What affects the surgical site segmental lordosis after MIS-TLIF?

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Directed by Professor Jeong-Yoon Park

The Master's Thesis
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Soo-Heon Kim

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This certifies that the Master's Thesis of Soo-Heon Kim is approved.

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<TABLE OF CONTENTS>

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

What affects the surgical site segmental lordosis after MIS-TLIF?

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Recently, MIS-TLIF using a single cage has become popular. Cage insertion plays a major role in creating lordosis during MIS-TLIF compared with conventional interbody fusion. In this study, we sought to find out factors that affects segmental lordosis after MIS-TLIF by comparing patients whose segmental lordosis increased with those who experienced a decrease.

A retrospective analysis was performed on 55 patients who underwent MIS-TLIF at our institute from January 2018 to September 2019. Demographic, pre- and postoperative radiologic and cage-related factors were included. The statistical analyses compared patients whose SL increased with decreased after surgery.

After surgery, SL increased in 34 patients (group I) and decreased in 21 patients (group D). All preoperative and postoperative radiologic parameters differed significantly except Segmental Lordosis, Pelvic Incidence, and Distal Lumbar Lordosis. The index level, Disc Lordosis (DCL), Segmental Lordosis (SL), Lumbar Lordosis (LL), Proximal Lumbar Lordosis (PL), and Y axis position of the cage center differed significantly between groups I and D. In group I, the index level was more often L4/5 (94.1%) than L3/4 (5.9%) compared with group D (71.4% and 28.6%). DCL (5.15° vs. 8.27°), SL (12.40° vs. 16.31°). LL (41.29° vs. 47.28°), and PL (9.40° vs. 15.86°) were significantly smaller in group I than group D. The cage in group I was more anterior than in group D (cage Y axis: 55.84 vs. 51.24). The multivariate analysis showed that SL decreased more significantly after MIS-

TLIF when the index level was L3/4 than when it was L4/5 (OR: 0.46, p =0.019), as preoperative SL (OR: 0.82, p =0.037) or PL (OR: 0.68, p =0.028) increased, and as the cage became more anterior (OR: 1.10, p =0.032).

Changes in SL after MIS-TLIF are associated with preoperative SL and PL, the index level, and the Y axis position of the cage. An index level at L4/5 instead of L3/4, smaller preoperative SL or PL, and an anterior position for the cage are likely to result in increased SL after MIS-TLIF.

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I. INTRODUCTION

Interbody fusion is widely used in treating degenerative diseases of the spine. Many techniques have been developed to decompress and restore sagittal alignment, including anterior lumbar interbody fusion (ALIF), lateral lumbar interbody fusion (LLIF), transforaminal lumbar interbody fusion (TLIF), and posterior lumbar interbody fusion. Many authors have emphasized the importance of adequately restoring sagittal alignment by means of interbody fusion[1,2] because it is associated with both adjacent segment disease after surgery and clinical outcomes.

Recently, minimally invasive transforaminal interbody fusion (MIS-TLIF) using a single cage and percutaneous pedicle screw fixation has become popular. MIS-TLIF has many advantages compared with conventional TLIF[3-10]. It uses smaller surgical incisions, damages less paraspinal muscle, and causes less bleeding during surgery. Furthermore, it is associated with shorter hospitalization and a shorter postoperative period with an external brace.

Unlike in conventional surgery, because it requires less dissection of paraspinal tissue and a more limited extent of osteotomy, the cage plays a major role in creating lordosis in MIS surgery. Many studies have reported on the relationship between cage characteristics and lordosis[11-21]. However, how cage position affects postoperative lordosis after MIS-TLIF has been studied indirectly only by comparing dichotomized group of anterior or posterior cage positioning, but not quantitively[13,18]. As far as we know, this is first analysis between exact cage position and postoperative lordosis. In this study, we sought to find out factors that

affects segmental lordosis after MIS-TLIF by comparing patients whose segmental lordosis increased with those who experienced a decrease.

II. MATERIALS AND METHODS

1. Patients selection

We performed a retrospective analysis in patients who underwent MIS-TLIF for degenerative lumbar disease at our institute from January 2018 to September 2019. We set our exclusion criteria to control variables and thereby achieve coherent data. Our exclusion criteria were: revision cases (adjacent level had underwent laminectomy or fusion previously), index level for surgery of L1/2 or 2/3, more than one interbody fusion level, and missing data. In that way, we included patients who received MIS-TLIF at only one index level (L3/4 or L4/5) with a CAPSTONE® PEEK cage (Medtronic, Minneapolis, MN, USA) and ARTeMIS® Percutaneous screw (Medyssey, Buffalo, IL, USA) for lumbar degenerative disease (**Figure 1**). The Human Research Protection Center of our university waived the need for Institutional Review Board approval, and the Institutional Review Board of Gangnam Severance Hospital, Yonsei University College of Medicine approved this study (No. 3-2020-0150).

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┌─────────────────────────────────────────────────┐
│ MIS TLIF, Lumbar degenerative disease (n=80)      │
└─────────────────────────────────────────────────┘
                    │                ┌──────────────────┐
                    │          →     │ Revision (n=3)   │
                    ↓                └──────────────────┘
          ┌──────────────────────┐
          │ Index surgery (n=77) │
          └──────────────────────┘
                    │
                    ↓
          ┌──────────────────────┐      ┌──────────────────────────┐
          │ No. of fusion level  │  →   │ 2 level fusion (n=13)    │
          └──────────────────────┘      │ 3 level fusion (n=2)     │
                    │                    └──────────────────────────┘
                    ↓
          ┌──────────────────────────┐
          │ 1 level fusion (n=62)    │
          └──────────────────────────┘
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          ┌──────────────────┐      ┌──────────────────┐
          │ Index level      │  →   │ L1/2 (n=1)       │
          └──────────────────┘      │ L2/3 (n=2)       │
                    │                └──────────────────┘
                    ↓
          ┌──────────────────────────┐
          │ L3/4, L4/5 (n=59)        │
          └──────────────────────────┘
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          ┌──────────┐      ┌──────────────────────────┐
          │ Cage     │  →   │ Anyplus cage (n=1)       │
          └──────────┘      │ Panther cage (n=1)       │
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          │ Capstone cage (n=57)     │
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               │ N=55     │
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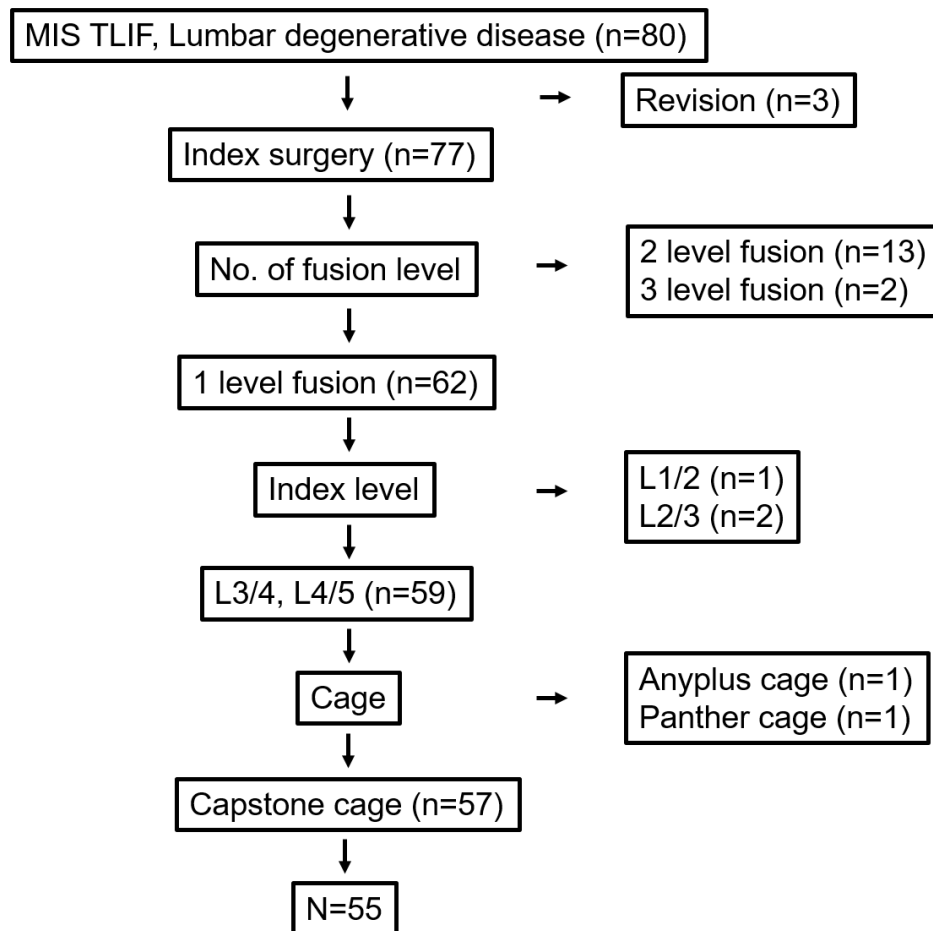
Fig. 1. Flow diagram for patient selection.

2. Parameters

A. Preoperative radiologic parameters

We examined 33 parameters, which we divided into demographic, pre- and postoperative radiologic, and cage-related parameters. The demographic parameters were age, sex, diagnosis, and index level of surgery. The pre- and postoperative radiologic parameters were disc lordosis (DCL), anterior disc height (DHA), posterior disc height (DHP), segmental lordosis (SL), lumbar lordosis (LL), proximal lumbar lordosis (PL), distal lumbar lordosis (DL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and PI-LL which were measured on postoperative 1 year standing lumbar x-ray image. The detailed measurement method for the radiologic parameters is shown in **Figure 2**.
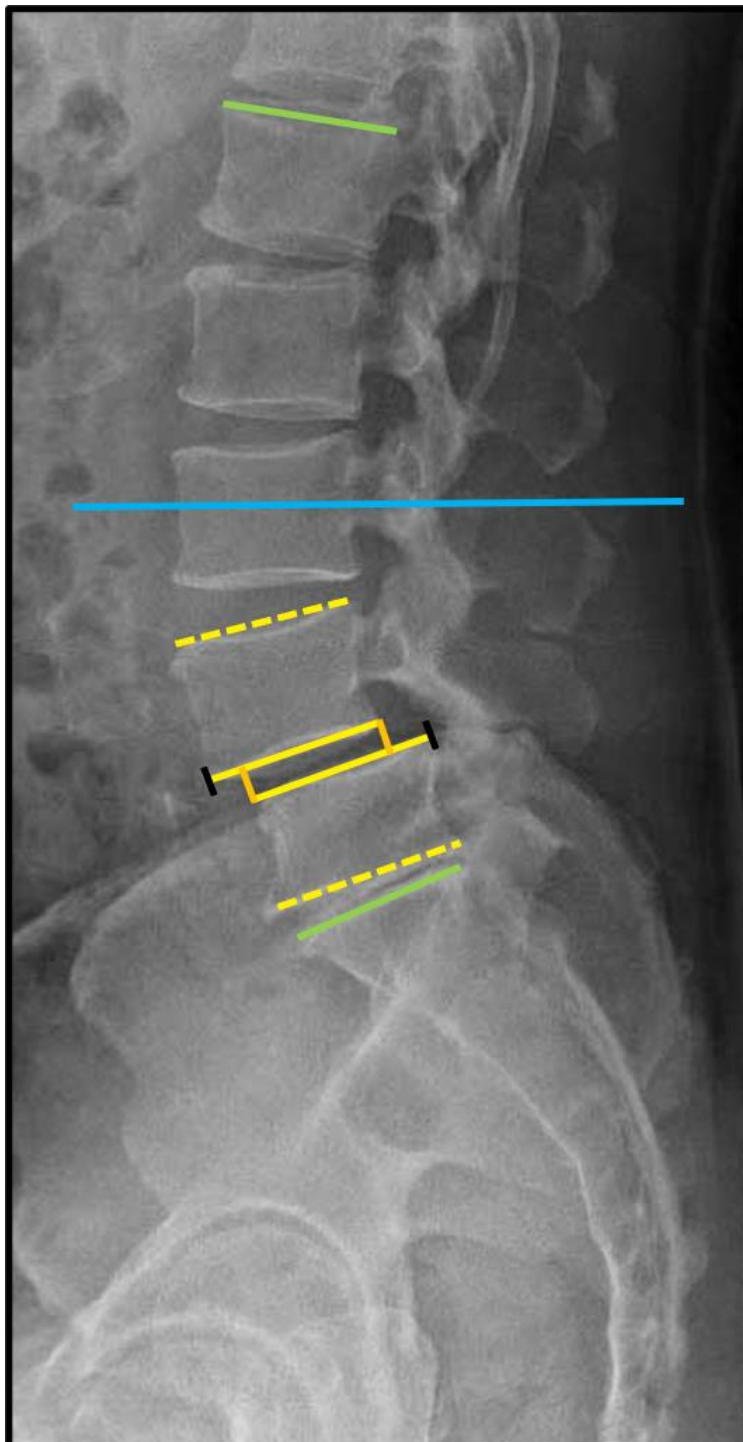
.

Fig. 2. Preoperative radiologic parameters. Disc lodosis (DCL): angle between the inferior endplate of the upper vertebra and the superior endplate of the lower vertebra of the index level (yellow line), Segmental lordosis (SL): angle between the superior endplate of the upper vertebra and the inferior endplate of the lower vertebra of the index level (yellow dotted line). Anterior disc height (DHA): perpendicular distance between the superior endplate of the anterior end of the lower vertebra and the inferior endplate of the upper vertebra of the index level (anterior orange line). Posterior disc height (DHP): perpendicular distance between the inferior endplate at the posterior end of the upper vertebra and the superior endplate of the lower vertebra of the index level (posterior orange line). Lumbar lordosis (LL): angle between the superior endplate of L1 and the superior endplate of S1 (green line). Proximal lordosis (PL): angle between a horizontal line (blue line) and the superior endplate of the L1 vertebra (superior green line). Distal lordosis (DL): angle between a horizontal line and the superior endplate of S1 (inferior green and blue line).

DCL was defined as the angle between the inferior endplate of the upper vertebra of the index level and the superior endplate of the lower vertebra of the index level. SL was defined as the angle between the superior endplate of the upper vertebra of the index level and the inferior endplate of the lower vertebra of the index level. DHA was defined as the perpendicular distance between the anterior end of the superior endplate of the lower vertebra of the index level and the inferior endplate of the upper vertebra of the index level. DHP was defined as the perpendicular distance between the posterior end of the inferior endplate of the upper vertebra of the index level and the superior endplate of the lower vertebra of the index level. LL was defined as the angle between the superior endplate of the L1 vertebra and the superior endplate of the S1 vertebra. PL was defined as the angle between a horizontal line and the superior endplate of the L1 vertebra. DL was defined as the angle between a horizontal line and the superior endplate of the S1 vertebra. We used previously published definitions for PI, PT, and SS[22]

B. Cage related parameters

The cage-related parameters were cage height, cage length, insertion side of the cage, X axis position of the cage (Xc), Y axis position of the cage (Yc), and transverse angle of the cage (angle) which were measured on postoperative 1-year supine computed tomography (CT) image (**Figure 3**).
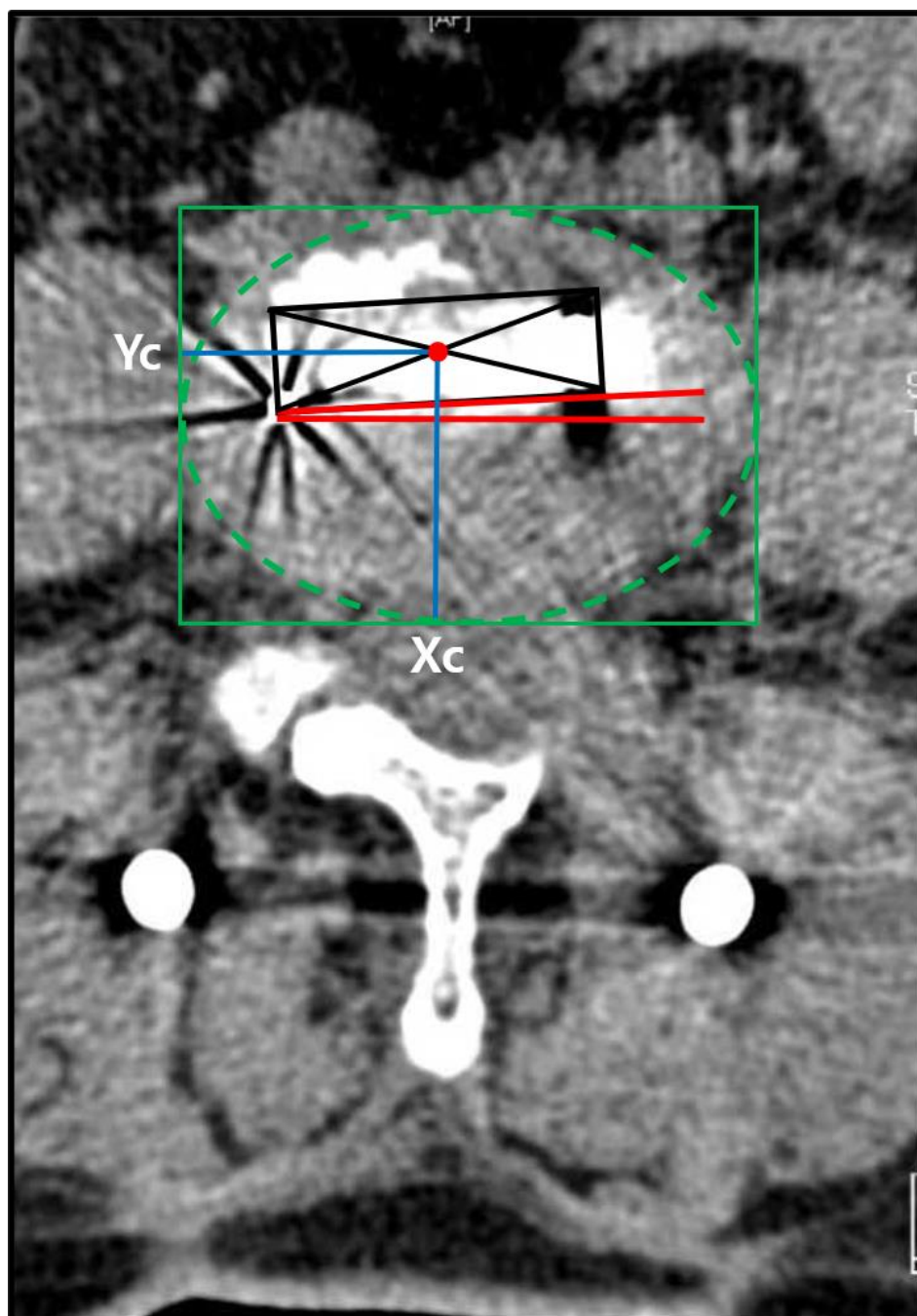
Fig. 3. Cage location–related radiologic variables. The center of the cage (red circle) was determined using the diagonal intersection of the cage on an axial computed tomography (CT) image. The corner of the vertebral body was determined by approximating an ellipse, and the X and Y axes were determined accordingly (green solid line). The cage position (blue line) was converted into a ratio by comparing the X and Y diameters of the ellipse. If Xc was less than 50%, the cage was located on the right, and if it was more than 50%, the cage was located on the left. If Yc was less than 50%, the cage was located at the posterior, and if it was more than 50%, the cage was located at the anterior. The angle of the cage was determined using the long axis of the cage and the X axis of the ellipse (red angle). Therefore, the smaller the angle, the more transversely the cage is positioned.

The center of the cage was defined as the intersection of the two diagonals of the cage on an axial CT image. The corner of the vertebral body was determined by approximating an ellipse, and the X and Y axes were then determined accordingly. The position of the cage was converted to a ratio by comparing the X and Y diameters of the ellipse. If Xc was less than 50%, the cage was located on the right, and if it was more than 50%, the cage was located on the left. If Yc was less than 50%, the cage was located at the posterior, and if it was more than 50%, the cage was located at the anterior. The angle of the cage was determined using the long axis of the cage and the X axis of the ellipse, such that the cage position became more transverse as the angle became smaller. The preoperative radiologic parameters were acquired from a preoperative whole standing x-ray obtained at the outpatient clinic before surgery. The cage-related parameters were obtained from medical records and the axial image of the postoperative 1-year lumbar CT. Postoperative radiologic parameters were obtained from the postoperative 1-year standing x-ray. Radiographic evaluation of fusion integrity was evaluated with postoperative 1year CT based on the Bridwell interbody fusion grading system as follows: I, fused with remodeling and trabeculae present; II, graft intact, not fully remodeled and incorporated, with no lucency; III, graft intact, potential lucency present at top and bottom of graft; and IV, fusion absent with collapse and/or resorption of graft. If patient's Bridwell grade is I or II, we considered fusion was achieved, otherwise we considered fusion was not achieved. Above all parameters were measured by two neurosurgeons (S.H.K and B.S.H) and averaged. There was no parameter with disagreement in terms of direction of the parameter change (ex. one measured parameter has increased after surgery and the other measure parameter has decreased after surgery.)

3. Operation technique

Surgery was done by single surgeon of single institute who has wrote many articles about MIS TLIF and experienced more than 15 years MIS TLIF operation[5,6,23-27]. Surgical techniques for MIS TLIF is same as described in our previous study.[5,6,24] We also did contralateral decompression but contralateral facet was not removed. We used specific

process to place cage more anterior so that lordosis can be created more effectively. After cage was inserted in through facetectomy side, cage pusher was place on the end side which is more closed to surgeon toward lateral and impacted with mallet so that it could be rotated and place more horizontally compared to initial location. Finally, to place the cage as anterior as possible, cage impactor was place on center of the cage and impacted with mallet until the resistance of anterior annulus is sensed. All CAPSTONE® PEEK cage we used was non expandable, no lordotic, bullet shaped cage with 10mm width. Cage length was either 32 or 36mm, which was selected concerning patient's preoperative image and intraoperative measurement.

4. Statistical methods

All continuous variables were tested for normality using the Shapiro-Wilk test and Kolmogorov Smirnov test. Continuous variables are expressed as the means ± standard deviation or medians (interquartile ranges [IQR], 25 to 75%). Categorical variables are expressed as frequencies and percentages. Continuous variables were analyzed with either independent two-sample t-testing or the Mann-Whitney U test, depending on the data distribution's normality. The chi-square test and Fisher's exact test were used to identify significant differences between categorical variables. $P < 0.05$ was considered statistically significant. Variables with a $P < 0.05$ were collected from the univariable logistic regressions. To consider multicollinearity, variables whose variance inflation factor was higher than 5 were excluded. The remaining variables were entered into a final multivariable logistic regression. Statistical analyses were performed using SAS (version 9.4, SAS Inc., Cary, NC, USA).

III. Results

1. Patient demographics

Overall, 77 patients received MIS-TLIF for lumbar degenerative disease at our institute from January 2018 to September 2019. Based on our selection criteria, 55 patients were included in the analysis. The patient demographics are shown in **Table 1**.

Table 1. Patient characteristics

	Total (n=55)	Increase (n=34)	Decrease (n=21)	P-value*
Demographic				
Sex				0.761
Male	25 (45.5%)	16 (47.1%)	9 (42.9%)	
Female	30 (54.5%)	18 (52.9%)	12 (57.1%)	
Age	59.47 ± 11.83	59.85 ± 10.89	59.86 ± 13.47	0.765
Diagnosis				0.947
Stenosis	17 (30.9%)	10 (29.4%)	7 (33.3%)	
Deg listhesis	29 (52.7%)	18 (53.0%)	11 (52.4%)	
Lytic listhesis	5 (9.1%)	3 (8.8%)	2 (9.5%)	
Massive HLD	4 (7.3%)	3 (8.8%)	1 (4.8%)	
Indication level				**0.020**
L3/4	8 (14.5%)	2 (5.9%)	6 (28.6%)	
L4/5	47 (85.5%)	32 (94.1%)	15 (71.4%)	
Preoperative radiologic parameters				
Disc				
Disc lordosis °	6.34 ± 4.78	5.15 ± 5.02	8.27 ± 3.70	0.017
Anterior height mm	9.96 ± 3.81	9.44 ± 3.76	10.81 ± 3.83	0.198
Posterior height mm	7.09 ± 2.55	7.26 ± 2.77	6.80 ± 2.18	0.521
Segmental lordosis °	13.90 ± 6.14	12.40 ± 6.18	16.31 ± 5.39	**0.020**
Lumbar lordosis °	43.58 ± 9.73	41.29 ± 9.38	47.28 ± 9.34	**0.025**
Proximal lumbar lordosis °	11.87 ± 7.45	9.40 ± 6.37	15.86 ± 7.47	**0.001**
Distal lumbar lordosis °	31.71 ± 5.41	31.90 ± 5.62	31.41 ± 5.18	0.751
Pelvic parameters°				
PI	50.73 ± 10.56	51.03 ± 11.80	50.25 ± 8.44	0.795

PT	18.22 ± 8.49	18.81 ± 9.21	17.27 ± 7.29	0.519
SS	32.49 ± 6.20	32.22 ± 6.21	32.93 ± 6.31	0.686
PI-LL	13.28 ± 8.25	10.49 ± 14.45	5.66 ± 10.64	
Cage-related parameters				
Height mm	11.36 ± 1.10	11.18±1.11	11.67 ± 1.02	0.107
Length mm				0.348
32	27 (49.1)	15 (44.1%)	12 (57.1%)	
36	28 (50.9)	19 (55.9%)	9 (42.9%)	
Insertion side				0.418
Right	30 (54.5%)	20 (58.8%)	10 (47.6%)	
Left	25 (45.5%)	14 (41.2%)	11 (52.4%)	
X axis position (%)	50.53 ± 6.10	50.79±6.25	50.12 ± 5.99	0.698
Y axis position (%)	54.08 ± 7.50	55.84±7.39	51.24 ± 6.92	**0.026**
Transverse angle	16.54 ± 14.26	15.41±13.53	18.37 ± 15.54	0.460
Fusion status				0.250
Fusion	44 (80%)	28 (75.7%)	16 (88.9%)	
No fusion	11 (20%)	9 (24.3%)	2 (11.1%)	

*Statistical analyses were performed to compare patients whose postoperative segmental lordosis increased with those whose decreased.

2. Comparison between preoperative and postoperative radiologic parameters (Table 2)

DCL (6.34 ± 4.78° *vs*. 8.96 ± 4.11°, *p*=0.000), DHA (9.96 ± 3.81 mm *vs.* 12.96 ± 2.31 mm, *p*=0.000), and DHP (7.09 ± 2.55 mm *vs.* 8.16 ± 1.78 mm, *p*=0.001) were significantly higher after surgery. SL was higher after surgery, but the difference was not statistically significant (13.90 ± 6.14° *vs.* 15.09 ± 5.98°, *p*=0.072). LL (43.58 ± 9.73° vs. 38.77 ± 10.47°, *p*=0.001) and PL (11.87 ± 7.45° vs. 8.77 ± 6.14°, *p*=0.001) were significantly smaller after surgery. DL was smaller after surgery, but the difference was not statistically significant (31.71 ± 5.41° *vs.* 29.99 ± 8.99°, *p*=0.134). PI did not change significantly after surgery (50.73 ± 10.56° *vs.* 51.65 ± 11.0°6, *p*=0.231). PT increased significantly after surgery (18.22 ± 8.49° *vs*. 21.00 ± 7.53°, *p*=0.000). SS decreased significantly after surgery (32.49 ± 6.20° *vs.* 30.64 ± 6.20°, *p*=0.032). PI-LL increased significantly after surgery (7.15 ± 13.13° *vs.* 12.88 ± 12.34°, *p*= 0.002).

Table 2. Comparison of changes in segmental lordosis after MIS-TLIF

	Preoperative	Postoperative	P-value
Disc			
Disc lordosis °	6.34 ± 4.78	8.96 ± 4.11	**0.000**
Anterior height °	9.96 ± 3.81	12.96 ± 2.31	**0.000**
Posterior height °	7.09 ± 2.55	8.16 ± 1.78	**0.001**
Segmental lordosis °	13.90 ± 6.14	15.09 ± 5.98	0.072
Lumbar lordosis °	43.58 ± 9.73	38.77 ± 10.47	**0.001**
Proximal lumbar lordosis °	11.87 ± 7.45	8.77 ± 6.14	**0.001**
Distal lumbar lordosis °	31.71 ± 5.41	29.99 ± 8.99	0.134
Pelvic parameters °			
PI	50.73 ± 10.56	51.65 ± 11.06	0.231
PT	18.22 ± 8.49	21.00 ± 7.53	**0.000**
SS	32.49 ± 6.20	30.64 ± 6.20	**0.032**
PI-LL	7.15 ± 13.13	12.88 ± 12.34	**0.002**

3. Comparison according to change in segmental lordosis after surgery

After surgery, SL increased in 34 patients (group I) and decreased in 21 patients (group D) (**Table 1**). The index level of surgery differed significantly between groups I and D (p=0.020). In group I, the index level was L4/5 in 94.1% of patients and L3/4 in 5.9%. In contrast, the index level in group D was L4/5 in 71.4% of patients and L3/4 in 28.6%. Among the preoperative radiologic parameters, DCL, SL, LL, and PL differed significantly between the groups. DCL (5.15 ± 5.02° *vs.* 8.27 ± 3.70°, p=0.017), SL (12.40 ± 6.18° *vs.* 16.31 ± 5.39°, p=0.020), LL (41.29 ± 9.38° *vs.* 47.28 ± 9.34°, p=0.025), and PL (9.40 ± 6.37° *vs.* 15.86 ± 7.47°, p=0.001) were all significantly smaller in group I than in group D. Among the cage-related parameters, Yc differed significantly between the groups. The cages in group I were more anterior than those in group D (55.84 ± 7.39% *vs.* 51.24 ± 6.92%, p=0.026). In fusion rate, there was no difference between groups (75.7 % vs. 88.9%).

4. Multivariate analysis of change in segmental lordosis after surgery

According to the univariate logistics regressions, an increase in postoperative SL was significantly associated with the index level and the preoperative DCL, SL, LL, PL, and Yc values (**Table 3**).

Table 3. Logistic regression between increased and decreased segmental lordosis after MIS-TLIF

	Univariate [95% CI]	P-value	Multivariate [95% CI]	P-value
Sex				
Male	reference			
Female	0.844 [0.282-2.524]	0.761		
Age	1.007 [0.962-1.055]	0.76		
Diagnosis				
Stenosis	reference			
Lytic listhesis	0.476 [0.041-5.577]	0.555		
Deg listhesis	0.545 [0.050-5.919]	0.618		
Massive HLD	0.500 [0.028-8.952]	0.638		
Indication Level				
L3/4	0.156 [0.028-0.867]	**0.034**	0.46 [0.04-0.60]	**0.019**
L4/5	reference			
Preoperative radiologic parameters				
Disc				
Disc lordosis	0.855 [0.747-0.979]	**0.023**	0.98 [0.81-1.18]	0.791
Anterior height	0.906 [0.780-1.053]	0.906		
Posterior height	1.075 [0.865-1.335]	0.514		
Segmental lordosis	0.890 [0.803-0.987]	**0.027**	0.82 [0.68-0.99]	**0.037**
Lumbar lordosis(L1-S1)	0.932 [0.874-0.994]	**0.031**	1.18 [0.97-1.44]	0.095
Proximal lumbar lordosis	0.871 [0.792-0.957]	**0.004**	0.68 [0.50-0.94]	**0.028**
Distal lumbar lordosis	1.017 [0.918-1.126]	0.746		
Pelvic parameters				
PI	1.007 [0.956-1.061]	0.79		
PT	1.022 [0.958-1.091]	0.511		
SS	0.981 [0.898-1.073]	0.68		
PI-LL	1.044 [0.997-1.095]	0.069		
Cage related parameters				
Height	0.633 [0.360-1.116]	0.114		
Length				

32 mm	reference			
36 mm	0.592 [0.198-1.775]	0.349		
Insertion side				
Right	reference			
Left	0.636 [0.213-1.903]	0.419		
X (%)	1.018 [0.931-1.114]	0.692		
Y (%)	1.096 [1.008-1.191]	**0.032**	1.22 [1.06-1.41]	**0.007**
Transverse angle	0.986 [0.949-1.024]	0.454		

Postoperative SL decreased when the index level was L3/4 compared with L4/5 (odds ratio [OR]: 0.16; 95% confidence interval 0.03–0.87, p=0.034). Postoperative SL also decreased as the preoperative DCL (OR: 0.86; 0.75-0.98, p=0.023), preoperative SL (OR: 0.89; 0.80–0.99, p=0.027), preoperative LL (OR: 0.93; 0.87–0.99, p=0.031), or preoperative PL (OR: 0.87; 0.79–0.96, p=0.004) increased. Postoperative SL increased as the cage became more anterior (OR: 1.10; 1.01–1.19, p=0.032). The multivariate analysis showed that the index level, preoperative SL, PL, and Yc were significantly associated with an increase in postoperative SL. Postoperative SL decreased significantly after MIS-TLIF when the index level was L3/4 compared with L4/5 (OR: 0.46; 0.04–0.60, p=0.019), as the preoperative SL (OR: 0.82; 0.68–0.99, p=0.037) or PL (OR: 0.68; 0.50–0.94, p=0.028) increased, and as the cage became more anterior (OR: 1.10; 1.01–1.19, p=0.032) (**Table 3**).

Discussion

An increase in lordosis is rather anticipated after surgery. However, SL did not significantly increase after MIS-TLIF. This is in line with the study of Champagne *et al.*, who investigated sagittal balance after TLIF, MIS-TLIF, and LLIF[28]. Only LLIF improved SL after surgery. Unlike LLIF, which is executed to restore lordosis and increase the foraminal height of flatback patients, MIS-TLIF is done to treat various degenerative lumbar diseases, such as spondylolisthesis and stenosis with unilateral facetectomy, and the increase in SL is thus limited in MIS-TLIF patients. However, Mcmordie *et al.*, who studied the outcomes of MIS-TLIF with lordotic cages, reported that SL increased postoperatively[20]. Changes in SL after MIS-TLIF were significantly associated with preoperative SL. When the preoperative SL was small, the postoperative SL was likely to increase. Berlin *et al*., reported in their study of 121 patient who underwent conventional TLIF, that postoperative SL correction at L4/5 was significantly associated with preoperative SL[29]. Frequency distribution analysis showed that postoperative SL of L4/5 is likely to decrease if patient's preoperative SL more than 23°, and preoperative SL less than 15° is likely to increase, which is consistent with our conclusion. However, some studies have reported opposite

results. In their systemic review, Calson *et al.,* reported that a larger preoperative SL correlated with a larger postoperative SL[30]. We think inconsistent conclusion on preoperative SL stems from different operation technique of each author, our result we also include cage position in analysis would aid more accuracy. However, further study is needed to investigate the role of preoperative SL.

Changes in SL after surgery were significantly associated with cage position. The more anteriorly the cage is located, the more likely it becomes that postoperative SL will increase. This is in line with Calson *et al*., who reported that an anterior position of the cage resulted in larger postoperative SL[30]. Lovecchio *et al*., also reported that SL increased more following ALIF than after TLIF or LLIF, and they thus concluded that the cage position was the only factor influencing SL change after MIS-TLIF[18]. We also found that the Yc axis of the cage was associated with SL, with an anterior cage position correlating with an increase in SL after MIS-TLIF. Specifically, our results should be applied cautiously in clinical situations because an anterior position for the cage sometimes doesn't result in an SL increase after surgery if the preoperative SL and PL are large (**Figure 4**). On the other hand, if the preoperative SL and PL are small, surgery can produce an SL increase, even if the cage is not positioned anteriorly enough (**Figure 5**).
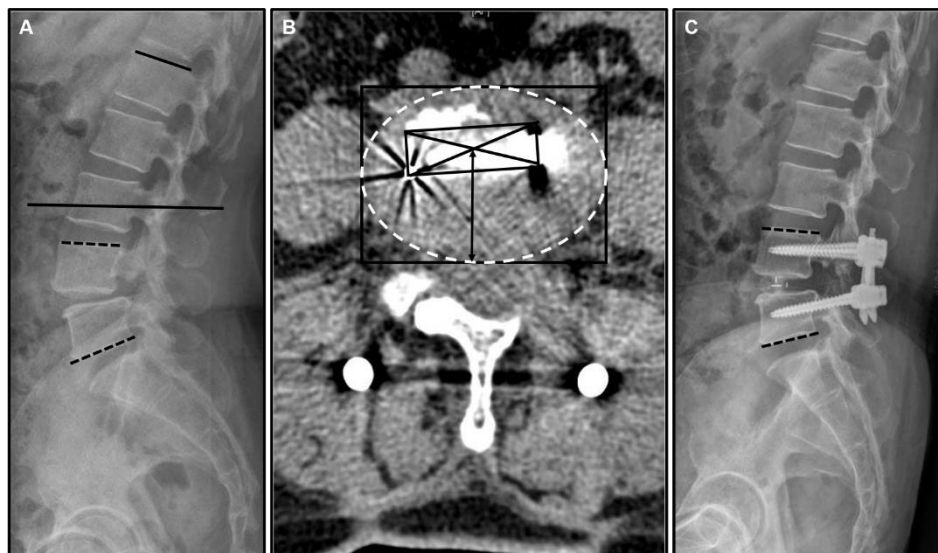
Fig. 4. Patient with decreased segmental lordosis after surgery even though cage was positioned anteriorly. This patient had large preoperative segmental lordosis (black dotted line, 26.6°) and proximal lordosis (black line, 17.7°) (A). Although the cage was positioned anteriorly (black arrow, 67.4%) in the axial CT image (B), postoperative segmental lordosis was decreased by 15.8° (black dotted line) in 1-year postoperative x-ray (C).
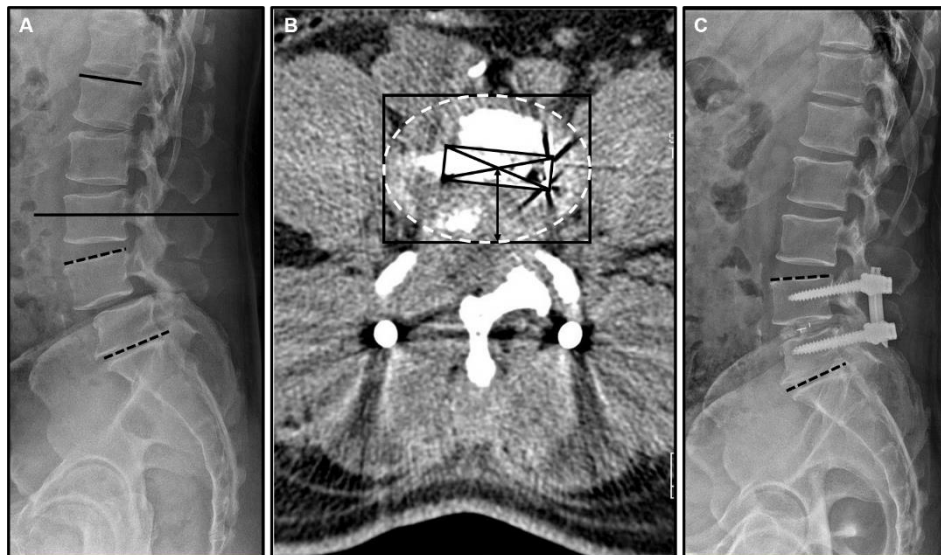
Fig. 5. Patient with increased segmental lordosis after surgery even though the cage was not positioned anteriorly. This patient had small preoperative segmental lordosis (black dotted line, 6.2°) and proximal lordosis (black line, 6.7°) (A). Even though the cage was not positioned anteriorly enough (black arrow, 44.4%) in the axial CT image (B), postoperative segmental lordosis increased by 20.5° (black dotted line) on the 1-year postoperative x-ray (C).

Changes in SL after surgery were significantly associated with preoperative PL, with small preoperative PL values correlating with increases in postoperative SL. Lafage *et al.,* also reported that in adult spinal deformity patients with flat proximal lordosis (smaller PL), PL increased postoperatively, and DL showed no change[31]. We also found that DL before and after surgery did not differ significantly. Pesenti *et al*., reported that, unlike PL, which moves to compensate for sagittal balance, DL, which accounts 2/3 of the total LL, is invariable[32]. The only way to increase SL during MIS –TLIF, is to position the cage as forward as possible. If the goal of surgery is to make a large SL and patient's preoperative SL and PL is not small enough, rather than MIS-TLIF, other surgery such as ALIF should be considered.

Postoperative SL was significantly associated with the index level of surgery. MIS-TLIF was more likely to increase postoperative SL at L4/5 than at L3/4 in our study population. This is in line with the study by Ricciardi *et al*., who reported that TLIF changed SL more at L4/5 than at L3/4[33]. However, we found no research results explaining why TLIF at L4/5 affects SL more than at L3/4. Bernhardt *et al*, reported in their radiologic study of 102 normal subject that, lumbar segmental lordosis gradually increases at each caudally to sacrum[34]. Accordingly, SL of L3/4 is smaller than L4/5 and with our study's result L3/4 would create more postoperative SL, which is contradiction. We think not only segmental lordosis but other condition underlies beneath this result. Further study, comparing L4/5 with L5/S1 would shed light on this opposite result. Degenerative spondylolisthesis (DS) is known to commonly occur at L4/5, while spondylolytic spondylolisthesis commonly occur at L5/S1. DS is reported to commonly occur at L4/5 rather than L3/4[35-37]. However, diagnosis has no significant correlation between postoperative SL changes as seen in **Table 1**. Furthermore, although the increased SL group had more L4/5 patients than L3/4 (94.1% *vs*. 5.9%), the decreased group also had more L4/5 patients (71.4%) than L3/4 (28.6%). It is likely that each patient's apex of lordosis is unique and that the effects of cage insertion on PL and DL also differ by patient, so the surgical level is not considered to be significantly related to postoperative SL changes.

Our study has some limitations. First, as Le Huec *et al.,* presented, according to the formula for calculating a patient's ideal LL from their PI, ideal LL can be achieved by either increasing or decreasing LL, depending on the preoperative LL value. Therefore, the results of our study should be applied in clinical situations according to each patient's preoperative LL and ideal LL, keeping in mind that increasing LL is not always the right answer. In addition, our study does not include clinical outcome which is as much important as radiological outcome. Second, our study is limited by both our study duration and sample size. To emphasize the effect of operative factors, we compared the preoperative x-ray with the 1-year postoperative x-ray, but that means that we lack data about long-term changes. Furthermore, to measure the effect of operative factors as clearly as possible, we maximally controlled our data by excluding unfit data, and this resulted in a small sample size. Despite the fact that all operation was done by single surgeon in single institution aids in consistency of the data, small sample size is inherent limitation of this study. Third, the parameters included in this study are related to one another. Among the preoperative radiologic parameters, PI, PT, SS, and LL have close relationships. Furthermore, LL consists of PL and DL; therefore, if either PL or DL is determined, its counterpart is automatically defined. Among the cage-related parameters, the X axis, Y axis, and transverse angle are not three independent variables but are related by the position of the cage. Therefore, although we used a multivariable logistic regression to reduce the covariance of the variables, those variables still produce structural error in the study. Fourth, we confined the index level with L3/4 and 4/5. This was to control the consistency of the data, and our study does not provide information with L5/S1 which is common level with lumbar spondylolisthesis. Further study incorporating L5/S1 level is needed to provide suggestions helpful for spine surgeons in practice. Fifth, cage used in this study does not have lordotic angle. However, use of lordotic cage is growing not only in open lumbar surgery but also in minimal invasive lumbar surgery[18,38,39]. Lordotic cage which could be an option. Sixth, global balance has recently been spotlighted as closely associated with clinical outcomes. We investigated changes in SL, which is a more local change than global

balance, because we thought it would be directly affected by operative factors. However, a study of global balance and operative factors would shed more light on how their association affects long-term clinical outcomes. Finally, although parameter measurement was done by two neurosurgeons and averaged, this study is not free from measurement, inter and intra-observer error. Considering comparison between dichotomized group of "increased" versus "decrease" segmental lordosis was main analysis of this study, these errors could swing a patient into one group or another. This is certainly a limitation of our study.

Conclusion

Changes in SL after MIS-TLIF are associated with preoperative SL, PL, index level, and the Y axis of the cage position. Smaller preoperative SL and PL, an index level at L4/5 instead of L3/4, and an anterior position for the cage are likely to result in increased SL after MIS-TLIF.

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ABSTRACT(IN KOREAN)

최소침습 추간공접근하 요추체간유합술에서 수술 부위의 전만각에 영향을 미치는 요소에는 어떤것들이 있는가?

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김수헌

내용

최근들어 최소침습 추간공접근하 요추체간유합술에 대한 인기는 점점 늘어가고 있다. 케이지를 삽입하는 것이 전만각을 형성하는 데 있어 고식적인 유합술에 비해 최소침습 추간공접근하 요추체간유합술에서 더 큰 비중을 차지한다. 우리는 이 연구에서 최소침습 추간공접근하 요추체간유합술에서 전만각을 형성하는데 영향을 미치는 인자를 조사하고자 최소침습 추간공접근하 요추체간유합술 시행후 전만각이 증가된 환자와 감소된 환자를 비교해보고자 하였다.

2018년 1월부터 2019년 9월까지 최소침습 추간공접근하 요추체간유합술을 시행한 총 55명의 환자를 대상으로 연구를 수행하였다. 이 결과 전만각이 증가된 군(34명)은 감소된 군(21명)에 비해 수술레벨이 요추 3/4번 보다는 4/5번에 더 치우쳐있었다. (증가군 4/5 (94.1%), L3/4 (5.9%), 감소군 4/5(71.4%) , 3/4(28.6%)) 수술레벨은 odds ratio 0.46(p =0.019)으로 3/4번일수록 수술후

수술레벨의 전만각이 감소했다. 또한 수술전 수술레벨의 전만각(12.40° vs. 16.31°) 과 근위부 전만각(9.40° vs. 15.86°)은 증가군에서 감소군에 비해 그 크기가 작았다. 수술레벨의 전만각이 커질수록 odds ratio 0.82(p =0.037)으로 수술후 수술레벨의 전만각이 감소했다. 근위부 전만각이 커질수록 odds ratio 0.68(p =0.028)으로 수술후 수술레벨의 전만각이 감소했다.

핵심되는 말 : 최소침습, 추간공하 요추체간 유합술, 요추 전만각, 케이지, 예후, 척추수술, 수술레벨의 전만각