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ORIGINAL ARTICLE

Differences in the interbody bone graft area and fusion rate between minimally invasive and traditional open transforaminal lumbar interbody fusion: a retrospective short-term image analysis

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Abstract

Purpose We aimed to quantify the interbody bone graft area following transforaminal lumbar interbody fusion (TLIF) using traditional open and minimally invasive surgeries (MIS) and investigate their correlations with rates of fusion, complications, and clinical outcomes.

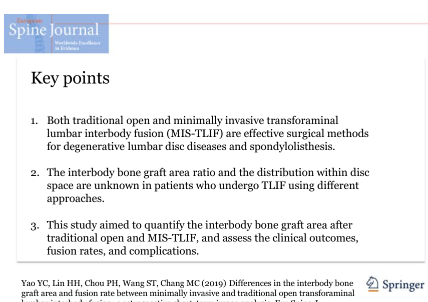
Methods Patients undergoing TLIF of 1 or 2 levels between October 2015 and December 2016 were retrospectively included. Fusion and bone graft areas were assessed with computed tomography (CT) at 6 months postoperatively. The bone graft area ratio was defined as the bone graft area divided by the average endplate area. The distributions of bone graft area within the discs were also recorded. Clinical outcomes were assessed using the visual analog scale (VAS) and Oswestry Disability Index (ODI) questionnaires.

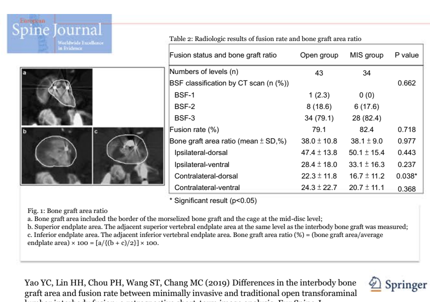
Results In total, 77 disc levels in 57 patients were analyzed. The fusion rate was 79.1% in the open group and 82.4% in the MIS group ($p=0.718$). Clinical outcomes of both groups improved significantly. Changes in VAS and ODI scores at 12 months postoperatively were comparable between groups. Bone graft area ratio was not significantly different between the two groups (open, 38 ± 10.8%; MIS, 38.1 ± 9.0%, $p=0.977$). Analysis of bone graft distribution revealed that the contralateral-dorsal part of the disc had the lowest bone graft area. The bone graft area ratio was significantly higher in the solid union group (39.2 ± 10.4%) than in the non-solid union group (33.5 ± 6.4%, $p=0.048$).

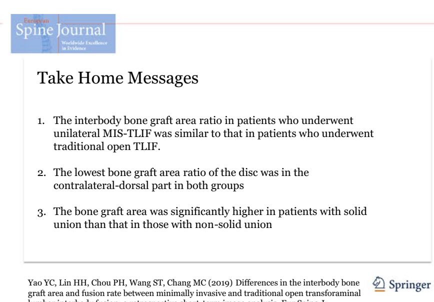
Conclusions The fusion rates, bone graft area ratios, clinical outcomes, and complications were similar between MIS and open TLIF.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords TLIF · MIS · Bone graft area · Endplate preparation · Fusion rate · Clinical outcome

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-06002-4) contains supplementary material, which is available to authorized users.

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Introduction

Transforaminal lumbar interbody fusion (TLIF) is an effective treatment method for degenerative lumbar disc diseases and spondylolisthesis [1, 2]. The TLIF procedure was developed by Harms [3] as a modification of posterior lumbar interbody fusion (PLIF). Unlike PLIF, it comprises a unilateral, more far-lateral approach involving insertion of only one cage rather than the bilateral parallel small cages used in PLIF. The clinical outcomes of TLIF and PLIF have been previously compared [4, 5]. Minimally invasive surgery (MIS) in TLIF has recently become more popular as it results in fewer morbidities, including less soft tissue dissection, shorter hospital stays, and lower blood loss than the traditional open approach [6, 7]. Because of the difficulty of the technique and the steep learning curve of MIS-TLIF, early postoperative complications have been reported, and proper disc preparation and interbody fusion volume have been topics of concern [8, 9].

The bone graft area between the cage and endplate is important for determining the solidity of fusion. The greater the bone graft area, the greater the stability of the fusion segment, which is beneficial mechanically for load transmission [10]. The interbody bone graft area ratio in PLIF has been reported to be 52–53% at 6 months postoperatively by computed tomography (CT) [11, 12]. However, the interbody bone graft area ratio has not been analyzed in patients who underwent TLIF with successful union. Furthermore, the differences in the interbody bone graft volumes between traditional open and MIS-TLIF have not been studied before. The purpose of the current study was to quantify the interbody bone graft area after traditional open and MIS-TLIF and assess their relationships with the rates of fusion, clinical outcomes, and complications.

Methods

We retrospectively collected the data of patients treated between October 2015 and December 2016, after receiving institutional review board approval. The inclusion criteria were: age > 18 years; history of TLIF involving 1–2 segments for degenerative lumbar spinal diseases, such as grade 1 or 2 degenerative or isthmic spondylolisthesis; and failure of prior conservative treatment for more than 6 months. All surgeries were performed by one senior surgeon. They were performed by either the traditional open or minimally invasive approach. The choice of open or minimally invasive surgery was made by the patient themselves, after being provided with a detailed explanation of the procedures by the surgeon. Those who had spinal fractures, spinal infections, spinal tumors, or a history of previous spinal surgery, and those who were lost to follow-up or failed to complete the questionnaires or radiographic examinations, were excluded. The demographic and perioperative parameters that were recorded through review of medical records were: age, gender, body mass index, comorbidities, surgical level, bone mineral density, surgical duration, length of hospital stay, estimated blood loss, and complications. All included patients completed follow-up at 6 weeks, and 3, 6, and 12 months postoperatively. Plain static radiographs, including supine anteroposterior and lateral images, were taken at each follow-up visit. Patients were asked to wear a brace for 3 to 6 months until solid fusion was observed by plain film or CT scan. We performed CT scans at 6 months postoperatively to evaluate the fusion status and decide whether the patient could remove the brace for exercise.

Surgical technique

The traditional open TLIF was performed through the classic posterior midline incision. Facetectomy was performed on the same side as the patient's leg pain. Autologous morselized bone graft from local bone and 1 cc demineralized bone matrix (OsteoSelect® DBM Putty, Bacterin International, Inc., Belgrade, MT, USA) were used for fusion in all patients. No bone substitutes were used to increase the bulk of the bone grafts, and TLIF was performed with a polyetheretherketone cage (Rainboo® polymer lumbar cage, A-SPINE, United Orthopedic Corporation, Taiwan). The cage was packed with mixed morselized bone grafts and additional bone grafts were packed behind the cage.

The surgical protocol for MIS-TLIF included percutaneous pedicle screw insertion and a paramedian unilateral approach with bilateral decompression. The decompression, disc preparation, and MIS-TLIF were performed under a microscope using a microendoscopic retractor as previously described [13]. The grafting materials used in MIS-TLIF were the same as those used in open TLIF.

Assessment

The clinical functional outcomes were based on the Oswestry Disability Index (ODI) questionnaire and the visual analog scale (VAS) for back pain both preoperatively and at 1 year postoperatively. The success of interbody fusion was determined by standard CT scanning with 3-mm slices at the 6-month follow-up using the Brantigan–Steffee–Fraser (BSF) classification [14]. A classification of BSF-3 was considered as radiographic union, whereas BSF-2 was considered as locked pseudarthrosis and BSF-1 as non-union.

The PACS system software SmartIris (Taiwan Electronic Data Processing Co., Taiwan) was used to measure the bone graft surface area on axial films. The bone graft area was measured including the border of the morselized bone graft and the cage at the mid-disc level. The average endplate area was calculated as the average area of the superior and inferior adjacent vertebral endplates at the same level as the interbody bone graft. (Fig. 1) The bone graft area ratio was defined as the ratio of the bone graft area to the average endplate area. Bone graft area ratio (%) = (bone graft area/average endplate area) × 100 = [a/{(b + c)/2}] × 100. To analyze the distribution of bone graft surface area within the disc, we divided the total disc area into four parts: ipsilateral-dorsal, ipsilateral-ventral, contralateral-dorsal, and contralateral-ventral parts. The bone graft area ratio of each part of the disc was also recorded. All parameters were measured by two independent orthopedic specialists, and the average of their measurement was recorded for each parameter. Good intra- and interobserver reliabilities were demonstrated by Cronbach's alpha coefficients of 0.97 and 0.98, respectively, obtained from a random sample of patients.

Statistical analysis

Statistical analysis was performed using SPSS (version 22.0; IBM Corp., Armonk, NY, USA). Categorical data were compared using the Chi-square or Fisher's exact tests. Continuous data were compared using the independent t test. The two-tailed significance level was set at $p < 0.05$. The intra- and interobserver reliabilities were verified using Cronbach's alpha coefficient. Using the t test, we evaluated the power of the study and investigated whether these comparative results were convincing. We used G*Power software (Heinrich-Heine Universität Düsseldorf, Düsseldorf, Germany) to calculate the power of each comparison between the two groups.

Results

Fifty-seven patients with a total of 77 disc levels were included in the current study. Twenty-eight patients with 43 disc levels underwent open surgery (mean age, 69.1 ± 12.5 years), and 29 patients with 34 disc levels underwent MIS (mean age, 67.5 ± 8.9 years). There were no significant differences between the groups in terms of demographic characteristics including age, gender, body mass index, diabetes, smoking habits, and bone mineral density. Subgroup analysis revealed that there were more 1-level spine surgeries performed in the MIS group. The estimated blood loss, length of hospital stays, and surgery time were not different between the two groups for either 1- or 2-level surgery (Table 1).

To compare the fusion rates on CT scans, BSF-3 was regarded as successful solid union, while BSF-2 and BSF-1 were regarded as non-solid union. Of the 77 levels, 62 were considered as solid union, and the overall fusion rate was 80.5%. The fusion rate was 79.1% in the open group and 82.4% in the MIS group ($p = 0.718$; Table 2). Bone graft area ratio showed no difference between the two groups (open, 38 ± 10.8%; MIS, 38.1 ± 9.0%, $p = 0.977$). Figure 2 shows the results of bone graft area measurements in open and MIS TLIF. Analysis of the bone graft area distribution within the disc showed that the ipsilateral-dorsal part had the highest bone graft area ratio (open, 47.4 ± 13.8%; MIS, 50.1 ± 15.4%, $p = 0.443$). The second highest bone graft area ratio was within the ipsilateral-ventral part (open, 28.4 ± 18.0%; MIS, 33.1 ± 16.3%, $p = 0.237$). The second lowest bone graft area ratio was within the contralateral-ventral part (open, 24.3 ± 22.7%; MIS, 20.7 ± 11.1%, $p = 0.368$). Finally, the contralateral-dorsal part had the lowest bone graft area ratio, and the MIS group exhibited significantly lower bone graft area

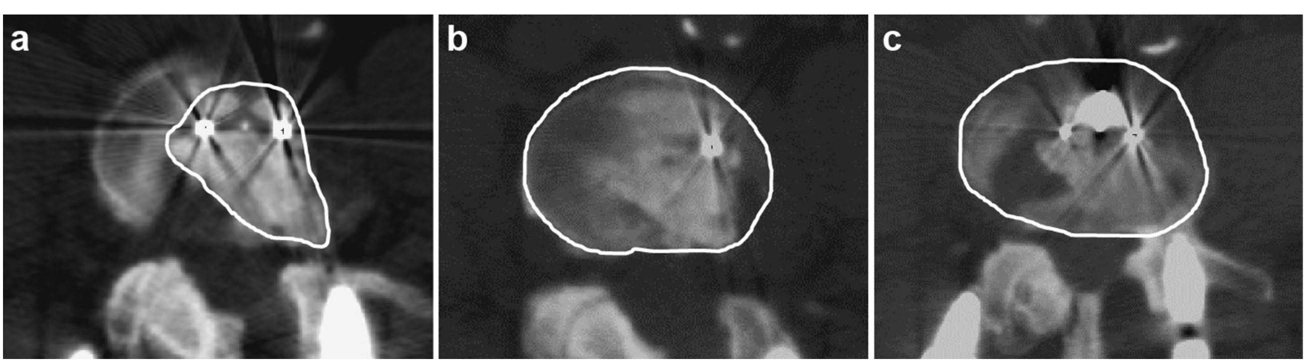

Fig. 1 Bone graft area ratio. **a** Bone graft area included the border of the morselized bone graft and the cage at the mid-disc level; **b** superior endplate area. The adjacent superior vertebral endplate area at the same level as the interbody bone graft was measured; c. inferior endplate area. The adjacent inferior vertebral endplate area. Bone graft area ratio (%) = (bone graft area/average endplate area) × 100 = [a/{(b + c)/2}] × 100

Table 1 Demographic data of the patients

Variables	Open group	MIS group	*P* value
Numbers of patients (*n*)	28	29	
Age (mean ± SD, years)	69.1 ± 12.5	67.5 ± 8.9	0.566
Sex (male/female)	11/17	11/18	0.916
BMI (mean ± SD, kg/m^2)	26.7 ± 3.7	26.8 ± 4.3	0.926
Diabetes (*n* (%))	9 (32.1%)	6 (21.5%)	0.365
Smoking (*n* (%))	2 (7.1%)	5 (17.9%)	0.422
T-score for BMD (mean ± SD)	− 1.2 ± 1.6	− 1.5 ± 1.3	0.811
Spinal level, fused (*n* (%))			
L4-5	9 (32.1%)	22 (75.9%)	
L5-S1	4 (14.3%)	2 (6.9%)	
L3-5	10 (35.7%)	4 (13.8%)	
L4-S1	5 (17.9%)	1 (3.4%)	
Subgroup analysis			0.004*
2-level surgery (*n* (%))	15 (53.6%)	5 (17.2%)	
1-level surgery (*n* (%))	13 (46.4%)	24 (82.8%)	
Patients received 1-level surgery (*n*)	13	24	
EBL (mean ± SD, ml)	353.9 ± 190.9	302.1 ± 137.9	0.399
Surgery time (mean ± SD, mins)	189.2 ± 55.2	220.0 ± 71.9	0.17
Hospital stay (mean ± SD, days)	7.6 ± 1.4	6.7 ± 2.3	0.15

MIS minimally invasive surgery, *SD* standard deviation, *BMI* body mass index, *BMD* bone marrow density, *EBL* estimated blood loss

* Significant result ($p < 0.05$)

Table 2 Radiologic results of fusion rate and bone graft area ratio

Fusion status and bone graft ratio	Open group	MIS group	*P* value
Numbers of levels (*n*)	43	34	
BSF classification by CT scan (*n* (%))			0.662
BSF-1	1 (2.3)	0 (0)	
BSF-2	8 (18.6)	6 (17.6)	
BSF-3	34 (79.1)	28 (82.4)	
Fusion rate (%)	79.1	82.4	0.718
Bone graft area ratio (mean ± SD,%)	38.0 ± 10.8	38.1 ± 9.0	0.977
Ipsilateral-dorsal	47.4 ± 13.8	50.1 ± 15.4	0.443
Ipsilateral-ventral	28.4 ± 18.0	33.1 ± 16.3	0.237
Contralateral-dorsal	22.3 ± 11.8	16.7 ± 11.2	0.038*
Contralateral-ventral	24.3 ± 22.7	20.7 ± 11.1	0.368

Bone graft area ratio (%) = (bone graft area)/(average endplate area) × 100

*Significant result ($p < 0.05$)

ratio than the open group (open, 22.3 ± 11.8%; MIS, 16.7 ± 11.2%, $p = 0.038$), with a power of 55%.

Clinical evaluation showed that the preoperative VAS scores of the two groups were not statistically different (open, 6.0 ± 1.7; MIS, 6.4 ± 2.3, $p = 0.59$). At the 12-month postoperative follow-up, the change in VAS score was similar between the open group (3.3 ± 2.8) and MIS group (5.1 ± 2.6, $p = 0.105$). The delta change in VAS score between the groups was not different (open, 3.3 ± 2.8; MIS, 5.1 ± 2.6, $p = 0.105$). The mean VAS scores significantly improved after the surgery compared to the baseline in both groups ($p < 0.001$ for the open group and $p < 0.001$ for the MIS group). The mean preoperative ODI scores were not significantly different between the two groups (open, 49.7 ± 11.2; MIS, 43.1 ± 17.6, $p = 0.245$). At the 12-month postoperative follow-up, the delta change in ODI score was similar between the open group (26.2 ± 27.2) and MIS group (38.1 ± 17.2, $p = 0.188$). The mean ODI scores significantly improved after surgery compared with the baseline in both groups ($p < 0.001$ for the open group and $p < 0.001$ for the MIS group) (Table 3).

The risk factors between solid and non-solid union levels were also analyzed. Of the total 77 fused levels in both the open and MIS-TLIF groups, 15 levels were considered as non-solid union and 62 as solid union (Table 4). In the non-solid union group, 2-level surgeries were more frequent ($p = 0.004$). Age, body mass index, and bone mineral density were not different between the two groups. Diabetes ($p = 0.063$) and smoking ($p = 0.101$) were slightly more common in the non-solid union group, but this was not a statistically significant difference. TLIF by MIS or the open method was not a risk factor for non-solid union ($p = 0.718$). Bone graft area ratio was significantly higher in the solid union

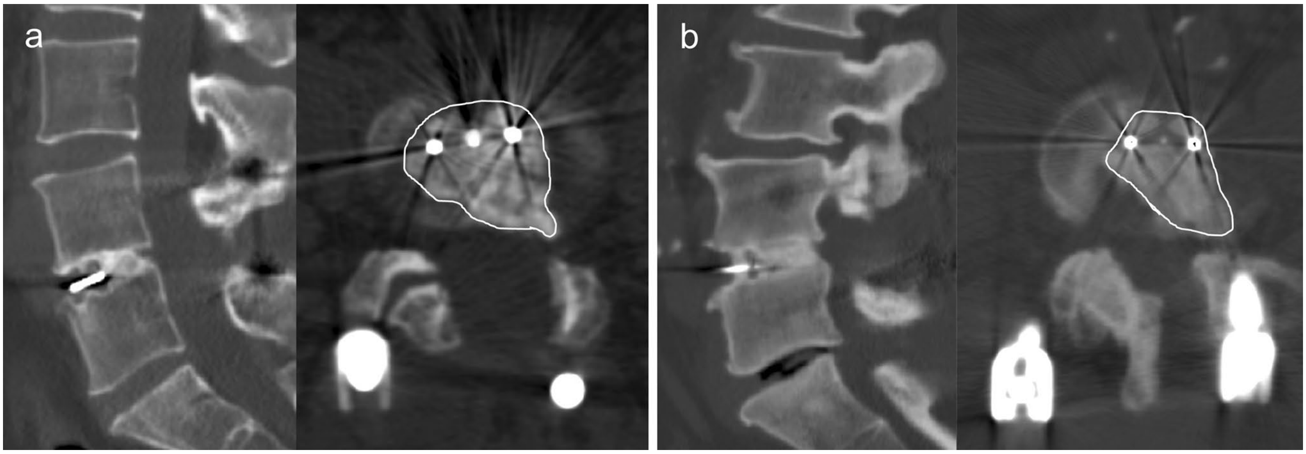

Fig. 2 Bone graft area measurements in open and minimally invasive transforaminal lumbar interbody fusion. **a** Bone graft areas of patients who underwent open transforaminal lumbar interbody fusion (TLIF). **b** Bone graft areas of patients who underwent minimally invasive TLIF

Table 3 VAS and ODI scores of MIS and open groups

Variables	Open group	MIS group	*P* value
Numbers of patients (*n*)	28	29	
VAS (mean ± SD)			
Pre-op	6.0 ± 1.7	6.4 ± 2.3	0.59
Post-op 12 months	2.2 ± 2.2	1.3 ± 1.7	0.077
Delta change	3.3 ± 2.8	5.1 ± 2.6	0.105
ODI (mean ± SD)			
Pre-op	49.7 ± 11.2	43.1 ± 17.6	0.245
Post-op 12 months	16.4 ± 18.6	4.4 ± 6.6	0.003*
Delta change	26.2 ± 27.2	38.1 ± 17.2	0.188

VAS visual analog scale, *ODI* Oswestry disability index

*Significant result ($p < 0.05$)

group (39.2 ± 10.4%) than in the non-solid union group (33.5 ± 6.4%, $p = 0.048$), with a power of 62%.

The rates of surgical complications were low in both groups. No root damage or early implant dislodgement occurred in either group. In the MIS group, six loosened screws were observed in four patients; and in the open group, four loosened screws were observed in two patients. The screw loosening rates were 7.7% in the MIS group and 3.4% in the open group. Only one broken screw was found in each group. None of the complications required surgery, and the reoperation rate in both groups was 0%.

Table 4 Risk factors between solid and non-solid union groups

Variables	Solid union group	Non-solid union group	*P* value
Numbers of levels (*n*)	62	15	0.004*
2-level surgery (*n* (%))	24 (38.7%)	12 (80%)	
1-level surgery (*n* (%))	38 (61.3%)	3 (20%)	
Age (mean ± SD, years)	69.7 ± 10.9	65.9 ± 6.7	0.206
BMI (mean ± SD, kg/m^2)	27.1 ± 4.1	25.9 ± 3.0	0.213
Diabetes (*n* (%))	16 (26.2%)	8 (53.3%)	0.063
Smoking (*n* (%))	6 (9.8%)	4 (26.7%)	0.101
T-score for BMD (mean ± SD)	− 1.4 ± 1.1	− 1.5 ± 1.4	0.858
Subgroup analysis (*n* (%))			0.718
MIS-TLIF	28 (45.2%)	6 (40%)	
Open-TLIF	34 (54.8%)	9 (60%)	
Bone graft area ratio (mean ± SD,%)	39.2 ± 10.4	33.5 ± 6.4	0.048*

Bone graft area ratio (%) = (bone graft area)/(average endplate area)

BMI body mass index, *BMD* bone marrow density, *MIS* minimally invasive surgery

*Significant result ($p < 0.05$)

Discussion

The method of TLIF with a single cage for interbody support has been gaining popularity due to its many advantages. It is one of the most popular fusion methods for degenerative lumbar diseases. Either open or MIS technique is frequently used, with both having good outcomes. The short-term outcomes of MIS-TLIF such as reduced estimated blood loss, shorter hospital stays, decreased narcotic use, and earlier mobilization in comparison with the open technique have been reported [9]. The long-term outcomes, such as the successful fusion rate, are of concern due to the challenging technique. A meta-analysis concluded that the fusion rates of both open and MIS-TLIF are relatively high and within similar ranges [15]. However, most of the previous studies used postoperative flexion–extension radiographs rather than CT scans to assess fusion. Furthermore, the interbody bone graft area was unknown. Thus, this is the first study to analyze the interbody bone graft area ratio in TLIF. There was no difference between the bone graft area ratios of open and MIS-TLIF on the 6 month postoperative CT scan.

The quantitative bone graft area in PLIF with two cages was reported to be approximately 52–53% on the 6 month postoperative CT scan [11, 12]. The interbody bone graft ratio in TLIF in the current study was lower than that previously reported in PLIF. Biomechanical studies have reported that the stiffness of lumbar interbody fusion with a single cage is almost equivalent to that with two standard cages in all modes of testing [16, 17]. Successful fusion and clinical results of the single cage method were compared with those of the two cage method [18]. Biomechanical studies have reported that the interbody graft area should be significantly greater than 30% of the total endplate area to provide a margin of safety [10, 19]. Although the bone graft area in our study was lower than that in PLIF, the fusion rate and clinical outcomes in patients who underwent open or MIS-TLIF were good at the 1-year follow-up. Additionally, the bone graft area within the disc space grows with time [11, 12, 20].

The bone graft area ratio is affected by discectomy and endplate preparation. In vitro cadaveric studies found that the rate of endplate preparation varied in different fusion approaches. Tatsumi et al. [21] showed that the average area of endplate preparation in MIS-TLIF (39.2%) was lower than that in MIS-PLIF (46.7%). In another cadaveric study, Rihn et al. [22] found that the endplate preparation rate could be as high as 71% when performed by an experienced surgeon and that it was not different between the MIS and open TLIF approaches. The contralateral-dorsal part was reported to have the lowest endplate preparation rate in the cadaveric study, which was similar to the findings of the current study. A possible explanation could be that it is more difficult to approach the contralateral-dorsal endplate with unilateral facetectomy. To enhance the bone graft area, intense endplate preparation over the contralateral-dorsal part may help while performing discectomy.

The fusion rate on the 6-month follow-up CT was relatively low. There are some possible explanations. First, we used CT scans to evaluate fusion status rather than plain film. The CT scans provide better resolution of the bridging callus than plain film, which may overestimate the fusion rate [23]. Second, we performed the CT scans at 6 months postoperatively. Several studies have reported that the interbody bone graft volume increases with time and that the fusion rate may also increase [11, 12, 20]. Third, although the fusion rates were lower than those reported in other studies at 6 months postoperatively, the clinical outcomes at the 1-year follow-up showed significant improvement in both groups. We conclude that both open and MIS TLIF were effective treatment methods.

There are some limitations to this study. First, the bone graft area was not measured by thin-cut CT; the 3-mm slices of standard CT may not be precise enough. Second, the number of enrolled patients was small, and the power of the study was insufficient to generalize our conclusions. Third, the volume of the inserted morselized bone graft was not measured, which might have an influence on the bone graft area. Fourth, we enrolled patients who received either 1- or 2-level spine surgeries. The levels may present another confounding factor which affected the outcome, and this was not adjusted for in the study. Finally, we did not compare the bone graft area ratio with respect to fusion status in the open and MIS TLIF groups separately. Elucidating the effect of bone graft area ratio on fusion status in open or MIS TLIF requires further study.

Conclusions

The interbody bone graft area ratio in patients who underwent unilateral MIS-TLIF was similar to that of patients who underwent traditional open TLIF. The lowest bone graft area ratio of the disc was in the contralateral-dorsal part in both groups. The fusion rate, clinical outcomes, and complications were similar between patients who underwent MIS and open TLIF. The bone graft area was significantly higher in patients with solid union than that in those with non-solid union.

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Compliance with ethical standards

Conflict of interest None of the authors have any potential conflict of interests.

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