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Original Article

Outcomes of Transforaminal Lumbar Interbody Fusion Using Unilateral Versus Bilateral Interbody Cages

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Objective: To assess the impact of bilateral versus unilateral interbody cages on outcomes for minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) procedures.
Methods: A retrospective review for primary, elective, single-level MIS TLIF procedures with bilateral posterior instrumentation from 2008–2020 was performed. Patients were grouped according to unilateral or bilateral interbody cage use. Procedures performed without static interbody cages or indicated for trauma, infection, malignancy were excluded. Patient-reported outcomes (PROs) included visual analogue scale (VAS), Oswestry Disability Index, 12-item Short Form health survey physical composite score (SF-12 PCS), Patient-Reported Outcome Measurement Information System physical function (PROMIS-PF). PROs were collected preoperatively and postoperatively. Change in PROs (Δ) was calculated and compared between groups. Achievement of minimum clinically important difference (MCID) was calculated using established values from the literature. Achievement rates were compared between groups using logistic regression.
Results: The study included 151 patients, with 111 unilateral and 40 bilateral cage placements. Charlson Comorbidity Index, diabetes, and insurance status differed between groups ($p < 0.050$). Prevalence of degenerative and isthmic spondylolisthesis (both $p \leq 0.002$), operative level ($p = 0.003$), and postoperative length of stay ($p = 0.022$) significantly differed between groups. The unilateral group had lower 1-year arthrodesis rates ($p = 0.035$). Preoperative VAS leg ($p = 0.017$) and SF-12 PCS ($p = 0.045$) were worse for the unilateral group. ΔPROMIS-PF was greater for the bilateral group at 2 years ($p = 0.001$). Majority of patients achieved an overall MCID for all PROs, except VAS leg (bilateral group).
Conclusion: While preoperative status and postoperative arthrodesis rates differed, patients achieved an MCID at similar rates regardless of use of unilateral or bilateral cages.

Keywords: Interbody cage, Instrumentation, Patient-reported outcomes, Transforaminal lumbar interbody fusion, Lumbar fusion

INTRODUCTION

Recent years have seen a steep increase in the number of elective lumbar fusions performed in the United States.[1] While a number of lumbar fusion techniques exist, the minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) was more recently introduced to mitigate risks associated with established fusion procedures such as nerve root damage and trauma to surrounding soft tissue.[2-4] MIS TLIF has several advantages over more traditional fusion procedures including shorter operative times and more rapid postoperative recovery.[2,4,5] This technique involves a posterolateral approach to the disc space followed by insertion of a spacer between vertebral bodies to help maintain adequate distance. The most common type of spacer is an interbody cage, which helps maintain intervertebral height and rigidity while reducing the chances of graft

collapse. Surgeons have a number of options regarding interbody cages, including the placement of either unilateral or bilateral cages, a choice that may vary based on patient-specific complexities or limited disc space.[6]

Currently, literature is limited regarding the impact of unilateral or bilateral placement of interbody cages on postoperative outcomes following TLIF. Results of some studies have suggested that unilateral cages may be associated with shorter operative duration and decreased blood loss,[7,8] while others suggest that unilateral cage placement may result in decreased stability or increased risk of cage failure compared to other techniques.[9,10] Furthermore, Aoki et al.[7] have suggested that similar rates of definitive arthrodesis may be achieved with either type of cage placement. However, many of these previous studies have not adequately controlled for the effects of pedicle screw instrumentation, which has a number of important implications for postoperative outcomes.[11-13]

In addition to more objective biomechanical models and perioperative measurements, surgeons may turn to Patient-Reported Outcome Measures (PROMs) to better quantify patients' actual perceptions in order to evaluate interventional effectiveness. Massel et al. compared visual analogue scale (VAS) back pain between cage techniques and Aoki et al. utilized VAS back and leg as well as Japanese Orthopaedic Association scores to compare patient-reported outcomes (PROs).[7,8] Although both studies offered insight into how cage technique may alter PROMs, the former specifically aimed to compare outcomes for isthmic vs degenerative spondylolisthesis while the latter failed to control for posterior instrumentation.[7,8]

Given limited literature available regarding the use of unilateral vs bilateral cages for TLIF procedures, the present study employs a broader range of PROMs to assess pain, disability, and physical function. Additionally, our analysis considers these postoperative outcomes in terms of the minimum clinically important difference (MCID), which measures the smallest magnitude of change in scores that a patient still perceives as beneficial[14] and can therefore be helpful in assessing the true benefit of an intervention. Furthermore, by including only patients with bilateral posterior instrumentation, we seek to provide a less biased assessment of objective outcomes such as rates of arthrodesis, cage subsidence, and need for revision surgery. This study aims to expand upon the available literature by assessing whether comparable outcomes can be achieved through the use of bilateral vs unilateral interbody cages for MIS TLIF procedures with the use of bilateral posterior instrumentation.

MATERIALS AND METHODS

1. Patient Population

Informed patient consent and Institutional Review Board approval (ORA 14051301) were obtained prior to study onset. We conducted a retrospective review of a prospectively maintained surgical registry for lumbar fusion patients from April 2008 to September 2020. Patients undergoing primary, elective, single-level MIS TLIF procedures with bilateral pedicle screw instrumentation performed for degenerative spinal pathology were included. Exclusion criteria were procedures that did not include the use of an interbody cage, used an expandable (non-static) cage, or were indicated due to trauma, infection, or malignancy. All procedures were performed by a single attending spine surgeon at a single academic institution.

2. Data Collection

Information regarding patient demographics, preoperative spinal pathology, and perioperative characteristics were collected. Demographic information consisted of age, sex, body mass index (BMI), smoking status, diabetic status, American Society of Anesthesiologists (ASA) physical status classification, Charlson Comorbidity Index (CCI), and insurance/payment type. Preoperative spinal pathology was categorized in terms of recurrent herniated nucleus pulposus, degenerative spondylolisthesis, and isthmic spondylolisthesis. Operative levels as well as the type of bone graft material used were recorded for all patients. Perioperative variables included operative duration (from skin incision to skin closure, in minutes), estimated blood loss (EBL; in mL), and postoperative length of stay (in days). Arthrodesis was assessed based on computed tomography of the lumbar spine at 1-year follow-up. PROMs including VAS back, VAS leg, Oswestry Disability Index (ODI), 12-item Short Form health survey physical composite score (SF-12 PCS), and Patient-Reported Outcomes Measurement Information System Physical Function (PROMIS-PF) were administered at preoperative and 6 weeks, 12 weeks, 6 months, 1 year, and 2 years postoperative timepoints.

3. Surgical Technique

All MIS TLIF procedures were performed utilizing the Wiltse technique. Fluoroscopic guidance was used to identify the level of interest. For patients undergoing unilateral cage placement, a 2- to 3-cm incision was made lateral to midline on side of intended cage facilitating a paramedian approach. Sequential dilators were used to enlarge the pathway progressively. Unilateral

laminectomy and facetectomy were performed through a single 20-mm nonexpandable tubular retractor.

For patients undergoing bilateral cage placement, 2 separate 2- to 3-cm incisions were made lateral to midline facilitating paramedian approaches bilaterally. Sequential dilators were used to enlarge the pathways progressively. Bilateral laminectomy and facetectomy were performed through bilateral 20-mm nonexpandable tubular retractors.

After decompression, the intervertebral disc was identified, incised, and removed; the end plates were prepared with sequential end plate cutters either unilaterally or bilaterally. Local allograft collected during laminectomy and facetectomy was prepared and impacted anteriorly before interbody cage placement. Cages were packed with local bone graft, iliac crest bone graft, and/or bone morphogenic protein-2 (BMP-2)/synthetic bone graft substitute. A single interbody cage was impacted into place for unilateral cases, and equivalent bilateral interbody cages were impacted for bilateral cases. Interbody cages primarily consisted of T-PAL and Concorde cages (DePuy Synthes, Raynham, MA, USA). Percutaneous pedicle screws were placed bilaterally over guide wires which were connected with rods and set screws.

4. Statistical Analysis

All calculations and statistical tests were performed using StataIC 16.1 (StataCorp., College Station, TX, USA). Patients were grouped according to whether they received unilateral or bilateral interbody cages. Demographics, prevalence of preoperative spinal pathologies, perioperative characteristics, and arthrodesis rates were compared between groups using chi-square and Student t-test for categorical and continuous variables, respectively.

Improvement in PROM scores (Δ) from preoperative baseline values were quantified at all postoperative timepoints. Preoperative PROM scores and Δ values were compared between groups using Student t-test. Achievement of MCID was determined by comparing Δ values to the following previously established thresholds: VAS back ≥2.2,[15] VAS leg ≥5.0,[15] ODI ≥8.2,[15] SF-12 PCS ≥2.5,[15] PROMIS-PF ≥4.5.[16] The proportion of patients achieving MCID in each measure at each timepoint was assessed between groups using logistic regression. In order to account for significant baseline differences between groups, 1-way analysis of covariance (ANCOVA) and multiple logistic regression analyses were used to assess postoperative improvement and rates of MCID achievement, respectively, while accounting for effects of significant covariates. Significant covariates were considered as any baseline characteristics that significantly differed between groups, as well as preoperative values for respective PROMs. An α of 0.05 was set for all statistical tests.

RESULTS

A total of 151 patients were included with 111 receiving a unilateral cage and 40 receiving bilateral cages. The cohort's mean age was 52.1 years, 39.1% were female, and 49.0% were obese (BMI ≥30 kg/m^2). Mean CCI score was significantly higher for the unilateral cage group (2.0±1.5 vs. 1.2 ±1.1, p=0.003). Diabetes status and insurance/payment type were significantly associated with cage type (p=0.041 and p=0.010) (Table 1). No other demographic variable significantly differed between groups.

Degenerative spondylolisthesis was significantly more prevalent among the unilateral cage group (51.4% vs. 22.5%, p<0.001), while isthmic spondylolisthesis was significantly more prevalent among the bilateral cage group (21.6% vs. 70.0%, p<0.001) (Table 2). A majority of procedures in the unilateral group were

Table 1. Patient demographics

Demographic	Unilateral cage (n=111)	Bilateral cages (n=40)	p-value
Age (yr)	53.1±11.4	49.2±10.5	0.058
Sex			0.538
Female	45 (40.5)	14 (35.0)	
Male	66 (59.5)	26 (65.0)	
Body mass index (kg/m^2)			0.554
<30	55 (49.6)	22 (55.0)	
≥30	56 (50.5)	18 (45.0)	
Smoking status			0.339
Nonsmoker	93 (83.8)	36 (90.0)	
Smoker	18 (16.2)	4 (10.0)	
Diabetes			0.041*
Nondiabetic	95 (85.9)	39 (97.5)	
Diabetic	16 (14.4)	2.5 (1	
ASA PS classification grade	2.1±0.5	2.0±0.5	0.242
CCI score	2.0±1.5	1.2±1.1	0.003*
Insurance			0.010*
Medicare/medicaid	11 (9.9)	0 (0)	
Workers' compensation	45 (40.5)	10 (25.0)	
Private	55 (49.6)	30 (75.0)	

Values are presented as mean±standard deviation or number (%).
ASA PS, American Society of Anesthesiologists physical status; CCI, Charlson Comorbidity Index; SD, standard deviation.
*p<0.05, statistical significance.

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performed at the L4/L5 level (53.2%) while most procedures in the bilateral group were at the L5/S1 level (75.0%), which represented a significant difference in distribution between groups (p = 0.003). Most patients in both groups received BMP-2 intraoperatively (87.4% unilateral, 85.0% bilateral) and the type of bone graft used did not significantly differ by group (p = 0.069). Postoperative length of stay was significantly longer for the unilateral cage group (56.3 ± 32.1 vs. 43.2 ± 21.8, p = 0.022). Neither operative duration (138.3 ± 33.3 vs. 143.2 ± 32.1, p = 0.429) nor EBL (64.0 ± 32.0 vs. 66.9 ± 51.4, p = 0.680) significantly differed between groups. All patients in the bilateral group demonstrated solid arthrodesis at 1-year follow-up, while a significantly lower proportion in the unilateral group had achieved fusion at the 1-year timepoint (100% vs. 89.0%, p = 0.035). In total, 12 patients underwent index-level revision procedures, all of whom were in the unilateral group. All patients with radiographically confirmed pseudoarthrosis subsequently underwent revision

Table 2. Perioperative characteristics

Characteristic	Unilateral cage (n = 111)	Bilateral cages (n = 40)	p-value
Spinal pathology			
Recurrent herniated nucleus pulposus	9 (8.1)	2 (5.0)	0.517
Degenerative spondylolisthesis	57 (51.4)	9 (22.5)	0.002*
Isthmic spondylolisthesis	24 (21.6)	28 (70.0)	< 0.001*
Fusion level			0.003*
L3/L4	3 (2.7)	0 (0)	
L4/L5	59 (53.2)	10 (25.0)	
L5/S1	49 (44.1)	30 (75.0)	
Bone graft			0.069
BMP-2	97 (87.4)	34 (85.0)	
Iliac crest bone graft	1 (0.9)	3 (7.5)	
Other†	13 (11.7)	3 (7.5)	
Operative time (min)	138.3 ± 33.3	143.2 ± 32.1	0.429
Estimated blood loss (mL)	64.0 ± 32.0	66.9 ± 51.4	0.680
Length of stay (hr)	56.3 ± 32.1	43.2 ± 21.8	0.022*
Arthrodesis by 1 year‡			0.035*
Nonunion	12 (11.0)	0 (0)	
Solid fusion	97 (89.0)	37 (100)	

Values are presented as number (%) or mean ± standard deviation.
BMP-2, bone morphogenic protein-2.
*p < 0.05, statistical significance. †Other synthetic bone graft substitute+ local bone graft without the use of BMP-2 or iliac crest bone graft. ‡Arthrodesis status was not able to be assessed for 5 patients due to unavailable postoperative computed tomography scans.

Table 3. Patient-reported outcomes

PROM	Unilateral cage	Bilateral cages	p-value†	p-value‡
VAS back				
Preoperative	6.8 ± 2.1	6.8 ± 2.4	0.932	
6 Weeks (Δ)	2.8 ± 2.7	2.4 ± 3.4	0.487	0.551
12 Weeks (Δ)	3.0 ± 2.8	3.6 ± 3.0	0.282	0.888
6 Months (Δ)	3.2 ± 2.9	4.0 ± 3.1	0.226	0.277
1 Year (Δ)	3.1 ± 2.4	3.9 ± 3.1	0.352	0.412
2 Years (Δ)	3.7 ± 3.1	2.9 ± 4.6	0.606	0.212
VAS leg				
Preoperative	6.1 ± 2.5	4.6 ± 3.2	0.017*	
6 Weeks (Δ)	3.1 ± 3.4	2.0 ± 4.1	0.214	0.995
12 Weeks (Δ)	3.0 ± 2.8	2.3 ± 3.5	0.308	0.805
6 Months (Δ)	3.3 ± 2.8	2.0 ± 3.1	0.084	0.393
1 Year (Δ)	3.9 ± 2.9	2.8 ± 2.5	0.199	0.054
2 Years (Δ)	3.8 ± 3.1	3.0 ± 3.4	0.547	0.380
ODI				
Preoperative	45.1 ± 17.2	39.6 ± 15.6	0.145	
6 Weeks (Δ)	7.9 ± 17.4	4.9 ± 21.7	0.511	0.259
12 Weeks (Δ)	13.2 ± 16.3	17.4 ± 17.8	0.296	0.615
6 Months (Δ)	17.7 ± 15.3	18.3 ± 22.2	0.888	0.930
1 Year (Δ)	19.0 ± 17.5	18.4 ± 14.6	0.915	0.412
2 Years (Δ)	25.8 ± 23.5	8.2 ± 29.6	0.118	0.026*
SF-12 PCS				
Preoperative	30.0 ± 9.0	34.9 ± 12.4	0.045*	
6 Weeks (Δ)	0.9 ± 9.4	-0.4 ± 8.4	0.642	0.666
12 Weeks (Δ)	7.2 ± 9.4	10.8 ± 11.4	0.307	0.611
6 Months (Δ)	9.8 ± 12.0	12.9 ± 12.4	0.469	0.663
1 Year (Δ)	13.6 ± 9.8	9.8 ± 8.3	0.212	0.170
2 Years (Δ)	11.9 ± 11.3	7.4 ± 11.1	0.289	0.253
PROMIS-PF				
Preoperative	34.0 ± 5.6	37.0 ± 4.7	0.165	
6 Weeks (Δ)	1.4 ± 5.3	-0.2 ± 6.2	0.556	0.108
12 Weeks (Δ)	2.9 ± 6.7	7.4 ± 5.5	0.120	0.434
6 Months (Δ)	8.5 ± 9.2	11.2 ± 5.0	0.469	0.436
1 Year (Δ)	7.2 ± 5.4	13.8 ± 8.6	0.091	0.423
2 Years (Δ)	3.7 ± 4.0	13.7 ± 4.4	0.001*	0.060

Values are presented as mean ± standard deviation.
PROM, Patient-Reported Outcome Measures; VAS, visual analogue scale; ODI, Oswestry Disability Index; SF-12 PCS, 12-item Short Form health survey physical composite score; PROMIS-PF, Patient-Reported Outcome Measurement Information System physical function.
*p < 0.05, statistical significance. †p-values calculated using Student t-test to compare mean preoperative scores and mean postoperative improvement between groups. ‡p-values calculated using 1-way analysis of covariance to compare mean postoperative improvement between groups while accounting for significant covariates.

procedures. Of these patients with pseudoarthrosis, 3 demonstrated significant concomitant subsidence. No additional incidences of index-level revision or clinically significant subsidence were observed.

Table 4. Achievement of MCID

PROM	Unilateral cage	Bilateral cages	OR (95% CI)	p-value†	p-value‡
VAS back					
6 Weeks	54 (55.1)	160 (50.0)	0.8 (0.4–1.8)	0.615	0.662
12 Weeks	49 (55.7)	20 (62.5)	1.3 (0.6–3.0)	0.505	0.749
6 Months	53 (63.9)	19 (67.9)	1.2 (0.5–3.0)	0.701	0.510
1 Year	15 (62.5)	12 (66.7)	1.2 (0.3–4.3)	0.780	0.226
2 Years	9 (60.0)	6 (60.0)	1.0 (0.2–5.2)	0.999	0.996
Overall	73 (73.0)	26 (74.3)	1.1 (0.4–2.6)	0.882	0.208
VAS leg					
6 Weeks	16 (36.4)	9 (30.0)	0.8 (0.3–2.0)	0.570	0.943
12 Weeks	14 (32.6)	8 (26.7)	0.8 (0.3–2.1)	0.590	0.428
6 Months	13 (32.5)	5 (18.5)	0.5 (0.1–1.5)	0.210	0.361
1 Year	9 (37.5)	4 (21.1)	0.4 (0.2–1.8)	0.249	0.020*
2 Years	4 (33.3)	3 (27.3)	0.8 (0.1–4.5)	0.753	-
Overall	26 (57.8)	110 (33.3)	0.4 (0.1–0.9)	0.035*	0.077
ODI					
6 Weeks	22 (46.8)	14 (46.7)	1.0 (0.4–2.5)	0.990	0.219
12 Weeks	26 (59.1)	21 (70.0)	1.6 (0.6–4.3)	0.340	0.892
6 Months	31 (75.6)	20 (74.1)	0.9 (0.3–2.8)	0.886	0.573
1 Year	16 (64.0)	14 (73.7)	1.6 (0.4–5.8)	0.496	0.962
2 Years	9 (69.3)	8 (72.7)	1.2 (0.2–7.0)	0.851	0.544
Overall	39 (81.3)	27 (79.4)	0.9 (0.3–2.7)	0.836	0.699
SF-12 PCS					
6 Weeks	9 (42.9)	8 (42.1)	1.0 (0.3–3.4)	0.962	0.898
12 Weeks	11 (57.9)	13 (72.2)	1.9 (0.5–7.5)	0.364	0.835
6 Months	15 (75.0)	11 (73.3)	0.9 (0.2–4.2)	0.911	0.745
1 Year	18 (85.7)	15 (79.0)	0.6 (0.1–3.2)	0.576	0.850
2 Years	12 (75.0)	9 (69.2)	0.8 (0.1–3.8)	0.730	0.796
Overall	25 (80.7)	22 (84.6)	1.3 (0.3–5.3)	0.695	0.807
PROMIS-PF					
6 Weeks	3 (37.5)	3 (25.0)	0.6 (0.1–3.9)	0.552	0.995
12 Weeks	3 (42.9)	10 (76.9)	4.4 (0.6–32.1)	0.139	0.878
6 Months	3 (50.0)	8 (88.9)	8.0 (0.6–110.3)	0.120	0.149
1 Year	5 (71.4)	10 (90.9)	4.0 (0.3–55.5)	0.301	0.585
2 Years	3 (50.0)	8 (100)	-	-	-
Overall	7 (77.8)	14 (87.5)	2.0 (0.2–17.3)	0.529	0.460

Values are presented as number (%).
MCID, minimum clinically important difference; PROM, Patient-Reported Outcome Measures; OR, odds ratio; CI, confidence interval; VAS, visual analogue scale; ODI, Oswestry Disability Index; SF-12 PCS, 12-item Short Form health survey physical composite score; PROMIS-PF, Patient-Reported Outcome Measurement Information System physical function.
*$p < 0.05$, statistical significance. †p-values calculated using logistic regression to assess rates of MCID achievement between groups. ‡p-values calculated using multiple logistic regression to assess rates of MCID achievement between groups while accounting for significant covariates.

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Preoperatively, VAS leg (6.1 ± 2.5 vs. 4.6 ± 3.2, p = 0.017), SF-12 PCS (30.0 ± 9.0 vs. 34.9 ± 12.4, p = 0.045) were significantly worse for the unilateral cage group (Table 3). Preoperative VAS back, ODI, and PROMIS-PF scores did not significantly differ between groups (all p > 0.05). Student t-test determined that postoperative Δ values were greater only for the bilateral group in PROMIS-PF at 2 years (3.7 ± 4.0 vs. 13.7 ± 4.4, p = 0.001), but did not significantly differ between groups for any other PROM at any timepoint (all p > 0.05). One-way ANCOVA revealed that when significant covariates were accounted for, improvement in ODI at 2 years was significantly greater for the unilateral group (25.8 ± 23.5 vs. 8.2 ± 29.6, p = 0.026). A majority of patients achieved an MCID overall for each PRO, with the exception of VAS leg for the bilateral group. Simple logistic regression demonstrated a significantly greater MCID achievement rate in the unilateral group only for overall VAS leg (57.8% vs. 33.3%, p = 0.035). Multiple logistic regression revealed that when significant covariates were accounted for, unilateral cage placement significantly predicted greater achievement rates for VAS leg at 1 year (p = 0.020) (Table 4).

DISCUSSION

MIS TLIF has a strong record of achieving favorable clinical outcomes while minimizing disruption of paraspinal musculature and surrounding structures.[2,3,17,18] Although a number of aspects and variations of the TLIF procedure have been described, literature regarding the use of unilateral or bilateral interbody cages is limited. A few studies have examined immediate perioperative outcomes or biomechanical differences, however, most of these have not adequately controlled for the role of posterior instrumentation.[7,9,10] Furthermore, the association of interbody cage placement with PROs has not been thoroughly assessed. The present study compared achievement of MCID in a number of PROMs based on the use of unilateral or bilateral cage placement in a cohort of patients undergoing MIS TLIF with bilateral pedicle screw instrumentation.

The topic of interbody cage placement and architecture is complex and multifaceted. Lee et al.[10] conducted a biomechanical study of 3 different cage conditions in a cadaveric PLIF model and determined that 2 cages placed bilaterally achieved greater stability and decreased stress compared with single cage techniques. Wang and Guo[9] performed a similar study of 3 interbody cage techniques in a biomechanical model of physiological loading and vibration following TLIF. The authors reported that unilateral cages may be associated with increased risk of cage failure or adjacent segment degeneration, while the crescent shaped cage imparted increased stability and potentially decreased subsidence risk. However, neither Lee et al.[9] nor Wang and Guo[10] included the use of posterior fixation constructs in their cadaveric models of the spine. Posterior instrumentation has been demonstrated to have a number of significant effects on the outcomes of TLIF procedures, including segmental stability and endplate stress.[11,12,19] This discrepancy is addressed by Ambati et al.,[11] who utilized a cadaveric finite element model of the lumbar spine to explore the biomechanical effects of a variety of combinations of unilateral, bilateral, or crescent shaped cages with either unilateral or pedicle screw instrumentation for single-level TLIF. Their main conclusion was that bilateral pedicle screw fixation provides superior spinal stability compared with unilateral posterior instrumentation. Interestingly, Ambati et al. concluded that neither cage shape nor number significantly affected segmental stability when accompanied by bilateral posterior instrumentation, as was used in our cohort.

Preoperatively, there were several important differences between groups in our cohort. Of particular note, most patients receiving unilateral cages had a diagnosis of degenerative spondylolisthesis, while isthmic spondylolisthesis was the prevailing spinal diagnosis among patients receiving bilateral cages. Massel et al.[8] have previously published on a similar trend, noting a unilateral approach for patients with degenerative spondylolisthesis or grade I isthmic spondylolisthesis and bilateral cage placement for patients with grade II isthmic spondylolisthesis. In spite of the potentially more complex pathology among the patients receiving bilateral cage placement, they noted no difference in VAS back improvement through 6-months postoperative, nor in rates of fusion, revision, blood loss, or length of stay. An additional study by Massel et al.[20] directly comparing grade I and grade II isthmic spondylolisthesis with the same division by cage placement likewise demonstrated no significant differences in the above outcomes. Importantly, all patients in both studies by Massel et al. underwent bilateral posterior instrumentation.

Aoki et al.[7] performed a randomized clinical trial of 50 TLIF patients assigned to receive either unilateral cage placement with unilateral pedicle screw instrumentation or bilateral cages with bilateral pedicle screws. The investigators demonstrated that while the unilateral group experienced shorter operative durations and less blood loss, they also reported significantly less improvement in leg pain (as measured by VAS leg) and numbness following their procedures. Aside from these findings, Aoki et al. reported no significant differences in back pain

(VAS back or JOA back pain) or fusion rates between groups. While the prospective, randomized nature of their study is compelling, as with many other previous studies, interpretation of Aoki et al.'s results regarding cage placement may be confounded by the choice of unilateral vs bilateral pedicle screw instrumentation. This factor is especially important to account for as it has been shown to independently affect postoperative outcomes in lumbar fusion.[11,13,21] A systematic review and meta-analysis by Ren et al.,[13] as well as a randomized clinical trial by Choi et al.[21] comparing unilateral and bilateral pedicle screw instrumentation for TLIF procedures both demonstrated significantly lower rates of fusion with unilateral posterior instrumentation. Furthermore, the finite element model of Ambati et al.[11] demonstrated decreased stability among lumbar fusion constructions using unilateral instrumentation. Our study controlled for the effects of posterior instrumentation by including only patients who received placement of bilateral pedicle screws. Given this important methodological distinction, our results differed from that of Aoki et al.[7] in several ways. First, we observed no significant differences in EBL or operative duration, likely due to the use of uniform posterior instrumentation procedures, regardless of cage placement. However, we did observe that patients who received unilateral cages had significantly longer postoperative stays. This may be interpreted as a result of differences in cage placement or may be related to the increased comorbidity burden observed in the unilateral cage group. In terms of PROMs, unlike Aoki et al.,[7] patients in our study demonstrated minimal differences in postoperative improvement based on their cage status. However, after accounting for significant covariates, we did observe greater rates of MCID achievement for VAS leg at 1 year among the unilateral cage group. These observed differences could potentially be related to the significantly more severe leg pain observed preoperatively among the unilateral group. While we did take measures to statistically account for these differences, the worse baseline leg pain among the unilateral group may have allowed these patients greater "room" to improve. A previous study by Jenkins et al.[22] concluded that, for patients undergoing MIS TLIF, postoperative physical function, as measured by PROMIS-PF, was significantly more strongly correlated with VAS back scores than VAS leg. This conclusion may help explain the minimal differences in overall physical health improvement in spite of transient differences in leg pain. Based on more global trends in PROM values, our results suggest that patients may perceive similar levels of improvement with the use of a unilateral cage compared to bilateral.

However, we did observe one significant difference between groups that was not demonstrated in cohort of Aoki et al.[7] Specifically, all patients that received bilateral cages had demonstrated solid fusion by the 1-year timepoint, while only 89.0% of patients that received unilateral cages were fused at this timepoint. Perhaps the most straightforward explanation for this difference in fusion rates is decreased segmental stability or increased range of motion with a unilateral cage. However, the results of biomechanical analysis of Ambati et al.[11] demonstrated similar stability between unilateral and bilateral cages when accompanied by bilateral pedicle screw instrumentation. Another possible contribution to differences in rates of arthrodesis is the incidence of cage subsidence, as both implant type/shape and position have been demonstrated as risk factors for the complication.[23,24] This may be a less likely scenario, but a possibility nonetheless, as only 3 patients underwent an index-level revision procedure due to pseudarthrosis with concomitant cage subsidence. Our results regarding fusion rates are especially interesting considering the lack of significant difference observed in MCID achievement, implying that patients reported similar improvements in spite of these differing arthrodesis rates. Additional high-quality studies of radiographic and biomechanical outcomes to study the clinical effects of cage placement while controlling for posterior instrumentation may be necessary to fully elucidate the mechanism of these observed differences.

To our knowledge, this is the first study to comprehensively explore the effects of unilateral versus bilateral cage placement on MCID achievement following TLIF procedures while controlling for posterior instrumentation. However, the present study is not without limitations. All procedures were performed by a single surgeon at a single academic institution, which may limit the generalizability of our findings to other providers and patients. Furthermore, self-reported data such as PROMs are inherently prone to recall bias, non-response bias, and other potentially confounding effects. Nonetheless, quantifying these patient perceptions is vital to understanding postoperative outcomes in a clinically relevant, patient-centered manner. Finally, limited response rates at long-term follow-ups may have limited our ability to detect statistical effects at these more longitudinal timepoints.

CONCLUSION

Among patients undergoing MIS TLIF with bilateral pedicle screw instrumentation, minimal differences were observed in terms of blood loss, operative duration, or PROs based on the use of unilateral versus bilateral interbody cages. Specifically,

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patients achieved a clinically important difference in pain, disability, and physical function at similar rates regardless of cage placement. However, all patients receiving bilateral cage placement had demonstrated solid fusion by 1 year, while the rate of fusion was significantly lower for patients receiving unilateral cage placement.

CONFLICT OF INTEREST

The authors have nothing to disclose.

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