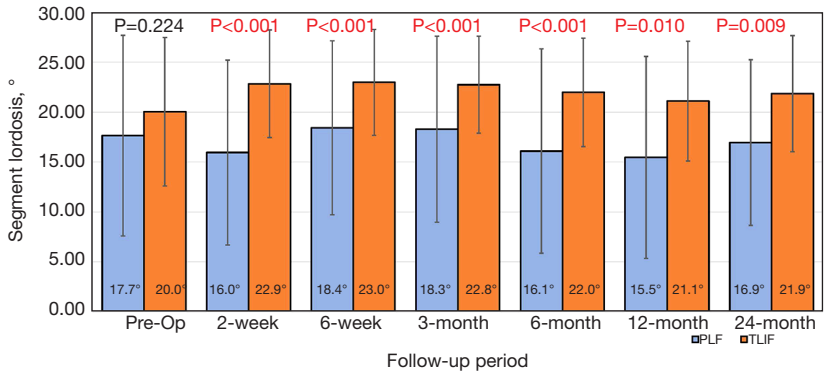


**Figure 6** Operative level segmental lordosis outcomes for patients with long term follow-up. PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion.

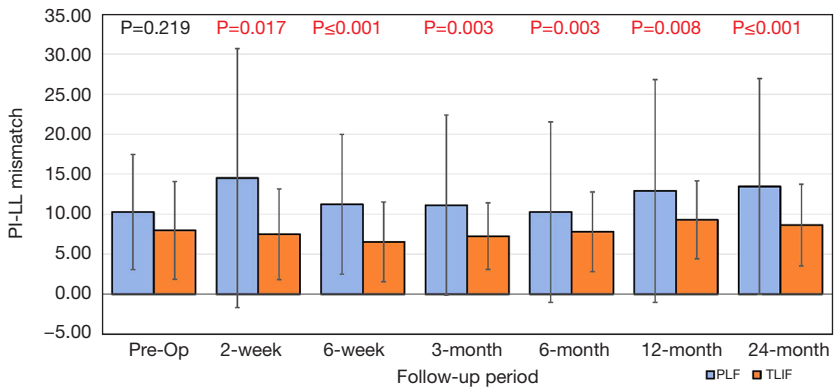


**Figure 7** PI-LL mismatch comparison for patients with long term follow-up. PI, pelvic incidence; LL, lumbar lordosis; PLF, posterolateral fusion; TLIF, transforaminal lumbar interbody fusion.

*vs.* 3.4%, P=0.90) or other complications such as length of stay, readmission rate or rate of durotomy (51). Zhang *et al.* completed a similar metanalysis for degenerative lumbar spondylosis and found no increase in reoperation rate for TLIF *vs.* PLF [relative risk (RR) =0.83, P=0.809] or increase in overall complication rate (RR =1.72, P=0.166) (10).

Our results were limited both by sample size and inconsistent patient follow-up intervals. In addition to limited patient numbers and attendant reduction in statistical power, the non-randomized retrospective nature of this study is another a limitation of the present report. Baseline foraminal heights also differed pre-operatively between the two groups, thereby limiting out ability to conclude that foraminal height restoration was directly related to the TLIF procedure itself. Although Cobb angle measurements are a validated metric (52), radiographic evaluations were completed by one surgeon, and not someone blinded to the study. No patient-reported outcomes or pain scales were collected; although these outcomes are extensively discussed in the literature (53). Finally we were not able to control for the bone graft utilization between cohorts, but it remained relatively consistent for the surgeon throughout the study interval.

## Conclusions

Our data suggest superiority of TLIF over PLF, in terms of radiographically-adjudicated fusion rates, disc and foraminal height restoration and increased segmental rigidity, without an increase in complication rates. All TLIF patients had successful radiographic fusion at 24 months, with the PLF patients achieving almost the same success. While not proven in this study, the enhanced osteogenic properties of $Si_3N_4$ interbody cases may have contributed to the observed differences between TLIF over PLF. Further studies are warranted to explore this hypothesis.

## Acknowledgments

The authors thank Lauren Jagger for her assistance in early data collection. The authors would like to thank Michael Hanna, PhD, for his assistance in reviewing the results.
*Funding:* This study was funded by the Student Research Fellowship Program of the Indiana University School of Medicine in Fort Wayne, Indiana. This work was additionally supported in part by Parkview Research Center and the Mirro Center for Research and Innovation in Fort Wayne, Indiana.

## Footnote

*Reporting Checklist:* The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-21-115/rc

*Data Sharing Statement:* Available at https://jss.amegroups.com/article/view/10.21037/jss-21-115/dss

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-21-115/coif). BSB serves as an unpaid editorial board member of from *Journal of Spine Surgery* from March 2020 to February 2022, and is an employee and stockholder of STINX Corporation (formerly Amedica Corporation) which manufactured the silicon nitride devices used in this study. MWS was a consulting surgeon of Amedica Corporation. BM was an employee and stockholder, now retired on Dec. 31, 2021, but retained as a consultant at STINX Corporation. The other authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Parkview Institutional Review Board (No. PRC17-1009 TLIF) on January 31st, 2018 and there was no written consent required for patients due to the retrospective nature of the study.



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**Cite this article as:** Gray MT, Davis KP, McEntire BJ, Bal BS, Smith MW. Transforaminal lumbar interbody fusion with a silicon nitride cage demonstrates early radiographic fusion. J Spine Surg 2022;8(1):29-43. doi: 10.21037/jss-21-115