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Radiographic Results of Minimally Invasive (MIS) Lumbar Interbody Fusion (LIF) Compared with Conventional Lumbar Interbody Fusion

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Objective: To evaluate the radiographic results of minimally invasive (MIS) anterior lumbar interbody fusion (ALIF) and transforaminal lumbar interbody fusion (TLIF).
Methods: Twelve and nineteen patients who underwent MIS-ALIF, MIS-TLIF, respectively, from 2006 to 2008 were analyzed with a minimum 24-months' follow-up. Additionally, 18 patients treated with single level open TLIF surgery in 2007 were evaluated as a comparative group. X-rays and CT images were evaluated preoperatively, postoperatively, and at the final follow-up. Fusion and subsidence rates were determined, and radiographic parameters, including lumbar lordosis angle (LLA), fused segment angle (FSA), sacral slope angle (SSA), disc height (DH), and foraminal height (FH), were analyzed. These parameters were also compared between the open and MIS-TLIF groups.
Results: In the MIS interbody fusion group, statistically significant increases were observed in LLA, FSA, and DH and FH between preoperative and final values. The changes in LLA, FSA, and DH were significantly increased in the MIS-ALIF group compared with the MIS-TLIF group, but SSA and FH were not significantly different. No significant differences were seen between open and MIS-TLIF except for DH. The interbody subsidence and fusion rates of the MIS groups were 12.0 ±4% and 96%, respectively.
Conclusion: Radiographic results of MIS interbody fusion surgery are as favorable as those with conventional surgery regarding fusion, restoration of disc height, foraminal height, and lumbar lordosis. MIS-ALIF is more effective than MIS-TLIF for intervertebral disc height restoration and lumbar lordosis.

Key Words: Minimally Invasive Interbody Fusion · Transforaminal Lumbar Interbody Fusion · Anterior Lumbar Interbody Fusion · Radiographic Results

INTRODUCTION

Various lumbar interbody fusion procedures are used to treat lumbar degenerative disc disease and spinal instability. Among them, posterior lumbar interbody fusion (PLIF) and transforaminal lumbar interbody fusion (TLIF) are representative surgical approaches. However, the disadvantages of wide open posterior approaches to the lumbar spine, such as persistent low back pain caused by iatrogenic muscle denervation resulting in atrophy and decreased trunk extensor strength, large amount of blood loss, and long recuperation time, are issues awaiting solutions[4,10,11,14,15,27,29,32]. Additionally, it has prompted the development of minimally invasive (MIS) spinal surgery techniques such as MIS-TLIF and MIS-ALIF. Such techniques have become increasingly popular for achieving lumbar interbody fusion. Moreover, numerous articles for MIS lumbar interbody fusion have been published.

However, most of these reports have focused on surgical techniques and clinically significant results, such as reduced intraoperative blood loss, improvement in post-operative back pain, and shorter hospitalization stays, in comparison with conventional open surgery. Very few studies based on radiographic results of MIS lumbar interbody fusion have been performed. Radiographic results, including interbody fusion, the restoration of disc height, foraminal height, and maintenance of normal lumbar lordosis are very important to post-operative clinical outcomes for lumbar interbody fusion surgery over the long term.

The purpose of the present study was to evaluate the radio-

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graphic results of MIS-ALIF and MIS-TLIF and also compare those of MIS lumbar interbody fusion with conventional lumbar interbody fusion.

MATERIALS AND METHODS

We assessed 31 patients who were treated with MIS lumbar interbody fusion in our hospital from July 2006 to September 2008. The mean follow-up period was 31.6 months with a minimum 24 months' follow-up. The patients consisted of 14 men and 17 women, and the mean age was 54 years (range, 35-70 years). All patients had symptoms unresponsive to conservative treatment for at least 6 months. Patients were diagnosed preoperatively with foraminal stenosis in 12 cases, degenerative spondylolisthesis in 7 cases, disc degenerative disorder (DDD) in 6 cases, isthmic spondylolisthesis in 4 cases, and recurrent HNP in 2 cases. Twelve patients presenting with back pain or bilateral leg pain dominant pathology were treated with MIS-ALIF, and 19 patients with unilateral radiating leg pain dominant pathology were treated with MIS-TLIF. Percutaneous pedicle screw fixations with the Sextant® or VIPER® system were used in all patients who underwent MIS interbody fusions. Thirty-four interbody fusion levels were performed in total: 6 on L3-4, 15 on L4-5, and 13 on the L5-S1 level. We selected 18 patients as a comparative group, with corresponding ages, gender ratio, and preoperative clinical symptoms, who underwent single level open TLIF in 2007 and were followed up for at least two years. All patients underwent follow-up CT and X-rays at 1, 6, 12, and 24 months postoperatively.

In the present study, the following radiographic parameters were determined: interbody fusion, lumbar lordosis angle (LLA), fused segment angle (FSA), sacral slope angle (SSA), disc height (DH) and foraminal height (FH), and the subsidence rate of interbody fusion. Successful bony fusion was determined as follows: presence of bony bridging, absence of radiolucent lines around the cage on final follow-up CT or X-rays, and no motion on flexion/extension lateral X-rays. LLA was estimated as the Cobb's angle between the L1 upper endplate and the S1 upper endplate. FSA was estimated as the Cobb's angle between the upper endplate of the upper vertebra and the lower endplate of the lower vertebra at the fusion level. SSA was determined as the angle between the S1 superior endplate and a horizontal reference line. Disc height (DH) was calculated as the average of anterior disc height (ADH) and posterior disc height (PDH). Foraminal height (FH) was estimated as the distance between the inferior pedicle wall above the index disc space and the superior pedicle wall of the lower vertebra (Fig. 1). A subsidence rate of interbody disc height was calculated as a percentage as follows: [immediate postoperative disc height - final disc height] / [immediate postoperative disc height] × 100.

Radiographic parameters of MIS lumbar interbody fusion

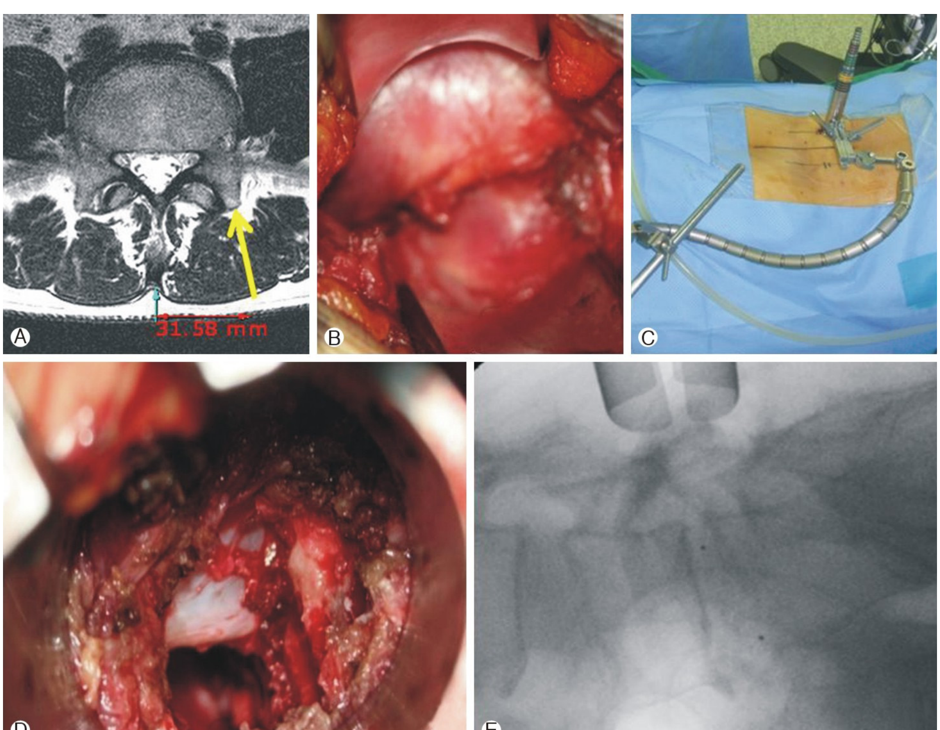

Fig. 1. Surgical procedure.
A: The intermuscular plane between the multifidus and longissimus muscles is measured about 3 cm lateral to the midline in a T2-weighted axial magnetic resonance image (MRI). Yellow arrow indicates a trajectory of surgical approach. B: After skin incision and muscle fascia dissection, the intermuscular plane is observed. C: After intermuscular dissection and dilation, a tubular retractor is inserted. D: An intraoperative microscopic photo shows the transversing nerve root and interbody disc space after unilateral total facetectomy, discectomy, and endplate preparation. E: An intraoperative lateral X-ray view shows an interbody single cage in the L5-S1 disc space.

were evaluated preoperatively and postoperatively and statistically analyzed. The changes of preoperative and final radiographic parameters were compared statistically between the MIS-ALIF and MIS-TLIF groups and the MIS-TLIF and open TLIF groups.

Statistical comparisons utilized the Wilcoxon signed-rank test and the Mann-Whitney U test. Statistically significant P values were considered as less than 0.05.

Surgical technique

Minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF)

Under general anesthesia, the patient was placed in a prone position on a Jackson operation table and taken to a lumbar lordosis position with hip extension. A longitudinal skin incision of approximately 3 cm in length was made lateral to the midline on the affected side. To approach the lesion facet joint precisely and minimize the skin incision, the distance from the spinous process line to the multifidus and longissimus muscle plane was measured on the preoperative axial MRI (Fig. 1A). Generally, the intermuscular plane is located at approximately 3 cm from the midline, and muscle dissection precedes 3 cm lateral to the midline; however, the skin incision was made at 3 to 4 cm lateral to the midline. It is easier to lay the tubular retractor slightly to the lateral side and to facilitate decompression of opposite disc.

An intermuscular plane dissection, which exfoliated the multifidus and longissimus muscles after fascial incision, was performed (Fig. 1B). After complete exfoliation of the facet joint lesion and part of the post lamina, the dilator was inserted to dilate the muscle, and a 22 mm Quadrant tubular retractor (Medtronic Sofamor Danek, Memphis, TN) was subsequently inserted. After adjustments were made, it was then fixed on the operation table (Fig. 1C).

The soft tissue on the lateral side of the facet joint was totally exfoliated, and a partial inferior vertebra transverse process was exposed. A fine high-speed drill was used to hollow out the groove at the inferior articular facet of the superior vertebra in "ㄱ" shape, and a bayonet-shaped osteotome was used to break the bone. The osteotome was also used to break the exposed superior articular facet of the inferior vertebra. After total facetectomy was completed, the exposed ligamentum flavum was incrementally removed, and then the spinal canal in the medial, the traversing nerve root in the inferior medial, and the exiting nerve root in the superior lateral side were confirmed (Fig. 1D). If a central canal stenosis or contralateral side disc herniation was present, the tubular retractor was leaned more. Then the central stenosis and contralateral side lesion was decompressed.

The maximum amount of disc was removed, and meticulous endplate preparation was executed with diverse shaped and diverse angled reamer, distractors, curettes, scarpers, and pituitary punches. This process is most important to generating a sufficient intervertebral bone fusion bed. Then, autologous and allograft bone were sufficiently inserted at the ventral disc space and was tamped down compactly using a bone impactor. A single large interbody cage was inserted as unilaterally as possible as oblique to the contralateral side while protecting the exiting and traversing nerve root with a root retractor (Fig. 1E).

After completion of the interbody fusion procedure, in the same incision area, percutaneous pedicle screw fixations were performed, and rods were inserted under fluoroscopic guidance. Identical procedures were performed on the opposite side. During rod compression and final tightening procedures, care was taken to keep the rod position stable.

RESULTS

Thirty-one patients who were treated with MIS lumbar interbody fusion in our hospital were evaluated in this study. Twelve patients underwent MIS-ALIF and 19 patients underwent MIS-TLIF procedures.

In the MIS interbody fusion cases, pre- and postoperative radiographic parameters were the following: mean lumbar lordosis angle (LLA), 32.8±12.1° and 38.9±11.1°; fused segment angle (FSA), 12.1±6.3° and 14.8±6.7°; sacral slope angle (SSA), 30.1±7.3° and 32.5±8.6°; disc height (DH), 10.0±3.0 mm and 13.9±2.5 mm; and foraminal height (FH), 16.7±4.5 mm and 19.9±3.9 mm. All radiographic parameters had statistically significant improvements at the postoperative measurement except for SSA (Table 1).

The changes (final value-preoperative value) of radiogra-

Table 1. Preoperative versus final values of radiographic parameters for MIS-LIF

Parameter	Preoperative data	Final data	p-value
LLA (°)	32.8±12.1	38.9±11.1	0.004*
FSA (°)	12.1±6.3	14.8±6.7	0.014*
SSA (°)	30.1±7.3	32.5±8.6	0.051
DH (mm)	10.0±3.0	13.9±2.5	0.000*
FH (mm)	16.7±4.5	19.9±3.9	0.000*

LLA, lumbar lordosis angle; FSA, fused segment angle; SSA, sacral slope angle; DH, disc height; FH, foraminal height. *This is significantly ($p<0.05$) different with preoperative and final data by Wilcoxon signed-rank test.

Table 2. MIS-ALIF versus MIS-TLIF

Final-preoperative value	MIS-ALIF	MIS-TLIF	p-value
LLA (°, final-preop)	12.1±7.4	2.1±9.7	0.02*
FSA (°, final-preop)	5.5±3.5	0.7±4.9	0.03*
SSA (°, final-preop)	3.5±5.2	1.5±5.2	0.41
DH (mm, final-preop)	6.3±2.6	2.3±1.9	0.00*
FH (mm, final-preop)	4.3±3.3	2.4±3.2	0.20

*This is significantly ($p<0.05$) different using a Mann-Whitney U-test.

Table 3. Open TLIF versus MIS-TLIF

Final-preoperative value	Open TLIF	MIS-TLIF	p-value
LLA (°, final-preop)	5.4±12.1	2.1±9.7	0.52
FSA (°, final-preop)	3.6±4.5	0.7±5.0	0.46
SSA (°, final-preop)	1.7±10.2	1.5±5.2	0.82
DH (mm, final-preop)	4.3±4.0	2.3±1.9	0.03*
FH (mm, final-preop)	3.0±3.2	2.4±3.2	0.71

*$p<0.05$, Mann-Whitney U test.

Table 4. Change of preoperative and postoperative disc height for MIS-LIF

Parameter	Preoperative data	Postoperative data	Final data
ADH (mm)	11.1±3.4	17.3±2.3	15.6±2.8
PDH (mm)	8.9±3.1	13.9±2.0	12.3±2.5
DH (mm)	10.0±3.0	15.6±2.0	13.9±2.5

ADH, anterior disc height; PDH, posterior disc height.

phic parameters between MIS-ALIF and MIS-TLIF were also analyzed. In the MIS-ALIF group, the changes of radiographic parameters were as follows: LLA, FSA, SSA, DH, and FH were 12.1±7.4°, 5.5±3.5°, 3.5±5.2°, 6.3±2.6 mm, and 4.3 ±3.3 mm, respectively. In the MIS-TLIF group, changes in values in the same order were as follows: 2.1±9.7°, 0.7±4.9°, 1.5±5.2°, 2.3±1.9 mm, and 2.4±3.2 mm. No significant differences in SSA and FH were observed between the two groups, although LLA, FSA, and DH showed statistically significant increases in the MIS-ALIF group (Table 2).

In 2007, 18 patients who had single level open TLIF with a minimum 12 months X-ray follow-up were analyzed for the same parameters. Between the open TLIF and MIS-TLIF groups, the changes (final value-preoperative value) of radiographic parameters were compared. The changes of LLA, FSA, SSA, DH, and FH in the open TLIF group were 5.4±12.1°, 3.6±4.5°, 1.7±10.2°, 4.3±4.0 mm, and 3.0±3.2 mm, respectively. Only the disc height was significantly increased in the open TLIF group; the other parameters were not significantly different (Table 3).

Additionally, a mean subsidence rate of interbody disc height was 12.0±4% (Table 4), and the fusion rate was 96% (one pseudarthrosis in the MIS-ALIF group).

DISCUSSION

The MIS-TLIF technique was reported by Foley et al.[6] in 2003 and has come into wide use. This technique involves partially dissecting and dilating the paraspinal muscle using a 20-24 mm-sized small tubular retractor, performing unilateral facetectomy, interbody bone fusion, and percutaneous pedicle screw fixation. Therefore, this procedure has the advantages of minimizing paraspinal muscle and soft tissue injury, no need for transfusion by reducing intraoperative bleeding, makes early ambulation possible because postoperative back pain is minimal, and reduces the number of in-hospital days as compared with standard open lumbar interbody fusion techniques[24,28]. Despite these many merits, this surgical technique requires a steep learning curve. Within a less than 3 cm operative field of view, the exposure and resection of the targeted facet joint (inferior and superior articular facet), epidural bleeding control, discectomy, sufficient neural decompression, endplate preparation, and appropriate interbody cage insertion without nerve root injury requires a great deal of time and is uncomfortable for the operator[22]. However, one level lesion can be finished up successfully within 3 hours after a learning curve period of approximately 15 cases. In our study, unilateral leg pain dominant pathologies, such as disc protrusion with instability, recurrent disc herniation, unilateral foraminal stenosis, unilateral foraminal disc herniation, and grade I spondylolisthesis were treated with MIS-TLIF. The MIS-ALIF technique was developed for minimizing abdominal soft tissue and internal organ injury, which can lead to the early recovery of the patient by reducing post-operative pain and complications such as wound problems. The greatest advantage of the ALIF approach may be the direct access and visualization of the intervertebral disc space. As a result, it is generally accepted that this approach can achieve a more complete discectomy, secure a wide fusion bed, and perform a more effective restoration of disc and foraminal height. Additionally, it is easier to correct a sagittal balance as lumbar lordosis by anterior column support and stabilization directly. Furthermore, ALIF does not violate the posterior spinal musculature or bony elements, and epidural scarring, nerve root retraction, and perineural fibrosis can be avoided. In this study, back pain dominant or bilateral pathologies, such as lumbar disc degenerative disorder (DDD), unilateral or bilateral foraminal stenosis with significant disc space narrowing, and grade II and more spondylolisthesis were treated with MIS-ALIF.

In the present study, evaluated radiographic parameters were shown as lumbar lordosis angle (LLA), fused segment angle

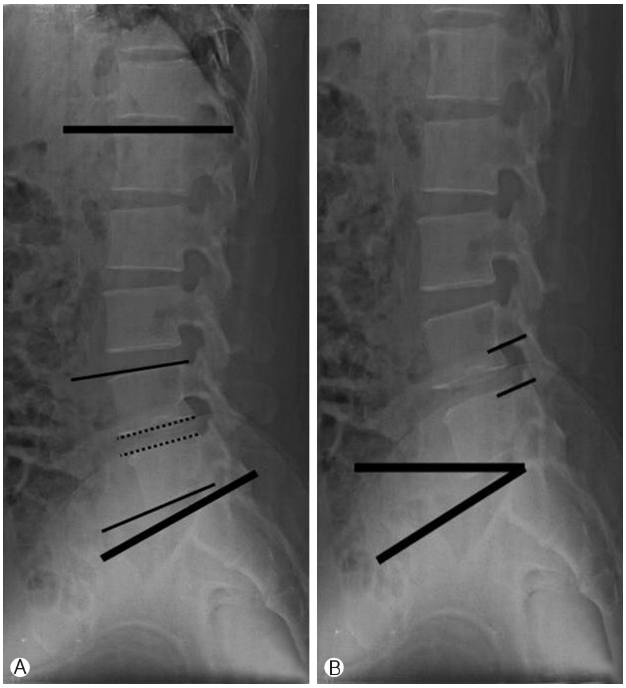

Fig. 2. The radiographic parameters.
A: Thick line angle indicates lumbar lordosis angle (LLA); thin line angle, fused segment angle (FSA); a distance between dotted lines, disc height (DH). B: Thick line angle, sacral slope angle (SSA); a distance between thin lines, foraminal height (FH).

(FSA), sacral slope angle (SSA), foraminal height (FH), and disc height (DH). These parameters have direct relations to preoperative clinical symptoms and postoperative clinical outcomes. Radiographic parameters related to sagittal balance, such as LLA, FSA, and SSA, are significantly correlated with low back pain (LBP)[17] and adjacent segment degeneration (ASD)[21], postoperatively. Lazennec et al.[19] reported that LBP developing after fusion surgery was shown to be significantly related to a decreased sacral tilt, increased pelvic tilt, and decreased lumbar lordosis. Additionally, postoperative sagittal lumbar malalignment can accelerate adjacent segment deterioration by loading the motion segment in a nonphysiologic fashion[30]. The optimal sagittal balance obtained with surgical correction of a spinal deformity may also affect the environment for bony fusion, preservation of the adjacent levels, and clinical outcome over the long term[1,5,8,18]. Unlike other studies, our study includes radiographic results of MIS-ALIF as well as MIS-TLIF. In the MIS-ALIF group, the change (final value-preoperative value) of LLA, FSA, and SSA was 12.1°, 5.5°, and 3.5°; it is an obvious improvement of regional sagittal balance. In the MIS-TLIF group, those parameters also increased. Statistical analysis between the two groups showed that MIS-ALIF was more effective in correcting sagittal balance than MIS-TLIF (Table 2). Moreover, the changes of LLA, FSA, and SSA after MIS-TLIF were comparable to those of open TLIF in statistical analysis between open TLIF and MIS-TLIF (Table 3). This indicates that MIS lumbar interbody fusion surgery is a viable strategy for sagittal balance correction of lumbar degenerative disc disease.

In the present study, evaluated foraminal height (FH) and disc height (DH) are correlated with radiculopathy. In foraminal stenosis, a nerve root is compressed laterally to the intervertebral foramen by bony structures such as a hypertrophied facet and spur developed by disc degeneration[7,31]. Disc degeneration causes disc height and foraminal height to be narrowed, which are checked on lateral X-ray as the parameters of foraminal stenosis. Surgical removal of bony structures and restoration of foraminal and disc height can decrease the radiating leg pain of the patient. Kim et al.[16] reported that by MIS-TLIF, DH was significantly increased at the final follow-up compared with the preoperative value, but FH was not evaluated. In our cases, DH was increased from 10.0 mm prior to surgery to 13.9 mm at the final follow-up, and FH was increased from 16.7 mm to 19.9 mm. Both changes were statistically significant differences (Table 1). In the MIS-ALIF group, the changes (final value-preoperative value) of DH and FH were obvious, as increases of 6.3 mm and 4.3 mm, respectively, were observed. In the MIS-TLIF group, those parameters were also increased. By statistical analysis between the two groups, MIS-ALIF was more effective in the restoration of disc height than MIS-TLIF (Table 2). These differences may be explained that MIS-ALIF is performed anterior opening and release by resection of ALL, and it can be more restored DH as well as FH compared that of MIS-TLIF. Additionally, both the open TLIF and MIS-TLIF groups showed statistically significant increases in FH; however, this was not the case for DH (Table 3). As a result, the restoration of DH and FH are sufficiently possible with MIS lumbar interbody fusion, which can resolve the radiating leg pain of patients.

A high fusion rate must be a precondition for lumbar interbody fusion surgery. Successful interbody bone fusion is essential to getting a good clinical outcome; if successful bony fusion is not achieved, back pain occurs in the long term. Previously reported fusion rates after PLIF ranged from 56 to 100%[2,13,23], and fusion rates after TLIF have ranged from 86 to 100%[9,12,22,25-28]. The limited exposure inherent to MIS techniques that requires fusion has the potential to affect adequate bone grafting and endplate preparation to allow for arthrodesis to occur. Potter et al.[25] have reported that for obtaining firm interbody fusion, exposure of more than 30% of the interbody endplate is required, and clinically, by using the unilateral transforaminal approach, an average of 69% of the disc volume (56% of the endplate) could be removed. It is actually very difficult within the narrow operative field of the MIS approach. Despite this concern, several articles on MIS-TLIF have demonstrated good bone fusion rates ranging from 92 to 100%[16,20,33]. On the other hand, Deutsch et al.[3] reported a fusion rate for MIS-TLIF of 65%. In the present study, the fusion rates of MIS-TLIF and MIS-ALIF group were 100% and 91.7% (one psuedoarthrodesis in MIS-ALIF group), respectively. We made a ceaseless effort for successful bone fusion in as many patients as possible; meticulous and precise endplate preparation and grafting a large amount of mixed bone chips to the ventral interbody disc space before cage insertion were performed within a narrow operative field. Finally, the subsidence of interbody disc height is important to lumbar interbody fusion surgery postoperatively. Progress of subsidence can cause a recurrent foraminal stenosis by narrowing foraminal height and destroy a corrected sagittal balance, which may lead to recurrent radiating leg and back pain. In our study, a subsidence rate of interbody disc height was 12% as 1.7 mm. Usually, significant subsidence is defined as a decrease in interbody disc height of more than 3 mm. Thus, our subsidence rate of interbody disc height seems remarkably low. For minimizing the subsidence rate of interbody disc height, grafting a lot of mixed bone chips compactly at the ventral disc space for anterior column support and inserting a single large interbody cage as unilaterally as possible as oblique to the contralateral side for equal distribution of axial loading to the cage is considered very helpful. These kinds of operator's efforts can bring out a high fusion rate and low subsidence rate. Furthermore, it is connected to good clinical outcome.

CONCLUSION

MIS lumbar interbody fusion (MIS-ALIF and MIS-TLIF) is successful and safe with the advantages of minimally invasive spine surgery (MISS). Radiographic results, including fusion rate, restoration of disc and foraminal height, and the improvement of lumbar lordosis were comparable to those with conventional open surgery. Additionally, MIS-ALIF is more effective in the restoration of lumbar lordosis and disc height than MIS-TLIF. To determine the effectiveness of MIS lumbar interbody fusion, larger, long-term, prospective studies are needed in the future.

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