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Clinical Studies

Instrumentation choice and early radiographic outcome following lateral lumbar interbody fusion (LLIF): Lateral instrumentation versus posterior pedicle screw fixation

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ABSTRACT

Background: Lateral lumbar interbody fusion (LLIF) is a minimally invasive fusion procedure that may be performed with or without supplemental instrumentation. However, there is a paucity of evidence on the effect of supplemental instrumentation technique on perioperative morbidity and fusion rate in LLIF.

Methods: A single-institutional retrospective review of patients who underwent LLIF for lumbar spondylosis was conducted. Patients were grouped according to supplemental instrumentation technique: stand-alone LLIF, LLIF with laterally placed instrumentation, or LLIF with posterior percutaneous pedicle screw fixation (PPSF). Outcomes included fusion rates, peri-operative complication, and reoperation; estimated blood loss (EBL); surgery duration; length of stay; and length of follow-up.

Results: 82 patients underwent LLIF at 114 levels. 35 patients (42.7%) received supplemental lateral instrumentation, 30 (36.6%) received supplemental PPSF, and 17 (20.7%) underwent stand-alone LLIF. More patients in the lateral instrumentation group had prior lumbar fusion at adjacent levels (23/35, 65.71%) versus stand-alone (3/17, 17.6%) or PPSF (2/30, 6.67%) groups ($p = 0.003$). 4/17 patients (23.5%) with stand-alone LLIF and 4/35 patients (11.42%) with lateral instrumentation underwent reoperation, versus 0/30 with PPSF ($p = 0.030$). There was no difference in fusion rates between groups ($p = 0.717$). Operation duration was longer in patients with PPSF ($p < 0.005$) and length of follow-up was longer for PPSF than lateral instrumentation ($p = 0.001$). Choice of instrumentation group was a statistically significant predictor of reoperation.

Conclusions: While rates of complete radiographic fusion on imaging follow-up didn't differ, patients receiving PPSF were less likely than stand-alone or lateral instrumentation groups to require reoperation, though operative time was significantly longer. Further study of choice of supplemental instrumentation with LLIF is indicated.

Introduction

Lateral lumbar interbody fusion (LLIF) is an increasingly popular minimally invasive approach to lumbar fusion in appropriately selected patients with symptomatic lumbar spondylosis [1]. Several studies have described the advantages of LLIF compared to posterior lumbar fusion procedures for these patients, including shorter operative time, decreased blood loss, decreased post-operative pain, reduced risk of direct neural injury, and shorter hospital stay [2–5]. As LLIF is a transpsoas retroperitoneal approach, postoperative plexopathy is an adverse outcome of concern reported at higher frequency in XLIF than in posterior approaches, which may be attenuated mainly through intraoperative neuromonitoring and minimizing psoas muscle retraction time.

LLIF is often supplemented with either lateral instrumentation applied through the same transpsoas approach or posterior percutaneous pedicle screw fixation (PPSF) placed through a separate posterior ap-

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proach. Supplemental instrumentation of either type is typically utilized with the intention of decreasing risk of graft subsidence, pseudarthrosis, and reoperation, [6] though it has been suggested that isolated lateral instrumentation may not provide as much rigidity as posterior fixation [7]. However, there are not clear symptomatic or pathoanatomical indications for the choice of supplementation in LLIF. Overall, data directly comparing techniques for supplemental instrumentation in LLIF are limited. In the present study, we hypothesized that lateral instrumentation may offer an advantage over PPSF in terms of shorter surgical time, operative blood loss, operative time, and length of stay, with a similar rate of arthrodesis, peri-operative morbidity, and reoperation. Secondarily, we hypothesized that use of supplemental posterior or lateral instrumentation with LLIF reduces the need for reoperation relative to stand-alone LLIF.

To our knowledge, there has been no clinical study directly comparing short-term outcomes between groups of patients who underwent stand-alone LLIF, LLIF with PPSF, and LLIF with lateral instrumentation. In this study we sought to analyze Brantigan-Steffee-Fraser (BSF) score (a radiographic marker of bony fusion), peri-operative complications, and reoperation rates between patients in these three categories. Patient demographics, presenting symptoms, prior spine surgery history, intraoperative blood loss, surgery duration, length of stay, and length of follow up were secondarily compared between groups.

Methods

A retrospective review of the electronic medical record (EMR) was performed to identify patients with lumbar spondylosis who underwent LLIF at a single institution. Four experienced spinal neurosurgeons (JF, AO, AT, PS) performed all LLIF procedures that were included in this study. Patients met inclusion criteria if they underwent single- or multi-level LLIF either without any supplemental instrumentation, with use of instrumentation secured through the same lateral transpsoas approach (such as plating or tabbed implants), or with PPSF. The choice of supplementation technique in each case was decided by the surgeon.

All procedures were carried out between May 2015 and December 2019. Patients were excluded if they had additional concurrent direct decompression surgery at the index level or at adjacent levels. 82 of 150 (55%) LLIF cases performed during the study period met inclusion criteria. Data extraction from the EMR included preoperative, surgical, postoperative, and radiographic data from all patients who met eligibly criteria. Specifically, demographic data (age, gender, BMI), presenting symptoms (back pain, leg pain, leg weakness, bowel or bladder incontinence, radiculopathy, neurogenic claudication, and myelopathy), prior lumbar fusion, operative time, estimated blood loss (EBL), length of follow up, peri-operative complications, and reoperation rates were abstracted into a study-specific database.

Post-operative complications considered included wound complications (seroma, hematoma, infection, dehiscence), pelvic plexus injury, CSF leak, ileus, graft subsidence, graft extrusion, other injuries to neural elements, any construct failure, or other complications reported by the surgeon. Intra-operative complications considered included visceral, vascular, or ureteral injury, difficulty docking retractors, canal violation during pedicle screw placement, loss of motor evoked potential (MEP) or somatosensory evoked potential (SSEP) recordings intraoperatively, or any other complications reported by the surgeon.

A previously validated modified version of the Brantigan, Steffee, and Fraser (BSF) fusion score was used as a validated metric to grade completeness of fusion on follow-up imaging [8,9]. Lumbar computed tomography (CT) and/or lumbar X-rays from the patients' most recent follow up were evaluated for determination of BSF fusion scores for each patient (Fig. 1). Patients that did not have imaging available at least 6 months after the date of their LLIF procedure were not included in BSF analysis. Each LLIF level was evaluated independently.

Differences between the three study groups were calculated using one-way ANOVA for continuous variables (number of levels fused, operative time, EBL, length of stay), and using chi squared tests for all categorical variables (occurrence of complications, presence of presenting symptoms, history of prior fusion at an adjacent level, need for reoperation). Further, univariate logistic regression analysis was performed to determine the association between each of the tested variables and reoperation, followed by multiple logistic regression to determine which of these variables independently predicted this outcome. A p-value of less than 0.05 was considered to represent a statistically significant difference. Statistical analysis for calculations was performed using STATA/SE for Mac version 15.0 (*StataCorp, College Station, TX)*.

This retrospective study was approved by the local Institutional Review Board with exemption from informed consent (board reference #816619). All patient data obtained were de-identified upon export from the secure research database for analysis.

Results

Demographic Data

A total of 82 patients were included in this study, who underwent LLIF at an average of 1.40 (±0.68) levels. The mean age was 63.71 years (±0.10.98), including 41 females and 41 males. Thirty-five (42.7%) patients received supplemental lateral instrumentation, 30 (36.6%) received supplemental PPSF, and 17 (20.7%) had stand-alone LLIF. The average BMI was 31.63 (±0.6.16). There was no difference in bone disease (osteoporosis or osteopenia) between lateral instrumentation (14.29%), PPSF (6.67%) or stand-alone groups (11.76%) (p = 0.62). Average age was lower in the lateral instrumentation group (59.80±11.76) than the stand-alone (65.56±9.58) or PPSF (67.18± 9.58) groups (p = 0.018). The proportion of patients who had undergone prior fusion at an adjacent level prior to the index surgery was significantly greater in the lateral instrumentation group (23 patients, 66.7%) compared to the PPSF group (2 patients, 6.67%), and the stand-alone LLIF group (3 patients, 17.6%; p = 0.003). Only one patient in the lateral instrumentation group had undergone prior lumbar fusion at non-adjacent levels relative to the index procedure.

In terms of symptomatic presentation, patients in the PPSF group presented primarily with back pain (90.00%), neurogenic claudication (86.67%), and leg pain (76.67%). Patients in the lateral instrumentation group presented with radiculopathy (62.86%), back pain (54.29%), and leg pain (40.00%). Patients in the stand-alone group presented with back pain (76.47%), radiculopathy (74.71%), and neurogenic claudication (47.06%). Only one patient in the PPSF group presented with bowel or bladder incontinence. The characteristics of the patient population is further summarized in Table 1.

Among 114 total levels fused across 82 patients, there was one fusion at T12-L1, six at L1-2, 25 at L2-3, 43 at L3-4, and 39 at L4-5. A higher percentage of patients who had lower lumbar fusions (L3-4 or L4-5) received PPSF or stand-alone procedures, while a higher percentage of patients who had upper lumbar fusions (L1-2 or L2-3) received lateral instrumentation (Table 2).

Primary Outcomes

Four of 35 patients with lateral instrumentation (11.42%) required reoperation following surgery, compared to zero of 30 patients in the PPSF group (0%) and four of 17 patients in the stand-alone group (23.5%), representing a statistically significant difference in reoperation rate between groups (p = 0.030). The primary indication for three reoperations in the lateral instrumentation group was inadequate indirect decompression leading to continuation of baseline symptoms immediately following surgery (Fig. 2), and one was due to displacement of hardware. Of the four reoperations in the stand-alone group, two were

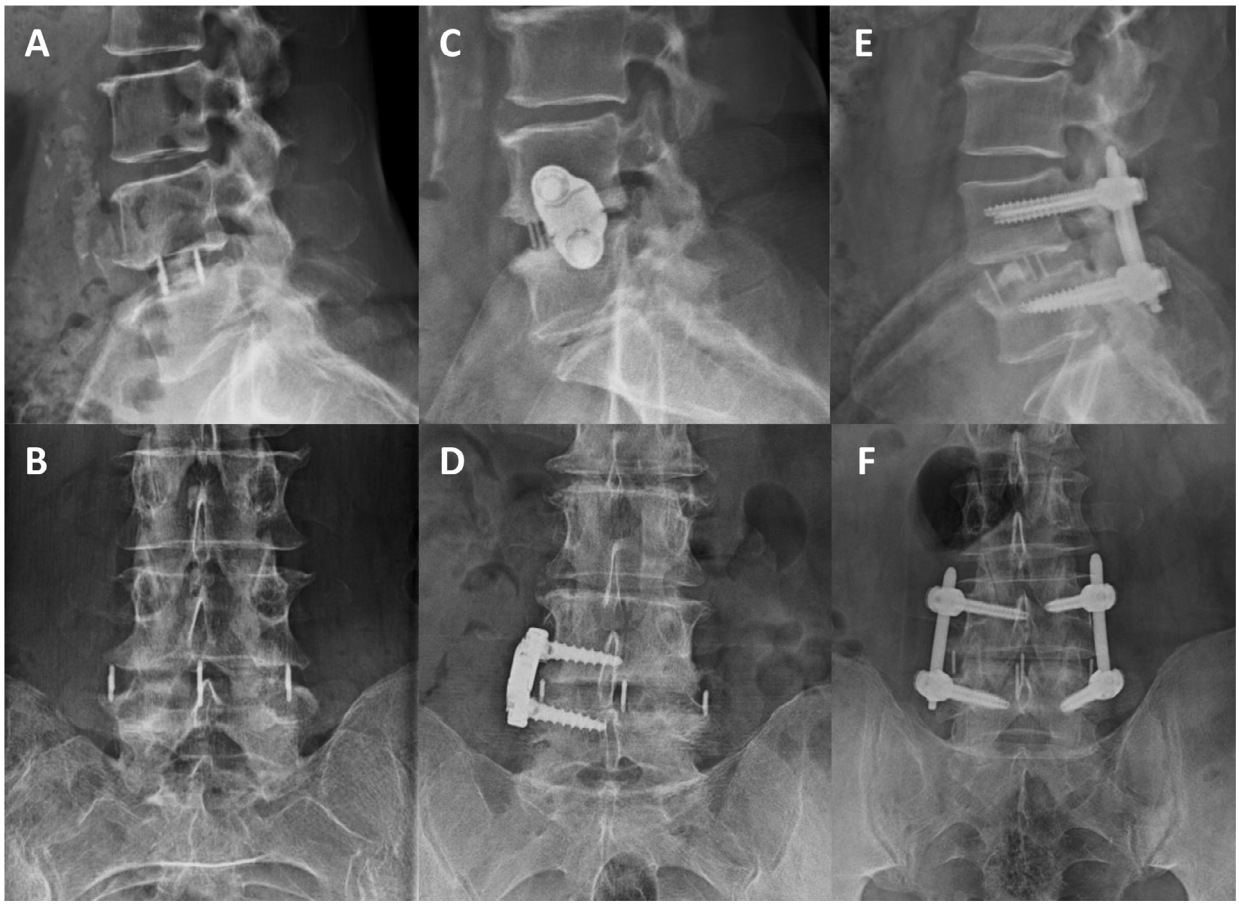

Fig. 1. Exemplary images of postoperative fusion results from patients who underwent single-level L4-5 LLIF in each of the three study groups: standalone LLIF (A, B); lateral supplemental instrumentation (C,D); and percutaneous pedicle screw fixation (E, F). In each example, lateral and anterior-posterior radiographs are provided.

Table 1
Patient Demographics.

Patient Characteristic	Stand-alone (N = 17)	Lateral Instrumentation (N = 35)	PPSF (N = 30)	
Age	65.56 (±9.58)	59.80 (±11.76)	67.18 (± 9.58)	p = **0.018**
BMI	30.87 (±6.94)	30.72 (±6.02)	33.10 (±5.78)	p = 0.256
Average number of levels fused	1.47 (±0.80)	1.14 (±0.43)	1.67 (±0.76)	p = **0.006**
Average number of presenting symptoms	1.88 (±1.21)	1.91 (±1.09)	3.37 (±0.94)	p = **0.002**
Bone Disease (osteopenia or osteoporosis)	2 (11.76%)	5 (14.29%)	2 (6.67%)	p = 0.615
Myelopathy	1 (5.88%)	0 (0.00%)	1 (3.33%)	p = 0.402
Neurogenic Claudication	8 (47.06%)	9 (25.71%)	26 (86.67%)	p < **0.005**
Radiculopathy	11 (64.71%)	22 (62.86%)	17 (56.57%)	p = 0.825
Bowel/Bladder Incontinence	0 (0.00%)	0 (0.00%)	1 (3.33%)	p = 0.416
Back Pain	13 (76.47%)	19 (54.29%)	27 (90.00%)	p = **0.005**
Leg Pain	6 (35.29%)	14 (40.00%)	23 (76.67%)	p = **0.004**
Leg Weakness	2 (11.76%)	2 (5.71%)	6 (20.00%)	p = 0.214
Number of Patients with Neurogenic Claudication Only	3 (17.60%)	2 (5.71%)	11 (36.7%)	p = **0.019**
Number of Patients with Radiculopathy Only	6 (35.30%)	15 (42.86%)	2 (6.70%)	p = **0.003**
Number of Patients with Both Neurogenic Claudication and Radiculopathy	5 (29.40%)	7 (20.00%)	15 (50.0%)	p = **0.035**
Number of Patients with Prior Fusion	3 (17.65%)	23 (65.71%)	2 (6.67%)	p = **0.003**

Abbreviations: LLIF = lateral lumbar interbody fusion; PPSF = percutaneous pedicle screw fixation.

Table 2
LLIF Instrumentation.

LLIF Fusion Level	Stand-alone (N = 17)	Lateral Instrumentation (N = 35)	PPSF (N = 30)	
# of T12-L1 LLIF	0 (0.00%)	1 (2.50%)	0 (0.00%)	p = 0.507
# of L1-L2 LLIF	1 (4.00%)	4 (10.00%)	1 (2.04%)	p = 0.444
# of L2-L3 LLIF	2 (8.00%)	14 (35.00%)	9 (18.37%)	p = 0.116
# of L3-L4 LLIF	9 (36.00%)	13 (32.50%)	21 (42.86%)	p = **0.030**
# of L4-L5 LLIF	13 (52.00%)	8 (20.00%)	18 (36.73%)	p < **0.005**

Abbreviations: LLIF = lateral lumbar interbody fusion; PPSF = percutaneous pedicle screw fixation.

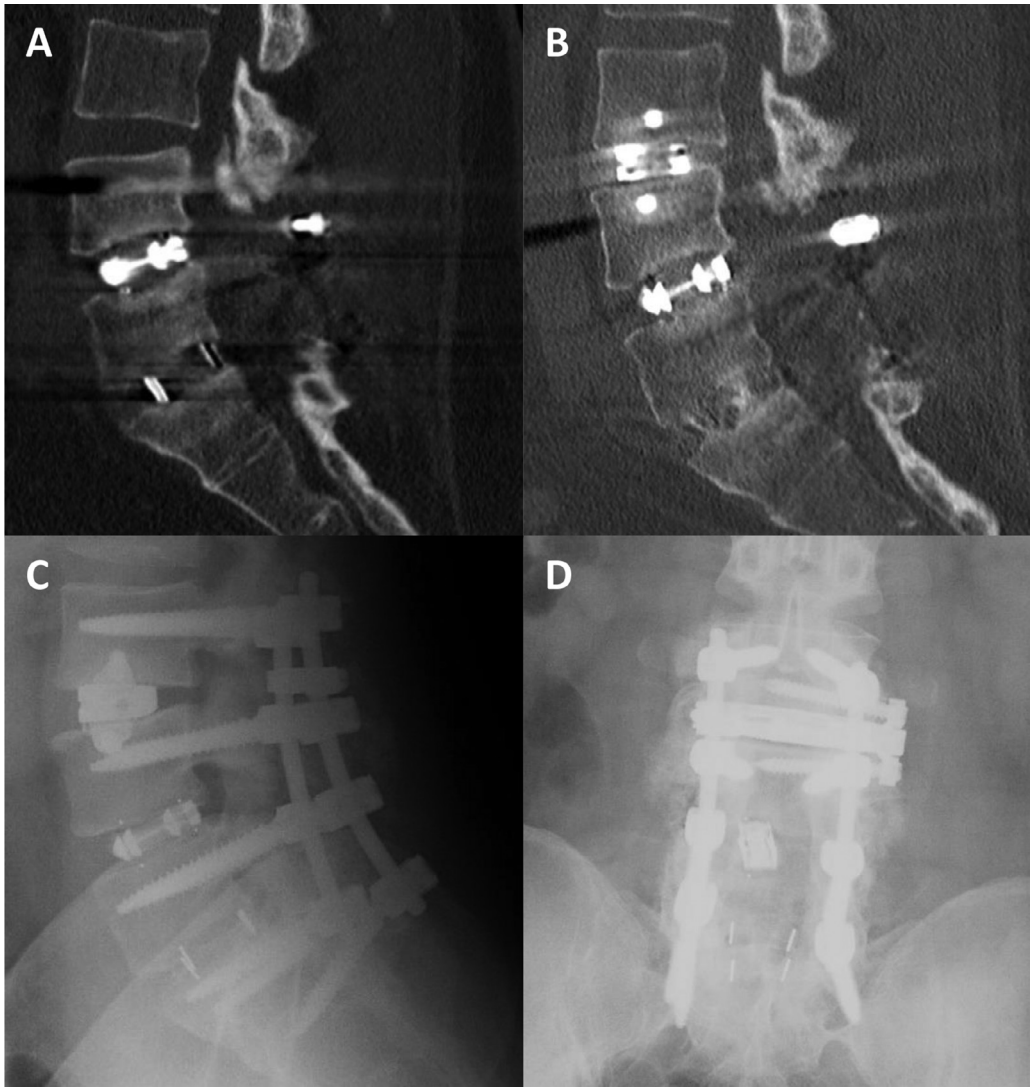

Fig. 2. A 45 y/o patient with a prior history of L4-S1 posterior decompression, fusion, and percutaneous pedicle screw fixation (PPSF) at the same levels presented with new, symptomatic adjacent level disease at L3-4 (A). The patient underwent L3-4 LLIF with supplemental lateral plating at the index procedure (B). Six months later, the patient returned to clinic with symptomatic residual stenosis at the index level, and ultimately underwent additional posterior decompression of the L3-4 level with superior extension of previously placed PPSF to L3 (C, D).

due to graft subsidence resulting in construct failure and persistent pain. The other two were due, respectively, to postoperative spinal instability as determined by evidence of motion on flexion-extension lumbar spine X-ray at the index level and persistent pain secondary to progressive spondylotic lumbar spinal stenosis diagnosed 21 months postoperatively via MRI.

Postoperative CT or X-Ray imaging of the lumbar spine more than six months following surgery were available for review from 29/30 (96.7%) patients in the PPSF group but only 9/17 (52.9%) in the stand-alone group and 26/35 (74.3%) in the lateral instrumentation group, with mean postoperative imaging follow-up durations of 17.6 (±8.0), 17.4 (±8.0), and 15.8 (±7.5) months in each group, respectively. Among these patients with sufficient imaging follow-up, 2/26 (7.7%) in the lateral instrumentation group, 3/29 (10.3%) in the PPSF group, and 2/9 (22.2%) in the stand-alone group had incomplete fusion (BSF grade 1 or 2) at last follow-up, which did not represent a statistically significant difference ($p = 0.717$, Table 3). All reoperation cases are summarized in Table 4.

Age, gender, BMI, prior fusion at an adjacent level, duration of surgery, number of levels fused, and symptomatic presentation including symptom overlap were assessed for statistical association with reoperation using univariate logistic regression. This analysis revealed that stand-alone LLIF was significantly associated with reoperation (correlation coefficient = 1.55 [0.04, 3.06], p=0.045). No other associations were found to be significant (Table 5). Given the demographic differences between instrumentation groups, the same variables were subsequently included in a multiple logistic regression model (Table 6). On this analysis, choice to not use instrumentation was no longer found to be a significant predictor of reoperation, there remained a trend towards greater re-operation when no instrumentation was utilized, though this finding did not reach statistical significance (correlation coefficient = 1.91 [-0.40, 4.23, $p = 0.106$).

Secondary Outcomes

Surgery duration and number of levels fused differed significantly between the three groups ($p < 0.005$; $p = 0.006$). There were more levels fused for the PPSF group (1.67±0.75 levels) and in the stand-alone groups (1.47±0.80 levels) than in the lateral instrumentation group (1.14 ± 0.43 levels), and this difference was statistically significant for both comparisons ($p = 0.0002$; $p = 0.049$). Operation duration was longer in patients who received PPSF (322.17 minutes) than

Table 3
LLIF Outcomes.

Outcome Variables	Stand-alone ($N = 17$)	Lateral Instrumentation ($N = 35$)	PPSF ($N = 30$)	
Estimated Blood Loss	85 (±117.67)	55.59 (±68.43)	66.33(± 48.33)	$p = 0.426$
Duration (minutes)	112.13 (±77.99)	106.02 (±38.09)	322.17 (± 82.04)	$\mathbf{p < 0.005}$
Intra-operative Complication Rate	0 (0.00%)	0 (0.00%)	3 (10.00%)	$p = 0.336$
Post-operative Complication Rate	2 (11.76%)	1 (2.85%)	3 (10.00%)	$p = 0.398$
Length of Stay (days)	2.76(±1.92)	2.80(±2.99)	3.27(±1.98)	$p = 0.697$
Length of Post-operative Follow Up (months)	11.25(±9.22)	6.06(±6.22)	15.04((±8.01)	$p = \mathbf{0.002}$
Required Reoperation	4 (23.52%)	4 (11.42%)	0 (0.00%)	$p = \mathbf{0.030}$
Patients with BSF < 3 on Follow Up Imaging ($n = 64$)	2 (22.22%)	2 (7.69%)	3 (10.34%)	$p = 0.717$
Length of Imaging Follow Up (months)	16.10 ± 8.69	14.86 ± 7.97	17.62 ± 7.95	$p = 0.813$

Abbreviations: LLIF = lateral lumbar interbody fusion; PPSF = percutaneous pedicle screw fixation. Intra-operative complications in the Stand-alone group included visceral injury (breach of peritoneum), screw canal violation, and other (decreased MEP in lower extremity). Post-operative complications in the Stand-alone group included graft subsidence and ileus; in lateral instrumentation group included graft subsidence; and in the PPSF group included wound dehiscence, ileus, and other (temporary discomfort). P-values were calculated with one way ANOVA test for continuous variables. P-values were calculated using X^2 for all other variables (categorical).

Table 4
Reoperation Cases.

Reoperation Cases						
Instrumentation Used	Index Levels Fused	Time Between Surgery and Reoperation (months)	Patient Age	Patient Sex	Reason for Revision	Type of Revision Surgery
Lateral Instrumentation	L3-L4	5	45	M	Symptomatic residual stenosis	PPSF + decompression
Lateral Instrumentation	L3-L4, L4-L5	6	56	M	Symptomatic residual stenosis	PPSF + decompression
Lateral Instrumentation	L4-L5	5	66	F	Symptomatic residual stenosis	Decompression
Lateral Instrumentation	L2-L3	0	59	M	Displacement of hardware	PPSF + decompression
Stand-alone	L4-L5	16	53	F	Lumbar instability	PPSF
Stand-alone	L3-L4, L4-L5	7	78	F	Subsidence of the interbody graft with resultant construct failure	PPSF + decompression
Stand-alone	L4-L5	20	55	F	Subsidence of the interbody graft with resultant construct failure	PPSF + decompression
Stand-alone	L3-L4, L4-L5	20	65	M	Symptomatic residual stenosis	PPSF + decompression

Abbreviations: LLIF = lateral lumbar interbody fusion; PPSF = percutaneous pedicle screw fixation.

Table 5
Univariate Regression of Patient-level Factors with Need for Reoperation.

Univariate Regression of Patient-level Factors with Need for Reoperation			
Independent Variable	Correlation Coefficient	Lower Bound	P Value
Age	-0.04	[-0.10, 0.03]	$p = 0.248$
Gender	0.00	[-1.46, 1.46]	$p = 1.000$
BMI	0.01	[-0.10, 0.13]	$p = 0.801$
Prior Fusion	0.015	[-1.50, 1.53]	$p = 0.984$
Surgery Duration	-0.01	[- 0.02, 0.00]	$p = 0.090$
Number of Levels Fused	-0.07	[-1.18, 1.104]	$p = 0.904$
Radiculopathy and Neurogenic Claudication	-1.10	[-3.48, 0.82]	$p = 0.224$
Neurogenic Claudication without Radiculopathy	-0.58	[-2.75, 1.59]	$p = 0.603$
Radiculopathy without Neurogenic Claudication	0.76	[-0.42, 2.54]	$p = 0.159$
Stand-alone	1.55	[0.04, 3.06]	$p = \mathbf{0.045}$
Lateral Instrumentation	0.75	[-1.13, 1.79]	$p = 0.661$
PPSF	—	—	—

Abbreviations: PPSF = percutaneous pedicle screw fixation. There were no reoperations in the PPSF group.

those who received lateral instrumentation or stand-alone (106.02 minutes; $p < 0.005$, 112.13 minutes; $p < 0.005$). Length of post-operative clinical follow-up was longer for the PPSF (15.04 ±8.01 months) than for the lateral instrumentation group (6.06 ±6.22 months, $p = 0.002$). EBL, post-operative complication rate, intraoperative complication rate, and length of stay did not differ significantly between the three groups (Table 3).

Patients who had a prior interbody fusion at a different level ($n = 29$) were more likely to receive lateral instrumentation than stand-alone LLIF or PPSF (RR = 2.25, $p = 0.031$; RR = 4.20, $p < 0.005$). Nearly

Table 6
Multivariate Regression of Patient-level Factors with Need for Reoperation.

Multivariate Regression				
Independent Variable	Correlation Coefficient	Lower Bound	Upper Bound	P Value
Age	-0.07	-0.19	0.04	*p = 0.227*
Gender	1.78	-0.52	4.08	*p = 0.130*
BMI	0.03	-0.12	0.17	*p = 0.667*
Prior Fusion	-0.30	-2.34	1.75	*p = 0.777*
Surgery Duration	-0.02	-0.05	0.01	*p = 0.154*
Number of Levels Fused	2.23	-0.55	5.00	*p = 0.116*
Radiculopathy and Neurogenic Claudication	-0.25	-3..84	3.35	*p = 0.8393*
Neurogenic Claudication without Radiculopathy	-0.47	-5.30	4.37	*p = 0.849*
Radiculopathy without Neurogenic Claudication	0.53	-2.13	3.20	*p = 0.694*
Stand-alone	1.91	-0.40	4.23	*p = 0.106*

Abbreviations: PPSF = percutaneous pedicle screw fixation. Multivariate analysis of LLIF requiring reoperation in stand-alone LLIF cases. Instrumentation groups were binarized in the multivariate model (no instrumentation versus any instrumentation) as there were no reoperation in the PPSF group.

all of these (28/29) were cases in which the level(s) of prior lumbar fusion was adjacent to the index fusion level(s).

Discussion

There are not currently any guidelines to aid in the decision between different instrumentation options for supplemental fixation during an LLIF procedure, particularly for multilevel LLIF cases that require a high level of spinal stabilization. While preliminary biomechanical studies have demonstrated posterior PPSF offers superior anterior-posterior stability versus lateral plates, no studies have yet tested this question in a clinical population over a wide range of patient demographics [10–15] Therefore, we hypothesized that the use of posterior or lateral instrumentation with LLIF would reduce the rate of re-operation and improve fusion rates relative to stand-alone LLIF. Furthermore, we hypothesized that lateral instrumentation may lead to shorter surgical time, operative blood loss, operative time, and length of stay. Our data suggest that the use of instrumentation, either lateral or PPSF, indeed improved re-operation rates relative to stand-alone LLIF. While there were no statistically significant differences in these outcomes between instrumentation groups, the use of PPSF was associated with lower rate of re-operation. While lateral instrumentation did reduce operation duration, there was no difference in length of stay, blood loss, or complication rates between lateral instrumentation and PPSF. Notably, trends did not reach statistical significance on multivariate regression in this modestly sized single-center cohort, possibly owing to selection bias between groups.

One of the potential advantages of lateral fixation is that it allows for a single approach compared to PPSF, which requires additional incisions and more operative time [10,16]. In the present study operative time was significantly longer in the PPSF group. Importantly, LLIF surgery with PPSF is typically performed in two stages. In the first stage, the cage is implanted with the patient in the lateral decubitus position. In the second stage, the patient is flipped to the prone position, and posterior pedicle screws are placed. In our study, while the majority of cases were performed in two stages, a subset underwent lateral position single-position lateral and posterior surgery. Recently, studies have demonstrated preliminary efficacy for single-approach alternatives performed entirely in the lateral decubitus or prone position, which may reduce operating time, surgical site infections, and length of stay in the hospital [17–20]. There were also more levels fused, on average, in patients who received PPSF versus lateral instrumentation (1.67± 0.76 vs 1.14±0.43, $p = 0.0002$). Overall, surgeons may feel more confident in the level of stabilization that PPSF offers for patients with more complex or advanced lumbar spondylosis distributed across multiple spinal levels.

More patients who had upper lumbar fusions undergoing lateral instrumentation versus those with lower fusions undergoing stand-alone LLIF or PPSF, suggesting that there may be some anatomical advantages to using lateral instrumentation. Although lateral instrumentation decreases the number of incisions and operative time, this technique may also increase the risk of lumbar plexus injury due to the increased psoas muscle dissection required to place instrumentation [21]. Additionally, lateral instrumentation may not be possible at the L4-5 and L1-2 levels due to anatomic obstruction by the iliac crest or lower ribs, respectively, which likely influenced surgeon instrumentation selection.

In our study, 18 patients with LLIF at L4-5 received PPSF, while only 8 patients with LLIF at L4-5 received lateral instrumentation. Importantly, we did not find a difference in the rate of postoperative plexopathy according to instrumentation choice. Taken together, these results indicate that instrumentation decisions for individual patients were likely anatomy- and level-dependent. Surgeons may have been more likely to choose a less invasive and quicker lateral instrumentation for patients undergoing upper lumbar fusions without degenerative disease or need for extension to lower lumbar levels. While variable patient anatomy should be taken into account when choosing instrumentation, prior studies have demonstrated that both lateral instrumentation and PPSF are viable options at L1-2 and L4-5 for well selected patients [22].

More patients in the lateral instrumentation group had a prior lumbar fusion at another level (60%) versus the PPSF (13.3%) or stand-alone groups (23.5%). Patients with prior fusion undergoing reoperation at the same level were excluded from the study given that pre-existing hardware would confound our comparison of outcomes between instrumentation groups. Interestingly, when asked about factors that impact decisions around instrumentation choice, one surgeon in our study felt that prior adjacent fusion was a relative indication to perform stand-alone surgery to avoid revision and extension of older adjacent fusions. This difference suggests prior fusion at an adjacent level may be a surgeon-specific factor that influences choice of technique.

Lateral instrumentation may have been used more commonly for patients with prior fusions at an adjacent level with subsequent adjacent level disease to limit the operative time and additional incision sites for patients who had already undergone surgery. Lateral instrumentation may also be used as a less invasive and less time-consuming option for addressing pathology in patients with prior posterior lumbar fusions to avoid re-opening prior posterior incision sites and extending hardware. It is worth noting that lateral instrumentation was also used in 14 patients (40%) who did not undergo prior fusion at an adjacent level, likely reflecting the diverse preferences from multiple surgeons.

The technique used in each case was determined by individual surgeon preference. Given the retrospective nature of this study, we cannot say with certainty which factors ultimately factored into surgeon instrumentation selection. However, our results demonstrate that patients were more likely to undergo PPSF if they had more symptoms, were older, had more levels fused, or did not have prior fusion (Table 1).

These findings highlight that spine surgeons may tend to favor posterior supplemental instrumentation in more complex cases with worse disease, whereas lateral instrumentation may be chosen preferentially in cases where posterior instrumentation is pre-existing from interbody fusion at other levels. When asked about supplemental instrumentation choice, surgeons in our study commented that factors that decreased graft stability, such as spondylithesis and facet distraction at the index level were relative indications for the use of instrumentation. Additionally, surgeons commented that severe loss of disc height, poor bone quality were also indications to use suplemental instrumentation. Interestingly, we observed a trend towards reoperation rate with instrumentation choice, independent of these factors which were accounted for as covariates.

While operative time was longer in the PPSF group, there were no statistically significant differences between lateral instrumentation and PPSF in terms of EBL or postoperative complications. A significant difference did exist in terms of reoperation rate. Four patients in the stand-alone group required reoperation, four patients in the lateral instrumentation group, and zero patients in the PPSF group, despite significantly longer length of follow-up and greater average number of levels fused in the PPSF group.

Three cases of reoperation in the lateral instrumentation group were related to symptomatic residual stenosis (back pain, leg pain, radiculopathy), rather than hardware failure or incomplete fusion. One of the reoperation cases in the lateral instrumentation group was due to displacement of hardware within the month following their operation. Two of the four reoperations in the stand-alone group were due to recognized graft subsidence with resultant construct failure. Furthermore, despite baseline differences between instrumentation groups in terms of age, average number of levels fused, and symptomatic presentation (Table 1), none of these variables were significantly associated with likelihood of reoperation on logistic regression. However, stand-alone LLIF, versus either lateral or posterior instrumented LLIF, was significantly associated with reoperation (correlation coefficient = 1.55 [0.04, 3.06], $p = 0.045$).

Of note, all four patients who underwent reoperation in this group subsequently received supplemental instrumentation during revision procedures (Table 4). It is important to note that length of follow up was a limitation in this study. It is possible that patients that underwent PPSF may experience more adjacent disk disease secondary to hardware placement on adjacent levels. Future studies should aim to evaluate fusion outcomes for patients over a longer duration.

The rate of patients who achieved radiographic fusion (BSF score of 3) did not differ significantly between PPSF, lateral instrumentation, or stand-alone groups ($p = 0.717$), which did not support our hypothesis that the use of instrumentation would improve radiographic fusion on imaging follow-up when averaging across patients. However, the clinical utility of this difference may be limited given none the patients with BSF scores of 1 or 2 ultimately required reoperation. The finding is further limited due to differences in the proportion of patients with follow-up imaging between groups (as with clinical follow-up duration, highest rate of imaging follow-up was seen in the PPSF group), though the length of imaging follow-up for patients who did receive follow-up CT or X-ray at least 6 months postoperatively was statistically similar between groups (Table 3).

Current literature reports LLIF fusion rates between 75–100%, which is similar to our study and those rates historically reported for ALIF, PLIF, and TLIF [23–26]. Ultimately, only 18 (21.95%) of our 82 patients were from the BSF analysis for not having follow-up imaging more than 6 months postoperatively, though reassuringly all of the patients who had reoperation or instrumentation complications were included in the analysis of BSF fusion scores. Our comparison of fusion rates may also have been underpowered due to relatively low overall failure rate in this retrospective cohort. Additionally, BSF fusion score comparisons may have been limited by the inclusion of plain radiographs to assess fusion when postoperative CT scans were not available. Prospective validation studies would be well served by a more uniform follow-up imaging protocol than we were able to include in this retrospective series.

Finally, the patient cohorts were heterogenous, which is a significant limitation of this study. Patient age, average number of levels fused, and presenting symptoms varied to a statistically significant extent between groups (Table 1). The lateral instrumentation group was younger, had fewer levels fused on average, and had higher rates of prior fusion at an adjacent level. Additionally, we found that patients who received PPSF underwent fusion at more levels on average during the index procedure, suggesting higher overall burden of degenerative disease in the PPSF group. Nevertheless, all three cases of failed indirect decompression with instrumentation were in the lateral instrumentation group. Furthermore, of all the variables above and choice of instrumentation, which were studied for possible association with reoperation rate on univariate and multivariate logistic regression, the only significant association identified was between reoperation and undergoing a stand-alone procedure in the univariate model (Table 5), though this finding was reduced to a trend that did not reach statistical significance on the multivariate analysis. Taken together, these analyses suggest that the difference observed in reoperation rate between groups is most likely attributed to decision to use instrumentation, however patient factors may influence whether instrumentation is used in the first place.

It is entirely possible that practice- and provider-specific trends in this single-center retrospective study led to bias in selection of instrumentation group. Indeed, the lack of clear guidelines for which to select in which circumstance is the key question which we sought to approach through this preliminary study. While differences between groups within our retrospective cohort limit the strength of the associations found, they also highlight the possibility that surgeons are selecting cases based on possible patient presentation and the need for future multicenter studies to create guidelines to assist in supplemental instrumentation choice in LLIF. A randomized trial for well selected patients would perhaps be feasible. In addition to reoperation rate, future studies should particularly focus on long-term maintenance of indirect lumbar decompression when lateral versus posterior fixation is employed, as this specific comparison may have been underpowered in the present retrospective study. Prior biomechanical and cadaveric studies which have suggested that PPSF provides improved spinal stability over LLIF with lateral plates alone or without supplemental fixation, and our findings generally align with those prior results [12,15,27–29].

Conclusion

There was no difference in blood loss or post-operative complications between patients who received LLIF with either lateral instrumentation, PPSF, or no supplemental fixation. However, radiographic fusion rate on follow-up imaging was higher in patients receiving supplemental instrumentation. Patients receiving PPSF also required fewer reoperations than other groups, despite presenting with more levels fused and more baseline symptoms. The use of lateral instrumentation, which significantly cuts down on surgical time, may be a good option for patients who require single level stabilization or have had prior fusions at adjacent levels. Similarly, the use of supplemental instrumentation during LLIF, whether lateral or posterior, may reduce rate of graft subsidence and need for revision surgery. Further studies should prospectively assess differences in outcome between instrumentation techniques in LLIF across a larger, multicenter cohort.

Conflicts of Interest

None.

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