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CLINICAL ARTICLE

Comparison of Lumbosacral Fusion Grade in Patients after Transforaminal and Anterior Lumbar Interbody Fusion with Minimum 2-Year Follow-Up

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Objective: Generally, anterior lumbar interbody fusion (ALIF) was believed superior to transforaminal lumbar interbody fusion (TLIF) in induction of fusion. However, many studies have reported comparable results in lumbosacral fusion rate between the two approaches. This study aimed to evaluate the realistic lumbosacral arthrodesis rates following ALIF and TLIF in patients with degenerative spondylolisthesis as measured by CT and radiology.

Methods: Ninety-six patients who underwent single-level L5-S1 fusion through ALIF ($n = 48$) or TLIF ($n = 48$) for degenerative spondylolisthesis at the Spine Center, University of California San Francisco, between October 2014 and December 2017 were retrospectively evaluated. Fusion was independently evaluated and categorized as solid fusion, indeterminate fusion, or pseudarthroses by two radiologists using the modified Brantigan–Steffee–Fraser (mBSF) grade. Clinical data on sex, age, body mass index, Meyerding grade, smoking status, follow-up times, complications, and radiological parameters including disc height, disc angle, segmental lordosis, and overall lumbar lordosis were collected. The fusion results and clinical and radiographic data were statistically compared between the ALIF and TLIF groups by using *t*-test or chi-square test.

Results: The mean follow-up period was 37.5 (ranging from 24 to 51) months. Clear, solid radiographic fusions were higher in the ALIF group compared with the TLIF group at the last follow-up (75% *vs* 47.9%, $p = 0.006$). Indeterminate fusion occurred in 20.8% (10/48) of ALIF cases and in 43.8% (21/48) of TLIF cases ($p = 0.028$). Radiographic pseudarthrosis was not significantly different between the TLIF and ALIF groups (16.7% *vs* 8.3%; $p = 0.677$). In subgroup analysis of the patients without bone morphogenetic protein (BMP), the solid radiographic fusion rate was significantly higher in the ALIF group than that in the TLIF group (78.6% *vs* 45.5%; $p = 0.037$). There were no differences in sex, age, body mass index, Meyerding grade, smoking status, or follow-up time between the two groups ($p > 0.05$). The ALIF group had more improvement in disc height (7.8 mm *vs* 4.7 mm), disc angle (5.2° *vs* 1.5°), segmental lordosis (7.0° *vs* 2.5°), and overall lumbar lordosis (4.7° *vs* 0.7°) compared with the TLIF group ($p < 0.05$). Overall complication rates were similar between the TLIF and ALIF groups (10.4% *vs* 8.33%; $p > 0.999$).

Conclusions: With a minimum 2-year radiographic analysis of arthrodesis at lumbosacral level by radiologists, the rate of solid radiographic fusions was higher in the ALIF group compared with the TLIF group, whereas the TLIF group had a higher rate of indeterminate fusion. Radiographic pseudarthrosis did not differ significantly between the TLIF and ALIF groups.

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Key words: ALIF; Arthrodesis; Pseudarthrosis; Fusion grade; Solid fusion; TLIF

Introduction

Historically, fusion at the level of lumbosacral junction tends to be more difficult than that of the rest of the spine. Han *et al.* reported that the radiographic fusion rates at L5-S1 were less than half of the fusion rate at L4-5 (42.9% *vs* 89.8%) ($p < 0.001$).[1] Various techniques have been implemented to enhance the lumbosacral fusion, through anterior or posterior approaches. Anterior lumbar interbody fusion (ALIF), introduced by Southwick and Robinson in 1957, utilizes an anterior retroperitoneal approach to access the lumbar spine.[2] Transforaminal lumbar interbody fusion (TLIF) was described by Harms and Jeszenszky in 1998, by which the anterior column is accessed through Kambin's triangle.[3] Although ALIF and TLIF are inherently different with regard to cage size, disc removal, endplate preparation, and ligamentous release, both of them are widely used to treat degenerative lumbar diseases. ALIF has theoretically been related to higher fusion rate and better alignment correction by facilitating complete endplate preparation and lordosis induction, and pseudarthroses following TLIF has been reported to eventually require ALIF to rectify in some cases.[4] However, the previous studies reported mixed results of fusion rate in TLIF when compared with ALIF. A meta-analysis by Ajiboye *et al.* reported that ALIF was superior to TLIF for the restoration of lumbar lordosis, but the two approaches were similar with regard to fusion rates and clinical outcomes.[5]

However, many previous studies on L5-S1 fusion were implemented by spine surgeons or spine fellows to assess and determine radiographic fusion.[6,7] This has two fundamental issues. One is the underlying favorable bias of the efficacy of spine surgery, particularly if a fellow or resident interprets his or her mentor's case. Second, spine surgeons do not receive the same rigorous training in radiographic interpretation as radiologists, specifically when it comes to windowing, identifying patterns on multiple sequences or different cuts, and delineating artifacts.

It is noteworthy that the concept of "fusion rate" is subject to interpretation in various studies, and different studies used non-identical criteria to establish fusion. The widely used Brantigan–Steffee–Fraser (BSF) classification introduced by Brantigan and Steffee in 1993 classified interbody fusion into five grades by plain radiographs: obvious radiographic pseudarthrosis, probable pseudarthrosis, radiographic status uncertain, probable radiographic fusion, and radiographic fusion.[8] Other fusion grading scales such as the Lenke, Bridwell, and CT-HU fusion, also divided fusion grades into several similar categories.[9] However, many studies simply regarded patients without clear pseudarthrosis as successful fusion.[5] This artificially inflated fusion rates and resulted in artificially similar results between ALIF and TLIF. The significance of the grading postoperative fusion is that understanding the realistic fusion grade of each method is important for both the patients and surgeons to make an informed decision, particularly as pseudarthrosis is associated with poorer outcomes and may require revision surgery.[10]

Moreover, many previous studies have not focused specifically on L5-S1 but have evaluated fusion throughout the lumbar spine. The purpose of this study is to: (i) evaluate fusion grade by radiologists independent of spine surgeons; and (ii) compare the realistic fusion rates of ALIF and TLIF at L5-S1 only and identify factors that influence fusion at the lumbosacral junction.

Methods

Patient Population

Patients who underwent L5-S1 ALIF or TLIF by four spine surgeons for degenerative spondylolisthesis (grades I and II, with or without lysis) between 2014 and 2017 were retrospectively studied. The selection of the surgical approach was based on surgeon and patient preferences. The Institutional Review Board (IRB) approval (#18-25040) was obtained from the Institutional Ethics Committee of University of California San Francisco, and individual patient consent was not required for this study.

Inclusion and Exclusion Criteria

Inclusion Criteria

The inclusion criteria were: (i) patients with single-level spondylolisthesis (Meyerding Grade I or II) at L5/S1 who presented with persistent lower back pain or radiculopathy for more than 6 months of failed, non-operative care; (ii) patients who underwent single-level ALIF or TLIF at L5/S1; and (iii) patients had postoperative CT and dynamic radiography at the last follow-up, with a minimum of 2-year follow-up.

Exclusion Criteria

The exclusion criteria were: (i) patients with scoliosis >10°; (ii) previous spine fusion at L5-S1, infection, tumor, or osteoporosis (T score < -2.5); and (iii) the need for simultaneous treatment of other levels besides L5-S1.

Surgical Technique: ALIF (Anterior–Posterior Approach)

The L5-S1 disc space was exposed through a retroperitoneal approach by a vascular surgeon in all patients. Discectomy was performed and the endplates were prepared. The disc space was released and distracted in order to achieve height restoration, lordosis, and partial reduction of the spondylolisthesis. The posterior longitudinal ligament was preserved. An appropriate interbody cage with filled with either allograft, bone morphogenetic protein (BMP), or both was placed under fluoroscopic guidance. Integrated screws were placed to secure the cages. The patient was then positioned prone for the posterior approach. A standard midline incision was made and decompression was performed; if necessary, pedicle screws and rods were placed, and posterior arthrodesis was performed with either local autograft bone, iliac crest bone, allograft, BMP, or a combination.

Surgical Technique: TLIF (Posterior Only Approach)

A posterior midline incision was made and pedicle screws were placed. A total unilateral facetectomy was performed to access the Kambin's triangle. The disc space was entered, the disc was removed, and the endplates were prepared. An interbody cage was placed and a graft material consisting of either a local autograft, iliac crest bone, allograft, BMP, or a combination of both was used in the disc space, in and around the cage, and in the posterolateral gutters. The rods and set screws were placed, the construct was tightened, and the wound was closed.

Radiographic Assessment

Radiographic assessment of fusion at the last follow-up (24–51 months) was performed independently by a neuroradiology fellow and a Professor of Radiology based on computed tomography (CT) scans or dynamic radiographs. A modified Brantigan–Steffee–Fraser (mBSF) scale was used. This was categorized as grade I (radiographic pseudarthrosis), grade II (Indeterminate fusion) and grade III (solid radiographic fusion).[31] Implant breakage, screw pull-out, segmental movement on dynamic x-ray greater than 2°, radiolucency (>1 mm) around the screws, or clear absence of bridging bone on CT was categorized as pseudarthrosis (grade I). Presence of uncertain bridging bone, a transverse radiolucent line with segmental movement <2° without implant failure, or radiolucency around the cages was categorized as indeterminate fusion (grade II). Presence of trabecular bridging bone at more than half the fusion area on sagittal or coronal CT scanning without movement was categorized as solid radiological fusion (grade III) (Figure 1).

The amount of Meyerding slip was determined by assessing pre- and post-operative standing lateral radiographs, and the grade of reduction was calculated. Three-foot standing lateral radiographs were obtained preoperatively and at the final follow-up. Radiographic analyses of lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), mismatch of PI and LL (PI-LL), disc angle (DA) at the surgical level, and segmental lordosis (SL) were measured independently by two attending spine surgeons (JL and PGD).

Statistical Analysis

Statistical analyses were performed using SPSS (version 20.0; IBM Corp., Armonk, NY, USA). Data were categorized using descriptive statistics as means and standard deviations for continuous variables, or as counts for categorical variables. Clinical and radiographic variables were compared between the two groups using either the unpaired *t*-test or chi-square test. Statistical analyses of intra- and inter-observer reliability were performed using weighted kappa coefficients. Statistical significance was defined as $p < 0.05$.

Results

Baseline Characteristics

A total of 125 patients were eligible for participation in the study (64 underwent ALIF and 61 underwent TLIF). Sixteen patients in the ALIF group and 13 patients in the TLIF group were excluded because of the absence of data on lumbar CT or dynamic radiography at follow-up. The mean follow-up period was 37.5 months (24–51). There were no differences in sex, age, body mass index, Meyerding grade, spondylolysis, smoking status, or follow-up time between the two groups ($p > 0.05$). The estimated blood loss was higher in the TLIF group than that in the ALIF group (350 ±90 mL *vs* 180 ±65 mL, $p < 0.001$) (Table 1).

Fusion Evaluation in ALIF and TLIF Groups

Overall, the solid radiographic fusion rate was higher in the ALIF group than that in the TLIF group at the final follow-up (75% *vs* 47.9%; $p = 0.006$). Indeterminate fusion was identified in 20.8% (10/48) of the cases in the ALIF and 43.8% (21/48) of cases in the TLIF groups ($p = 0.028$). Pseudarthrosis in the TLIF group was two times that of the ALIF group (8.3% *vs* 4.16%, $p = 0.677$) (Table 2). However, BMP (70.8% *vs* 8.3%, $p < 0.001$) was used more frequently in the ALIF group than in the TLIF group (Table 3). In subgroup analysis of the patients who did not have BMP, the solid radiographic fusion rate was still higher in the ALIF group compared with the TLIF group (78.6% *vs* 45.5%, $p = 0.037$) (Table 4). The inter-observer weighted kappa value was 0.766 (95% CI: 0.646–0.887; $p < 0.001$). The intra-observer weighted kappa value was 0.893 (95% CI: 0.809–0.977, $p < 0.001$), indicating good agreement.

Radiographic Parameters in the ALIF and TLIF Groups

The ALIF group had more restoration of disc height (7.8 mm *vs* 4.7 mm), segmental lordosis (7.0° *vs* 2.5°), and lumbar lordosis (4.7° *vs* 0.7°) than did the TLIF group ($p < 0.05$) (Table 5). There were no statistical differences in complications, including symptomatic pseudarthrosis with TLIF versus ALIF (4.2% *vs* 2.1%, $p > 0.999$) and adjacent segmental disease (6.3% *vs* 2.1%, $p = 0.617$). The overall complication rates were similar between the TLIF and ALIF groups (10.4% *vs* 8.33%, $p > 0.999$) (Table 6).

Discussion

Our study compared the realistic fusion rates of ALIF and TLIF at L5-S1 in patients by using a modified BSF scale based on computed tomography (CT) and dynamic x-ray. The

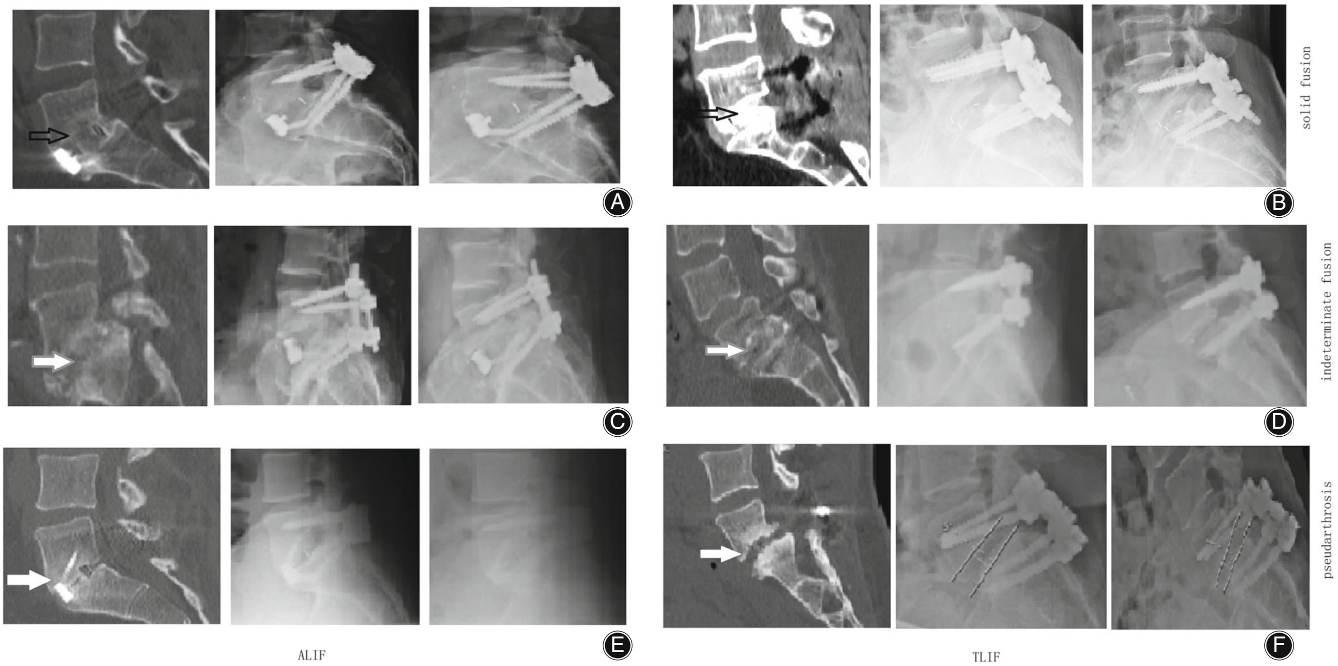

FIGURE 1 Radiographs and sagittal CT images demonstrating examples of solid fusion, indeterminate fusion, and pseudarthrosis evaluated by the modified Brantigan-Steffee-Fraser (mBSF) scale in patients underwent ALIF and TLIF. Presence of trabecular bridging bone (black arrow) on sagittal CT scanning and no movement on lateral dynamic X-ray is categorized as solid fusion (mBSF grade III) (A, B); Presence of uncertain bridging bone (blue arrow) without implant failure, or radiolucency around the cages and segmental movement on lateral dynamic X-ray <2° is categorized as indeterminate fusion (mBSF grade II) in patients underwent ALIF and TLIF (C, D); Implant breakage, clear absence of bridging bone on CT (white arrow), segmental movement on dynamic x-ray greater than 2° is categorized as pseudarthrosis (mBSF grade I) in patients underwent ALIF and TLIF (E, F).

TABLE 1 Comparison of demographic data between ALIF and TLIF patients

	ALIF ($n = 48$)	TLIF ($n = 48$)	*p*-value
Sex (male/female)	15/33	17/31	0.75
Average age (years)	55.2 ± 9.9	55.1 ± 12.6	0.99
BMI (kg/m^2)	29.3 ± 7.3	30.1 ± 6.5	0.89
Smokers	22.9% (11/48)	39.6% (19/48)	0.13
Meyerding (I/II)	10/38	12/36	0.81
Follow-up (months)	38.5 ± 18.3	33.8 ± 14.8	0.35

TABLE 2 Comparison of fusion between ALIF and TLIF

	ALIF ($n = 48$)	TLIF ($n = 48$)	*p*-value
Solid fusion (BSF III)	75.0% (36/48)	47.9% (23/48)	0.006
Indeterminate (BSF II)	20.8% (10/48)	43.8% (21/48)	0.028
Pseudarthrosis (BSF I)	4.16% (2/48)	8.3% (4/48)	0.677

results were interpreted independently by radiologists. With strict, independent analysis by radiologists, ALIF had higher solid fusion rates than TLIF at L5-S1 when excluding BMP use (75% *vs* 47.9%; $p = 0.006$). Indeterminate fusion was identified in more cases in the TLIF group than in the ALIF group ($p = 0.028$). Pseudarthrosis was not statistically different between the two groups (8.3% *vs* 4.16%, $p = 0.677$).

Despite the many published literature focused on the management of spondylolisthesis, there remain divergent options with regard to the surgical approach for treatment.[11–13] Although TLIF can be performed through a single approach, there have been reports indicating that lordosis induction is less than favorable.[14] The L5-S1 disc space represents the transition between the lumbar spine and sacrum. This region has been known to be more difficult to achieve arthrodesis than at other levels.[1]

Realistic Fusion Grade at Lumbosacral in ALIF and TLIF

The fusion grade can more precisely reflect the postoperative fusion status than fusion rate, as fusion status is usually a spectrum, not necessarily a binary status. In our study, fusions were categorized as three grades: solid fusion, indeterminate fusion, and pseudarthrosis. Solid radiographic fusion rate was higher in the ALIF group than that in the TLIF group at final follow-up. Indeterminate fusion was identified in more cases in the

TABLE 3 Comparison of perioperative parameters between ALIF and TLIF

	ALIF ($n = 48$)	TLIF ($n = 48$)	p-value
Operative time (min)	335 ± 35	250 ± 60	<0.01
Estimated blood loss (mL)	180 ± 65	350 ± 90	<0.001
Hospital stay (days)	4.3 ± 3.2	6.7 ± 4.5	0.021
Use of BMP in cage	70.8% (34/48)	8.3% (4/48)	<0.001
Use of allograft in cage	62.5% (30/48)	22.9 (11/48)	<0.001
Use of autograft in cage	0% (0/48)	95.8% (46/48)	<0.001

TABLE 4 Comparison of fusion rates with and without BMP

	Fusion status	ALIF	TLIF	p-value
Including BMP	Solid fusion	73.5% (25/34)	75% (3/4)	>0.999
	Indeterminate fusion	23.5% (8/34)	25% (1/4)	>0.999
	Pseudarthrosis	2.9% (1/34)	0/4	>0.999
	Total	34	4	
Excluding BMP	Solid fusion	78.6% (11/14)	45.5% (20/44)	0.037
	Intermediate fusion	14.3% (2/14)	45.5% (20/44)	0.327
	Pseudarthrosis	7.1% (1/14)	9.1% (4/44)	>0.999
	Total	14	44	

TABLE 5 Comparison of radiographic parameters between ALIF and TLIF

	ALIF ($n = 48$)	TLIF ($n = 48$)	p
Disc height (mm)			
Pre-operative	3.8 ± 2.8	4.1 ± 2.4	0.342
Post-operative	11.6 ± 2.5	8.8 ± 2.4	0.043
Change	7.8 ± 2.9	4.7 ± 2.6	0.012
Disc angle (°)			
Pre-operative	4.5 ± 6.3	5.5 ± 6.5	0.357
Post-operative	9.6 ± 7.4	6.9 ± 6.2	<0.001
Change	5.2 ± 13.5	1.5 ± 4.8	<0.001
Segmental lordosis (°)			
Pre-operative	21.8 ± 8.4	21.1 ± 7.3	0.761
Post-operative	28.4 ± 8.2	23.0 ± 6.2	0.013
Change	7.0 ± 9.9	2.5 ± 5.8	<0.001
Lumbar lordosis (°)			
Pre-operative	53.43 ± 11.0	54.9 ± 12.0	0.735
Post-operative	58.7 ± 11.5	54.2 ± 13.1	0.721
Change	4.70 ± 12.0	0.70 ± 12.8	<0.001
Pelvic tilt			
Pre-operative	19.2 ± 7.7	18.1 ± 8.3	0.121
Post-operative	18.8 ± 8.0	18.8 ± 8.1	0.342
Change	−1.3 ± 6.5	0.1 ± 7.86	0.093
Sacral slope			
Pre-operative	44.1 ± 92	41.9 ± 10.3	0.183
Post-operative	44.4 ± 9.7	40.8 ± 11.0	0.089
Change	1.5 ± 9.3	2.50 ± 7.80	0.216
Pelvic incidence	60.7 ± 11.8	59.9 ± 14.2	0.541

TLIF group than in the ALIF group, even though clear pseudarthrosis was not different between the two groups. To some extent, the results indicated that ALIF can more likely achieve a robust and confident fusion than TLIF. This was consistent with the studies by Kwon *et al.* and Swan *et al.*, which found that patients undergoing ALIF had superior rates of arthrodesis.[15,16] However, other studies showed comparable fusion rates and outcomes between TLIF and ALIF.[6,7] Faundez *et al.* reported comparable fusion rates between ALIF and TLIF (82.4% and 76.9%, $p > 0.05$), but level-specific fusion rates were not reported.[17] Chandra and Singh reported a 100% fusion rate in both ALIF and posterior lateral interbody fusion (PLIF).[18] However, these studies evaluated fusion only based on static radiographs without clear criteria for fusion.[19–21] Without dynamic radiographs, in the L5-S1 disc space, it can be difficult to assess fusion due to the iliac crest, leading to a higher false positive rate, particularly if assessed by a non-radiologist. In studies which showed no difference between ALIF and TLIF, there may have been reasons for this. First, these studies included other levels besides L5-S1, which is the hardest level to fuse and has the highest nonunion rate. Second, at the L5-S1 level, it is difficult to assess fusion radiographically because of visual obfuscation from the iliac crest. Without radiologists training, the L5-S1 artifact may be erroneously categorized as a fusion. Third, other studies may have designated spine surgeons or even residents and fellows to assess radiographic fusion. In our study, only radiologists assessed fusion, which eliminated surgeon bias and could more accurately assess the L5-S1 level. The relatively low fusion rates observed in our study may be related to the difficulty of arthrodesis at L5-S1 and the relative lack of radiographic clarity in evaluation of fusion at this level. The availability of CT scans and dynamic x-rays in our study contributed to increase the sensitivity in detecting pseudarthrosis compared to radiographs alone in other studies.

Radiographic Evaluation of Lumbosacral Fusion

Radiographic assessment of arthrodesis remains challenging, even with modern imaging and rigorous training. BSF classification of interbody fusion introduced by Brantigan and Steffee

TABLE 6 Comparison of complications between ALIF and TLIF

	ALIF ($n = 48$)	TLIF ($n = 48$)	p-value
Symptomatic pseudarthrosis	2.1% (1/48)	4.2% (2/48)	>0.999
Adjacent segmental disease	2.1% (1/48)	6.3% (3/48)	0.617
Insufficient decompression	2.1% (1/48)	0	>0.999
Infection and abdominal hernia	2.1% (1/48)	0	>0.999
Total	8.33% (4/48)	10.4% (5/48)	>0.999

in 1993 was widely used; however, it was merely based on plain radiographs.[8] With 3-dimensional CT and modern picture archiving and communication (PACS) systems, more accurate radiographic assessment and measurements can be performed, especially in the hands of trained radiologists. Although CT scans with coronal and sagittal reconstructions appear to be the most sensitive and specific tests for assessing fusion, dynamic radiographs can also be extremely useful. Lack of motion on flexion and extension radiographs is highly suggestive of successful fusion. However, the amount of movement (if any) that distinguishes between solid arthrodesis and pseudarthrosis has not been clearly defined. Previous studies have used 0°, 2°, 4°, and 5° as cutoff values for pseudarthrosis. Brodsky *et al.* reported the confirmation of solid fusion in the absence of any motion (0°) on flexion-extension radiographs.[22] Rothman and Glenn reported that even in cases of clear pseudarthrosis, motion greater than 5° was rare because of restricted movement from instrumentation.[23] In our study, we used 2° as a cut-off because it has been shown that motion less than 2° was most consistent with arthrodesis on CT.[24]

Other Factors Influencing Fusion

The use of BMP has been associated with increased arthrodesis rates.[25,26] More ALIF patients in our study had the use of BMP than TLIF patients. However, even when excluding these patients who had BMP use, the rate of solid arthrodesis in the ALIF group was still significantly higher with ALIF than with TLIF. One potential reason for this difference is that there may be increased micromotion with TLIF that is not seen with ALIF. In patients undergoing TLIF, the entire unilateral facet is excised, much of the disc is removed, and a relatively small interbody cage is placed. Despite pedicle screw fixation, the construct may be inherently unstable because of the lack of one facet, significant disc removal, and a small cage acting as a focal pivot point. With an ALIF, the facets were left intact and a significantly larger cage was placed. This larger cage could provide more surface area for fusion and may also have less micromotion because of the larger pivot point, and both intact facets provide more stability and more fusion surface for arthrodesis. Even without the use of BMP, there may be inherent reasons for the observed differences between ALIF and TLIF, especially at L5-S1, a difficult level to achieve solid arthrodesis.

Consistent with previous publications, our data showed that ALIF improved disc height, segmental lordosis, and overall lumbar lordosis compared with TLIF, with a concomitant decrease in PI-LL mismatch.[27–30] Dorward *et al.*[14] found that ALIF provided more segmental lordosis than TLIF, although TLIF provided more scoliosis correction due to the total facetectomy.[10] In addition, Kim *et al.* found that even the mini-open ALIF had better radiographic improvement compared with the mini-open TLIF in the treatment of spondylolisthesis.[21]

Of note, in our study, there was a lower rate of adjacent segment disease (ASD) after ALIF than after TLIF (nearly one-third of the amount). This finding is consistent with those of the previous studies. Min *et al.* reported that ALIF may have a lower rate of ASD due to better postoperative sagittal alignment.[31] Swan *et al.* also reported that due to better spinal alignment, there may be less adjacent segment stress.[16] Duan *et al.* also reported that in patients who had mismatched postoperative spinopelvic parameters, the rate of ASD was higher in patients with obesity.[32] Another noteworthy finding in our study, is that despite the higher rate of solid arthrodesis in ALIF compared with TLIF, the overall pseudoarthrosis and complication rates and revision surgery rates were not different. One reason for this is the overall approach-related complications from ALIF were anterior hernia in one case and insufficient indirect decompression in another, requiring revision surgery to decompress the neural elements. Hee *et al.* reported that TLIF was associated with a lower incidence of complications. However, this rate may have not included long-term complications.[33]

Strengths and Limitations

The strengths of this study are as follows: first, fusion was independently evaluated by radiologists to eliminate any bias that may be introduced by surgeons who analyzed fusions. Second, this study only included L5-S1, which is the hardest level for arthrodesis. Many other studies included L4-5 or other levels. By focusing only on the L5-S1 level, we have eliminated multiple confounders of other lumbar spine levels that may show more favorable fusion rates. Third, our study evaluated fusion by using lumbar CT and dynamic radiographic analysis. Previous studies have evaluated fusion using plain radiography. There are limitations to this study. First, this is a single-center study. However, this demographically matched study included patient data from four spine surgeons (both orthopedics and neurosurgery), which may, to some extent, increase the variability of the patient population and personal surgical techniques. Second, the use of BMP was a confounder in the fusion rates. However, a subanalysis in patients without BMP showed that ALIF still had a significantly higher solid fusion rate, even without the use of BMP. It is a limitation, that after controlling for the graft substrate material (specifically, BMP), the numbers are small. This limits the statistical power of the study and this should be considered when interpreting the data. Lastly, health-related quality of life (HRQOL) measures were not recorded because of inconsistent data collection and multiple variables that could have confounded the results.

Conclusion

In patients with lumbar degeneration, the rate of solid radiographic fusions at lumbosacral level was higher in the ALIF group than in the TLIF group, whereas the TLIF group had a higher rate of indeterminate fusion. Radiographic pseudarthrosis did not differ significantly between the TLIF and ALIF groups.

Author Contributions

Conceptualization: Jinping Liu and Dean Chou. Data curation and formal analysis: Rong Xie, Cynthia T. Chin, Priya Rajagopalan, Ping-Guo Duan. Software and Methodology: Bo Li. Writing—original draft: Jinping Liu and Rong Xie. Writing—review and editing: Sigurd H. Berven, Praveen V. Mummaneni, Shane Burch, and Dean Chou.

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Disclosure

The authors declared no conflict of interest.

Ethics Statement

The study was approved by the Institutional Ethics Committee of University of California, San Francisco. Written informed consent was obtained from the patient for the publication of this manuscript and any accompanying images. The study was conducted in compliance with the Helsinki Declaration.

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