CLINICAL ARTICLE

Do Radiographic Results of Transforaminal Lumbar Interbody Fusion Vary with Cage Position in Patients with Degenerative Lumbar Diseases?

Qing Ding, MD[1], Xiangyu Tang, MD[2], Ruizhuo Zhang, MD[1], Hua Wu, MD, PhD[1], Chaoxu Liu, MD, PhD[1]

Department of [1]Orthopedics, Tongji Hospital, Tongji Medical College and [2]Radiology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

Objective: To investigate whether the radiographic results are affected by cage position in single-level transforaminal lumbar interbody fusion (TLIF).

Method: Between January 2016 and June 2018, 130 patients (62 males and 68 females, average age: 55.28 ± 10.11 years) who underwent single-level TLIF were analyzed retrospectively. Standing lateral radiographs of the lumbar spine were collected and evaluated preoperatively, postoperatively, and at the time of last follow-up. Cage position in the fused segment was recorded using a central point ratio (CPR), which indicated the cage position. CPR is calculated by dividing the distance between the cage center point and the posterior extent of the superior endplate of the inferior vertebra by the length of the superior endplate of the inferior vertebra. Based on cage positions, the patients were divided into three groups: Anterior Group ($n = 38$); Middle Group ($n = 68$); and Posterior Group ($n = 24$). Segmental lumbar lordosis (SLL), foraminal height (FH), posterior disc height (PDH), and anterior disc height (ADH) were evaluated. A subanalysis was also performed on cage height within each group.

Results: The average follow-up time of the patients was 35.20 ± 4.43 months. The mean values of CPR in Anterior Group, Middle Group, and Posterior Group were 0.64, 0.51, and 0.37, respectively. The FH, PDH, and ADH were significantly increased after TLIF in all groups ($P < 0.05$). There were significant differences in increase of SLL in Anterior Group (4.4°) and Middle Group (3.0°), but not in Posterior Group (0.3°). Furthermore, in the comparison of the three groups, the increase of SLL, FH, and PDH was statistically different ($P < 0.05$), while not for ADH ($P > 0.05$). The significant correlations in surgery were: CPR and ΔSLL ($r = 0.584$, $P < 0.001$), CPR and ΔFH ($r = -0.411$, $P < 0.001$), and CPR and ΔPDH ($r = -0.457$, $P < 0.001$). However, ADH had a positive correlation with cage height when the cage was located in anterior and middle of the endplate. Moreover, cage height had a positive correlation with SLL when the cage was located anteriorly and had a negative correlation with SLL when the cage was located posteriorly. FH and PDH both had a positive correlation with cage height in any cage position.

Conclusion: The cage located in different positions has different effects on radiographic results in single-level TLIF. A thicker cage located anteriorly will gain maximum SLL and avoid the reduction of FH and PDH.

Key words: Cage position; Disc height; Foraminal height; Segmental lumbar lordosis; Transforaminal lumbar interbody fusion

Introduction

In the past few decades, the number of spinal fusion surgeries has increased dramatically. Transforaminal lumbar interbody fusion (TLIF) has been reported as a widely accepted surgical method for patients with degenerative lumbar diseases, which can provide immediate structural support

Address for correspondence Hua Wu, MD, PhD and Chaoxu Liu, MD, PhD, Department of Orthopedics, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, No. 1095, Jiefang Avenue, Wuhan 430030, Hubei Province, China. Tel: +86-027-83665319; Fax: +86-027-83665319; Email: wuhua@hust.edu.cn, chaoxuliu@hotmail.com

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and high fusion rate[1]. The anatomical advantage of TLIF is that it can reduce the risk of damage to the dural sac and nerve root[2]. There is an increasing evidence that patients receiving TLIF can achieve satisfactory clinical results[3–5].

Lumbar degenerative diseases are usually accompanied with reduced lumbar lordosis and loss of disc height. The loss of disc height will directly lead to stenosis of the intervertebral foramina, resulting in nerve root compression and pain. In lumbar interbody fusion, the intervertebral disc is removed as much as possible, and a cage that provides structural support and fusion area is placed in the disc space. The cage plays an important role in rebuilding the disc space and restoring segmental lumbar lordosis (SLL) and foraminal height (FH). Lumbar lordosis is critical for maintaining normal sagittal alignment. Spinopelvic sagittal imbalance was reported as a risk factor for adjacent segment disease after single-segment posterior lumbar interbody fusion[6]. Therefore, the necessity of lumbar lordosis reconstruction in lumbar surgery has been widely discussed. In recent years, much research on TLIF has focused on exploring issues related to cage, such as size,[7], material[8–10], shape[11–13], and inserted orientation[14,15]. The wedge-shaped cage and expandable cage have been demonstrated to be beneficial to the recovery of SLL. However, few studies have paid attention to the location of cage and its possible influence on radiographic results of TLIF. Radiographic results were increasingly reported to be correlated with clinical results[16–18]. Further, previous studies have proposed different recommendations for the position of cage placement. In the initial TLIF procedure, Harms and Jeszenszky[19] suggested placing two titanium mesh interbody cages in the middle/posterior third of the disc space. Kwon *et al.*[20] proposed that an interbody cage should be placed on the anterior part of the vertebral endplate to enhance stability and increase lordosis of the operated segment. A study on the basis of the lumbar polyurethane anatomical model concluded that posterior cage placement would increase the SLL[21]. This difference may be due to different research objects, research methods and implants. In addition, it was previously reported that FH and intervertebral disc height were also affected by cage position[16,22]. Kepler *et al.*[16] found anterior cage position was associated with greater postoperative intervertebral disk height. The research results of Iwata *et al.*[22] suggested that the FH was significant increased with posterior cage placement.

Based on these findings, we hypothesized that cage position could influence the radiographic results depending on its position on the endplate surface (anterior, middle or posterior). The purposes of this study were: (i) to observe whether the radiographic results were affected by cage position; (ii) to determine the specific relationship between the sagittal position of the cage and the recovery of intervertebral disc height, FH, and SLL; and (iii) to further analyze the effect of cage height on radiographic results in different cage positions.

Materials and Methods

Inclusion and Exclusion Criteria

Inclusion criteria were: (i) diagnosed as lumbar spinal stenosis, lumbar disc herniation or spondylolisthesis (≤II degree according to Meyerding classification); (ii) received single-level TLIF with a bullet-shaped cage; (iii) available radiographic examinations; and (iv) at least 2 years of postoperative follow-up. Exclusion criteria included diagnosis of congenital vertebral anomalies and lumbar degenerative scoliosis, history of lumbar fusion surgery, trauma, neoplasm and infection.

Patients

This was a retrospective study that was approved by the institutional ethics committee of our hospital. From January 2016 to June 2018, 287 consecutive patients who received TLIF treatment were retrospectively analyzed. The clinical characteristics and the preoperative and postoperative radiographs of the patients were reviewed. All patients in this study experienced leg pain or paralysis caused by lumbar degenerative diseases before operation, but conservative treatment could not alleviate these symptoms. Of 287 patients, 130 patients met the inclusion criteria.

Surgical Procedure

Anesthesia and Position

TLIFs were performed under intravenous inhalation combined anesthesia. The patient was placed in a prone position on the operating table. Fluoroscopy was used to determine the segment that required surgery.

Approach and Exposure

A posterior midline skin incision was performed to expose the lamina and facet joints on both sides. Pedicle screws were then inserted on both sides of the levels of interest. Unilateral facetectomy and partial laminectomy were done to expose the intervertebral disc and achieve adequate posterior decompression.

Discectomy and Cage Insertion

After meticulous discectomy and endplate preparation, the cage filled with the autologous bone graft was inserted into the disc space. All TLIFs were performed with bullet-shaped cages with no lordosis (DePuy spine, Raynham, MA, USA or WeGo Company, Shandong, China). After the cage was placed, the bilateral pedicle screws and rods were axially compressed and fixed to restore the lordosis while maintaining the recovered disc height. All cages were polyetheretherketone devices with radiopaque markers to identify its position.

Place Drainage Tube and Suture the Incision

A drainage tube was placed in the incision. Then, a closure in layers was performed and the incision was covered with aseptic dressing.

Cage Position and Grouping

Cage position was identified using metallic markers within the cage, which demarcated its anterior and posterior border. The center point of the cage was defined as the midpoint of the line connecting the anterior cage landmark and the midpoint of the two posterior cage landmarks. Cage position was recorded using center point ratio (CPR) which was calculated by dividing the distance between the cage center point and the posterior extent of the superior endplate of the inferior vertebra by the length of the superior endplate of the inferior vertebra (Fig. 1A)[23]. The higher the CPR value was, the more anterior the cage was placed in the disc space. A CPR value of 0.5 indicated that the cage was perfectly placed in the middle of the endplate. Values close to zero or one were possible, but this would represent extreme positioning and require partial overhang of the cage out of the disc space either anteriorly or posteriorly. In fact, the value of CPR ranged from 0.2 to 0.8 at all surgical levels. We regarded CPR clustering of about 0.5 as middle cage placement. According to different cage positions, the patients were divided into three groups: Anterior Group (anterior, $0.6 < \text{CPR} < 0.8$); Middle Group (middle, $0.4 \le \text{CPR} \le 0.6$); and Posterior Group (posterior, $0.2 < \text{CPR} < 0.4$). The number of patients in Anterior Group, Middle Group and Posterior Group were 38, 68, and 24, respectively.

Parameter Measures

Lateral radiographs were taken according to a protocol set by the radiologist, and had a consistent standing position relative to the X-ray source. The postoperative radiographs were performed on days 5–7 after operation and at the final follow-up. Surgimap spine software (Version 2.3.2.1, Nemaris, Inc., New York, USA) was used by two independent orthopedic surgeons for radiographic evaluation. Radiographic assessments consisted of SLL, FH, posterior disc height (PDH), and anterior disc height (ADH). The measurement methods of these parameters were shown in Fig. 1B.

Segmental Lumbar Lordosis

SLL was defined as the angle formed by the lower endplate of the vertebra above the instrumented disc and the upper endplate of the vertebra below the instrumented disc. SLL was a part of total lumbar lordosis and the size of SLL would have an effect on the adjacent intervertebral discs.

Foraminal Height

FH was defined as the longest distance between the lower border of the superior pedicle and upper border of the inferior pedicle. The reduction of FH meant stenosis of the foramina and possible nerve root compression.

Posterior Disc Deight and Anterior Disc Height

PDH was defined as the vertical distance between the posterior end of the inferior and superior endplates, while ADH was the distance between the anterior ends. The loss of PDH and ADH indicated the degeneration of the lumbar spine

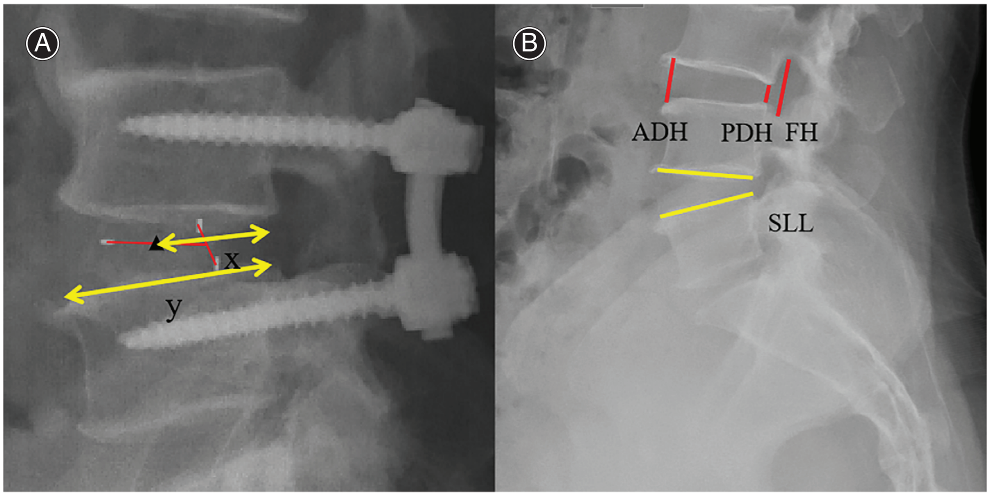

Fig. 1 (A) Measurement of center point ratio (CPR). The triangle indicates the cage center point. CPR (x/y) is calculated by dividing the distance between the cage center point and the posterior extent of the superior endplate of the inferior vertebra (x) by the length of the superior endplate of the inferior vertebra (y). (B) Segmental lumbar lordosis (SLL) is determined by the angle formed by the lower endplate of the vertebra above the instrumented disc and the upper endplate of the vertebra below the instrumented disc. Foraminal height (FH) is measured as the longest distance between the lower border of the superior pedicle and upper border of the inferior pedicle. Posterior disc height (PDH) is measured as the vertical distance between the posterior end of the inferior and superior endplates, while anterior disc height (ADH) is the distance between the anterior ends.

and would affect the lumbar lordosis. In addition, the change of PDH could indirectly indicate the change of FH.

Statistical Analysis

All analyses were performed using SPSS 22.0 software (IBM, Armonk, NY, USA). Quantitative data were presented as mean ± standard deviation. Pearson chi-square test or Fisher exact test was used to analyze qualitative comparative data. A paired *t* test was used to compare the difference between preoperative and postoperative radiographic parameters in the same group. For data that did not conform to the normal distribution, non-parametric test (the Wilcoxon signed rank test) was used in the same group. One-way analysis of variance (ANOVA) was performed to compare the values among the three groups. Pearson correlation coefficient was used to examine the correlation between cage position and the change in radiographic parameters. The two-tailed significance level was defined as $P < 0.05$. Statistically significant correlation coefficients were considered clinically significant only if correlation coefficients >0.3.

Results

General Results

This study included 130 patients (62 men and 68 women) with an average age of 55.28 ± 10.11 years. A comparison of the patient data showed there were no significant demographic differences among these groups ($P > 0.05$). The demographic data and surgical details of all patients were shown in Table 1. The mean values of CPR in Anterior Group, Middle Group, and Posterior Group were 0.64, 0.51, and 0.37, respectively. The overall follow-up period was 35.20 ± 4.43 months. The length and width of the cages were 22 mm and 10 mm, respectively. The height of the cages ranged from 8 to 14 mm. The average cage heights in Anterior Group, Middle Group, and Posterior Group were 11.81 ± 1.63 mm, 11.65 ± 1.39 mm, and 11.04 ± 1.71 mm, respectively ($P = 0.430$).

Changes in SLL after TLIF

In the Anterior Group, preoperative SLL averaged 6.88° ± 2.98° compared with 11.31° ± 2.98° postoperatively ($P < 0.05$) for an increase of 4.43° ± 1.37° per level in the patients, and the SLL at final follow-up averaged 11.07° ± 2.99°. In the Middle Group, preoperative SLL averaged 7.07° ± 3.67° compared with 10.09° ± 3.13° postoperatively ($P < 0.05$) for an increase of 3.02° ± 2.37° per level, and the SLL at final follow-up averaged 9.71° ± 3.18°. In Posterior Group, preoperative SLL averaged 8.37° ± 3.95° at instrumented levels compared with 8.70° ± 3.99° postoperatively ($P > 0.05$); thus, the mean increase was 0.33° ± 1.60° per level (Table 2). The SLL was significantly increased in Anterior Group (4.4°) and Middle Group (3.0°), while not in Posterior Group (0.3°). The increased amount of SLL was significantly different among the three groups ($P < 0.05$) (Tables 3 and 4), and the typical cases were shown in Fig. 2.

Changes in FH after TLIF

The average preoperative and immediate postoperative FH of the Posterior Group were 18.61 ± 3.46 mm and 22.00 ± 3.51 mm, respectively. Preoperative and immediate postoperative FH of

TABLE 1 Characteristics of patients in the three groups

Characteristics	Anterior group ($n = 38$)	Middle group ($n = 68$)	Posterior group ($n = 24$)
Male/female	18/20	35/33	10/14
Average age	55.58 ± 9.45	55.44 ± 10.84	54.33 ± 9.24
BMI (kg/m^2)	20.99 ± 1.47	21.99 ± 1.82	20.81 ± 1.87
Diagnoses			
Lumbar disc herniation	22	38	13
Lumbar spinal stenosis	12	24	9
Spondylolisthesis	4	6	2
Level of instrumented			
$L_{2/3}$	0	1	0
$L_{3/4}$	4	10	2
$L_{4/5}$	21	39	15
L_5/S_1	13	18	7
Cage height (mm)			
8	2	1	1
9	1	4	4
10	5	7	5
11	6	19	5
12	10	19	3
13	8	11	4
14	6	7	2

Abbreviation: BMI, body mass index.

TABLE 2 Changes in radiographic parameters in each group

	Variable	Preoperative	Postoperative	Final follow-up
Anterior group	SLL (°)	6.88 ± 2.98	11.31 ± 2.98*	11.07 ± 2.99*,†
	FH (mm)	18.47 ± 2.63	19.71 ± 2.52*	19.06 ± 2.66†
	PDH (mm)	6.92 ± 1.48	8.40 ± 1.56*	7.66 ± 1.72†
	ADH (mm)	12.20 ± 2.81	16.37 ± 2.32*	15.72 ± 2.47*,†
Middle group	SLL (°)	7.07 ± 3.67	10.09 ± 3.13*	9.71 ± 3.18*,†
	FH (mm)	19.00 ± 2.98	21.19 ± 2.65*	20.83 ± 2.69*,†
	PDH (mm)	6.80 ± 1.75	9.17 ± 1.66*	8.50 ± 1.93*,†
	ADH (mm)	12.02 ± 3.07	15.96 ± 2.55*	15.23 ± 2.74*,†
Posterior group	SLL (°)	8.37 ± 3.95	8.70 ± 3.99	8.59 ± 4.00†
	FH (mm)	18.61 ± 3.46	22.00 ± 3.51*	21.76 ± 3.55*,†
	PDH (mm)	7.02 ± 1.87	10.48 ± 1.91*	9.97 ± 2.19*,†
	ADH (mm)	13.00 ± 3.82	16.58 ± 2.77*	15.62 ± 2.97*,†

Abbreviations: ADH, anterior disc height; FH, foraminal height; PDH, posterior disc height; SLL, segmental lumbar lordosis. * Significantly different from preoperative ($P < 0.05$).; † No significant difference between postoperative and final follow-up ($P > 0.05$).

TABLE 3 Comparison of difference in postoperative (immediate) radiographic results

	Anterior group	Middle group	Posterior group	P^1	P^2	P^3
ΔSLL (°)	4.43 ± 1.37	3.02 ± 2.37	0.33 ± 1.60	<0.001	<0.001	<0.001
ΔFH (mm)	1.23 ± 1.01	2.21 ± 1.49	3.40 ± 1.46	<0.001	<0.001	0.001
ΔPDH (mm)	1.48 ± 1.21	2.37 ± 1.29	3.46 ± 1.40	0.001	<0.001	0.001
ΔADH (mm)	4.17 ± 1.76	3.94 ± 2.51	3.56 ± 2.09	0.574	0.237	0.536

ADH, anterior disc height; FH, foraminal height; SLL, segmental lumbar lordosis; PDH, posterior disc height. P^1: Comparison between Anterior Group and Middle Group; P^2: Comparison between Anterior Group and Posterior Group; P^3: Comparison between Middle Group and Posterior Group.

TABLE 4 Comparison of difference in postoperative (final follow-up) radiographic results

	Anterior group	Middle group	Posterior group	P^1	P^2	P^3
ΔSLL (°)	4.18 ± 1.35	2.64 ± 2.42	0.22 ± 1.50	<0.001	<0.001	<0.001
ΔFH (mm)	0.93 ± 1.02	1.83 ± 1.47	3.16 ± 1.54	<0.001	<0.001	<0.001
ΔPDH (mm)	0.85 ± 1.19	1.70 ± 1.28	2.95 ± 1.50	0.001	<0.001	<0.001
ΔADH (mm)	3.52 ± 1.90	3.21 ± 2.50	2.62 ± 1.89	0.469	0.074	0.239

SLL, segmental lumbar lordosis; FH, foraminal height; PDH, posterior disc height; ADH, anterior disc height. P^1: Comparison between Anterior Group and Middle Group; P^2: Comparison between Anterior Group and Posterior Group; P^3: Comparison between Middle Group and Posterior Group.

Middle Group averaged 19.00 ± 2.98 mm and 21.19 ± 2.65 mm, respectively. In the Anterior Group, preoperative FH averaged 18.47 ± 2.63 mm. Postoperative FH averaged 19.71 ± 2.52 mm initially, and 19.06 ± 2.66 mm at final follow-up. There was a significant difference between the preoperative and immediate postoperative values of FH in all three groups ($P < 0.05$). However, in the Anterior Group, the reconstruction of FH was lost at the final follow-up, with no statistical difference compared with preoperative ($P > 0.05$; Table 2). Postoperative FH in Posterior Group, Middle Group, and Anterior Group increased by 3.40 ± 1.46 mm, 2.21 ± 1.49 mm, and 1.23 ± 1.01 mm, respectively. In the comparison of the three groups, the increased amount of FH was significantly different ($P < 0.05$; Tables 3, 4).

Changes in PDH and ADH after TLIF

There was a significant difference between the preoperative and immediate postoperative values of PDH and ADH in all three groups ($P < 0.05$), and the decrease observed at the final follow-up was not statistically significant in the Middle Group ($P > 0.05$) and the Posterior Group ($P > 0.05$). However, in the Anterior Group, the reconstruction of PDH was lost at the final follow-up, with no statistical difference compared with preoperative (Table 2). Postoperative PDH in the

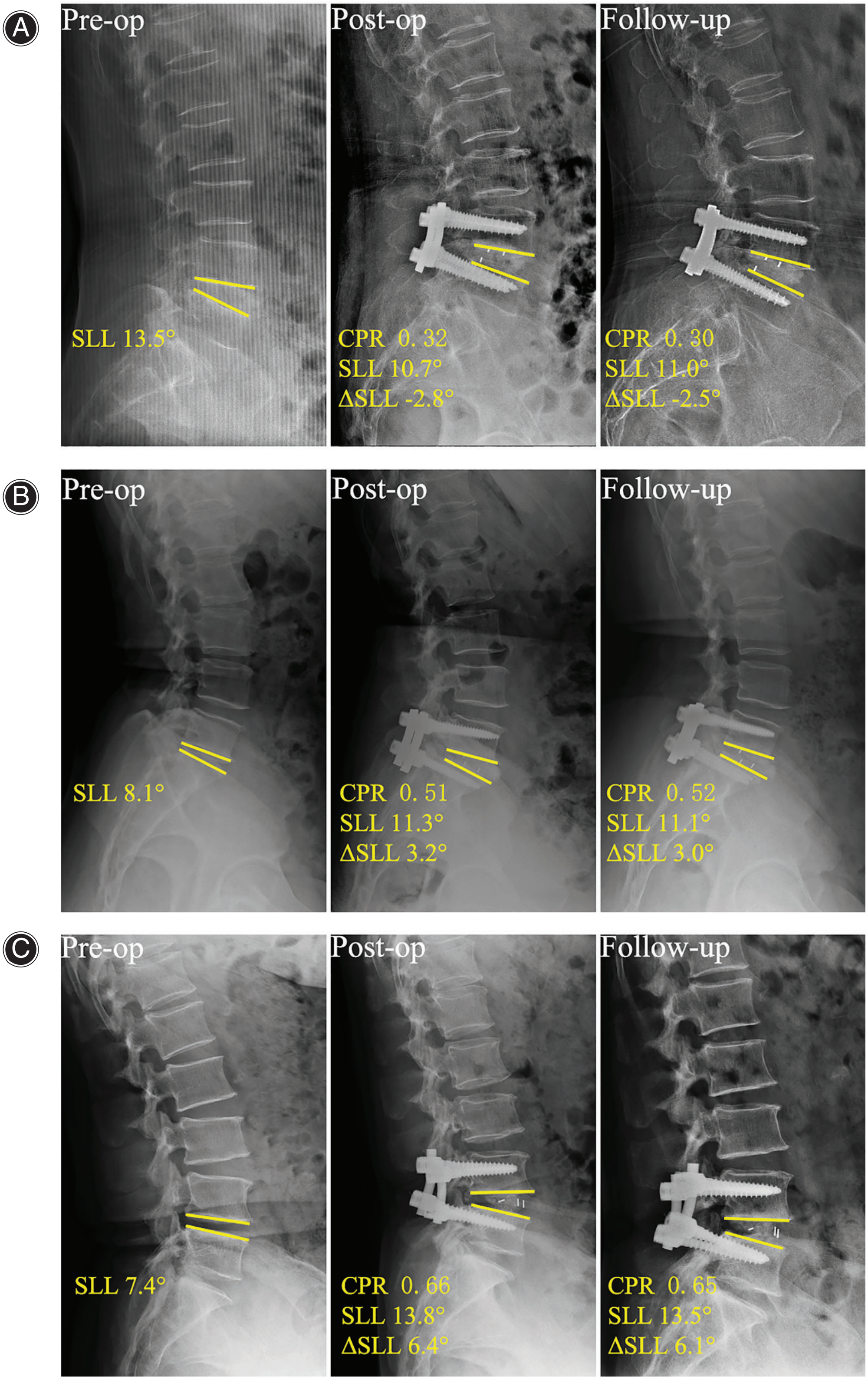

Fig. 2 Lateral radiographs of the typical cases at preoperative, postoperative, and the final follow-up: (A) case of posterior cage placement; (B) case of middle cage placement; (C) case of anterior cage placement. The preoperative center point ratio (CRP) values of the typical cases were 0.32, 0.51, and 0.66, respectively. Correspondingly, the changes in segmental lumbar lordosis (SLL) after surgery were −2.8°, 3.2°, and 6.4°, respectively. The changes in SLL at final follow-up were −2.5°, 3.0°, and 6.1°, respectively. This indicated that the increase of SLL was correlated with the cage position.

Posterior, Middle, and Anterior Groups increased by 3.46 ± 1.40 mm, 2.37 ± 1.29 mm, and 1.48 ± 1.21 mm, respectively. Postoperative ADH in all groups increased by 3.56 ± 2.09 mm, 3.94 ± 2.51 mm, and 4.17 ± 1.76 mm, respectively. The increased amount of PDH among the three groups was significantly different ($P < 0.05$), but there was no significant difference in the increase of ADH ($P > 0.05$) (Table 3). The comparison of these parameters showed the same results at the final follow-up (Table 4).

Relationship between CPR and Changes in Radiographic Parameters

The CPR was significantly positively related to the change of SLL at surgery ($r = 0.584$, $P < 0.001$; Fig. 3A), and the changes of FH and PDH were significantly negatively correlated with CPR ($r = -0.411$, $P < 0.001$, $r = -0.457$, $P < 0.001$, respectively) (Fig. 3B, C). The increase of ADH was not significantly associated with CPR ($r = 0.164$, $P = 0.063$; Fig. 3D). These correlations of the parameters with CPR were maintained at the final follow-up (ΔSLL: $r = 0.578$, $P < 0.001$, ΔFH: $r = -0.412$, $P < 0.001$, ΔPDH: $r = -0.478$, $P < 0.001$, and ΔADH: $r = 0.148$, $P = 0.092$, respectively).

Subanalysis According to Cage Position

Of note, the cage height had different effects on SLL in different cage positions. Cage height had a positive correlation with SLL when the cage was located anteriorly ($r = 0.543$, $P < 0.001$) and had a negative correlation with SLL when the

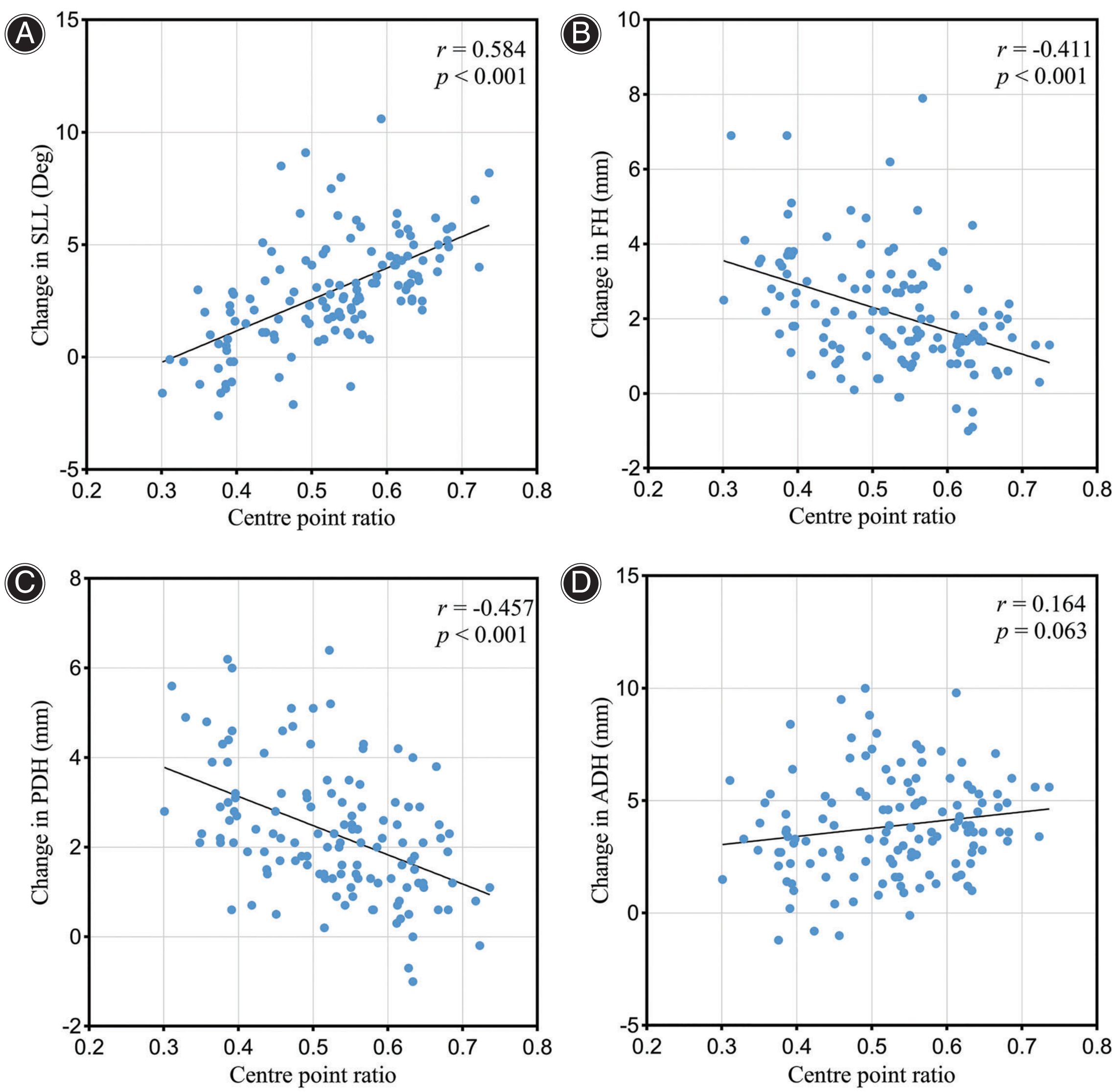

Fig. 3 (A) Relationship between center point ratio (CPR) and change in segmental lumbar lordosis (SLL); (B) Relationship between CPR and change in foraminal height (FH); (C) Relationship between CPR and change in posterior disc height (PDH); (D) Relationship between CPR and change in anterior disc height (ADH)

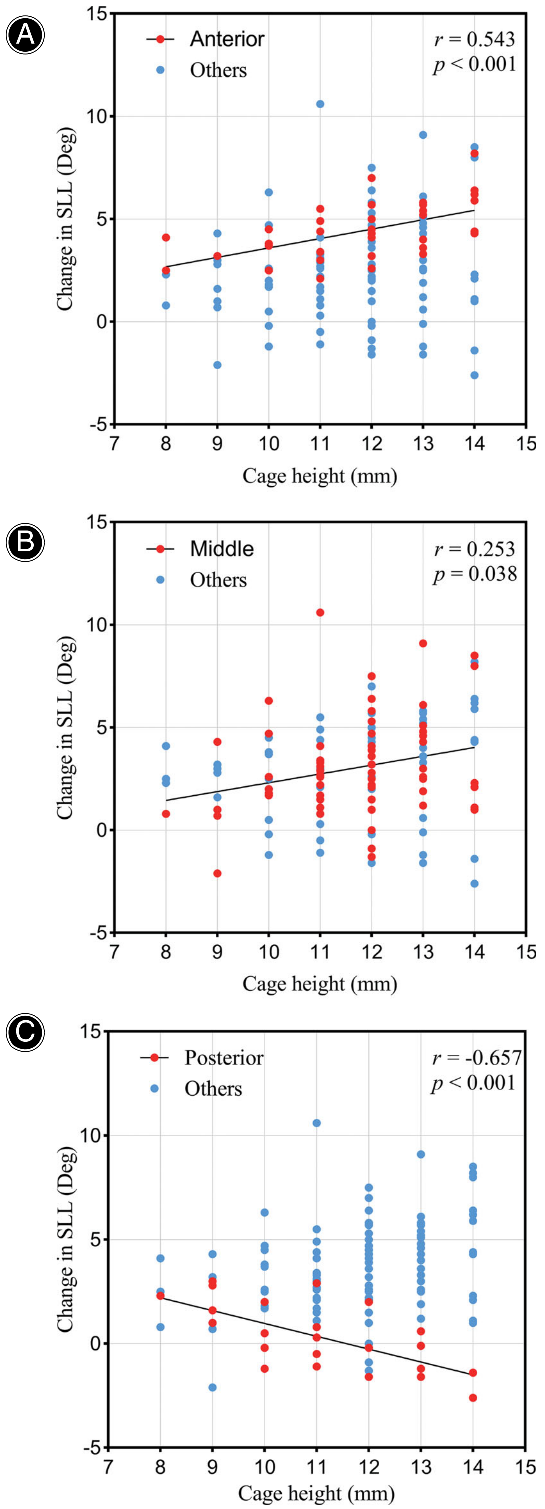

Fig. 4 Relationship between cage height and changes in segmental lumbar lordosis (SLL) with anterior (A), middle (B), and posterior (C) cage placement. Cage height had a positive correlation with SLL when the cage was located anteriorly and had a negative correlation with SLL when the cage was located posteriorly. If the cage was located in the middle, cage height had no significant correlation with SLL.

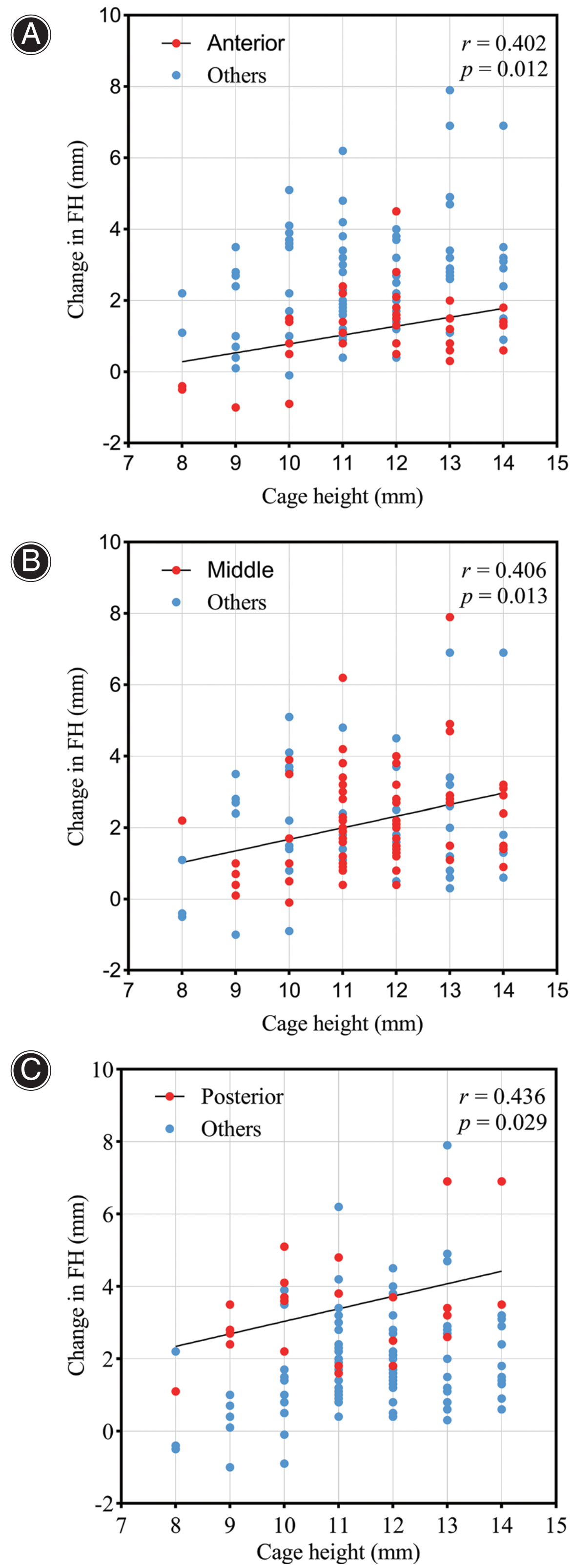

Fig. 5 Relationship between cage height and changes in foraminal height (FH) with anterior (A), middle (B), and posterior (C) cage placement. FH was positively correlated with cage height in any cage position.

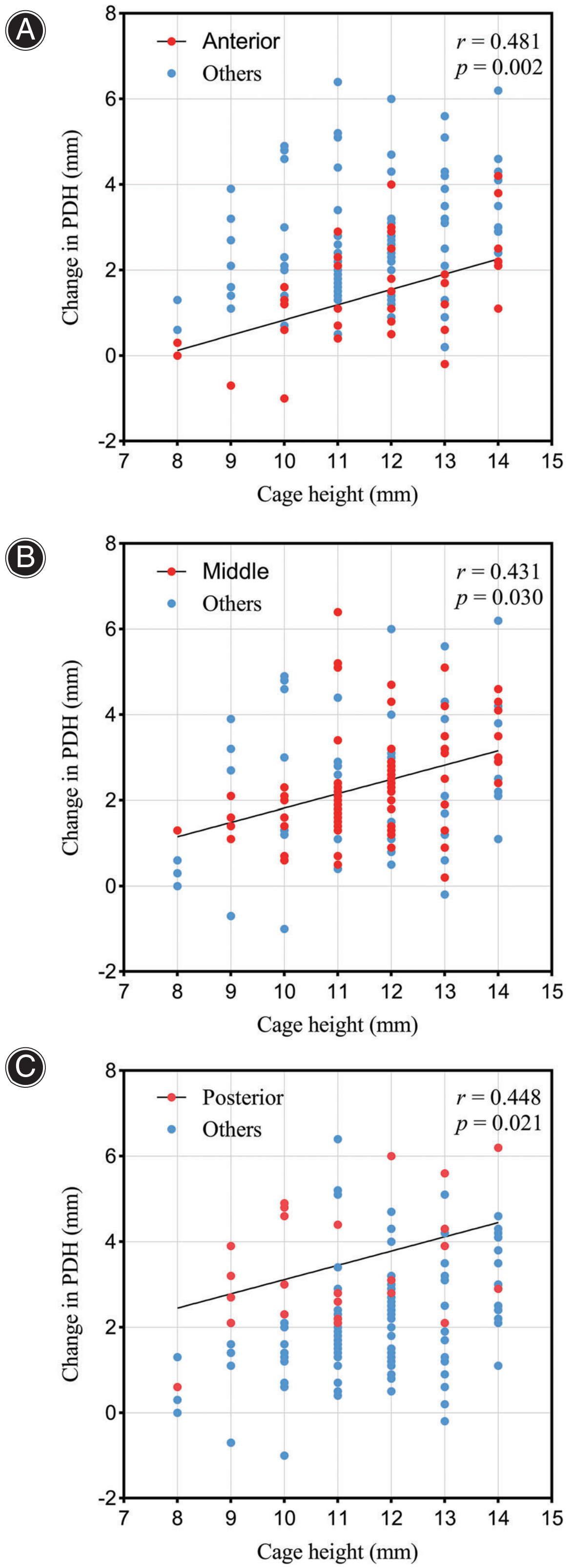

Fig. 6 Relationship between cage height and changes in posterior disc height (PDH) with anterior (A), middle (B), and posterior (C) cage placement. PDH was positively correlated with cage height in any cage position

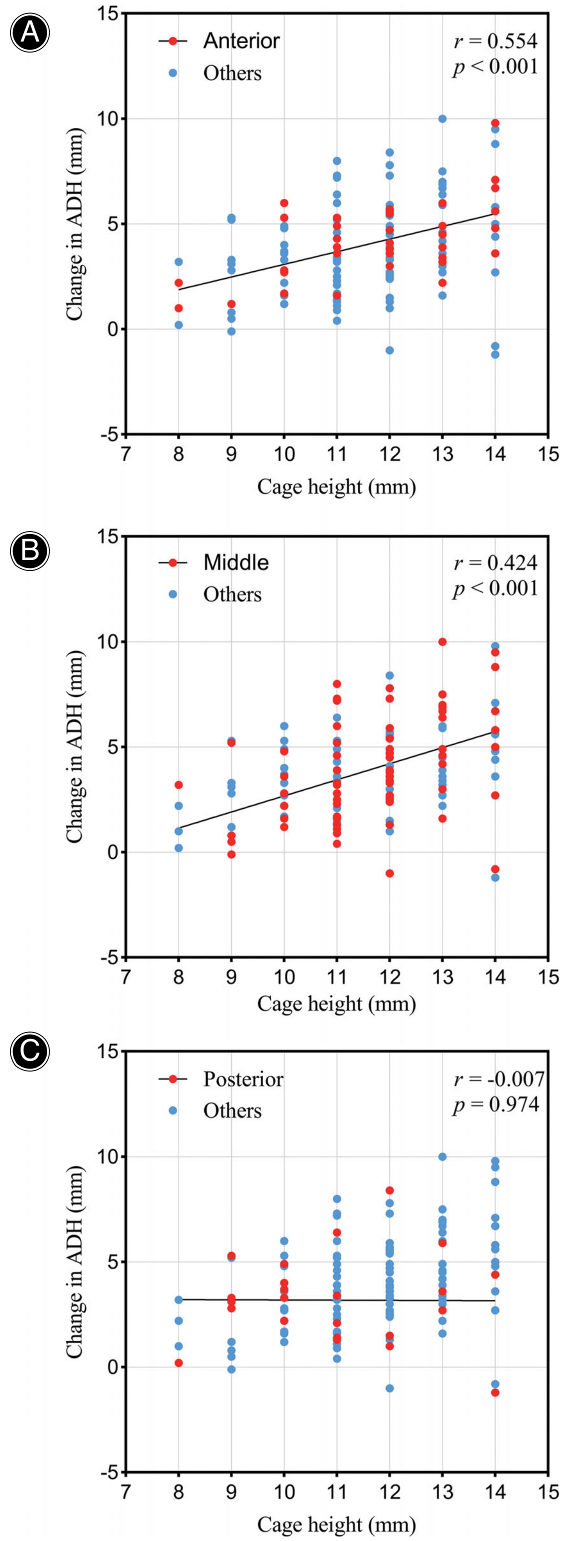

Fig. 7 Relationship between cage height and changes in anterior disc height (ADH) with anterior (A), middle (B), and posterior (C) cage placement. ADH had a positive correlation with cage height when the cage was located in anterior and middle of the endplate. If the cage was located in the posterior, cage height had no significant correlation with ADH.

cage was located posteriorly ($r = -0.657$, $P < 0.001$) (Fig. 4A, C). If the cage was located in the middle, cage height had no significant correlation with SLL ($r = 0.253$, $P = 0.038$) (Fig. 4B). Both FH and PDH were positively correlated with cage height in any cage position (Figs 5 and 6). However, ADH had a positive correlation with cage height only when the cage was located in the anterior and middle of the endplate ($r = 0.554$, $P < 0.001$, $r = 0.424$, $P < 0.001$; Fig. 7A, B). If the cage was located in the posterior, cage height had no significant correlation with ADH ($r = -0.007$, $P = 0.974$; Fig. 7C).

Discussion

Radiographic results of TLIF were increasingly reported to be correlated with clinical results[16–18]. The restoration of sagittal alignment after lumbar interbody fusion is important because it can increase the fusion rate and reduce the incidence of adjacent segment diseases. The impact of cage position on lumbar lordosis and disc height has been mentioned in some studies, but this has not yet become the subject of these studies[16,18,24,25]. This study focused on the effect of sagittal cage position on radiographic results of TLIF, especially the relationship between cage position and the improvement of SLL, FH, PDH, and ADH.

Relationship between Cage Position and SLL

SLL in the Anterior Group (4.4°) and Middle Group (3.0°) was significantly improved after operation, but not in Posterior Group (0.3°). Therefore, it can be concluded that the increase of SLL was correlated with the cage position. This was consistent with previous studies, which suggested that the cage should be placed as anteriorly as possible in disc space during TLIF surgery to optimize the lordosis of surgical level[18,20,24]. The same results were also found in lateral lumbar interbody fusion and posterior lumbar interbody fusion[23,26]. In contrast, in a vitro biomechanical study, Faundez *et al.*[27] found that SLL was not affected by the anterior or posterior position of the cage. This may be due to the difference between the internal and external biomechanical environment of the human body. In addition, straight rods were used in their study, nor did they aim for restoring lordosis, which may also limit the final lordosis achieved. As reported in previous studies, the amount of SLL that could be obtained after TLIF ranged from $-0.1°$ to $+20.2°$[17,24,25,28]. The substantially increase of SLL could be attributed to application of a surgical technique that involves bilateral facetectomies and utilization of a wedge-shaped cage with lordosis, which helped restore the lordosis[24,29]. In the present study, the TLIF surgery used routinely unilateral facetectomy and a bullet-shaped cage without lordosis. The difference in the increase of SLL among the three groups is mainly attributed to the cage positions which vary from anterior to posterior in disc space. The more anterior the cage is placed, the longer the lever arm, the easier it is to perform posterior compression and obtain lordosis. Therefore, some surgeons tended to place the cage as anteriorly as possible[20,24,25].

Attention should be paid to the restoration and maintenance of the SLL during TLIF. Reduced lumbar lordosis is common in patients with degenerative lumbar diseases, resulting in sagittal spinal misalignment. The restoration of SLL will contribute to the recovery of lumbar lordosis. In addition, a lower lordotic angle of the fused segment increases the joint load of the adjacent unfused segment.[30] The anterior cage placement can optimize the restoration of SLL and may avoid the occurrence of adjacent segment diseases. Matsumoto *et al.*[6] suggested that appropriate SLL should be obtained at surgery to prevent adjacent segment diseases, even with single-level lumbar interbody fusion. Furthermore, the improvement in lumbar lordosis is associated with back and leg pain alleviation as assessed by the visual analog scale[16].

Relationship between Cage Position and FH, PDH, and ADH

Degenerative changes of lumbar spine may lead to the loss of intervertebral disc height. Previous studies revealed that TLIF surgery had the ability to restore the height of the intervertebral space.[18,31] Our study emphasized this again, as we further investigated the impact of cage position on FH and intervertebral disc height (PDH and ADH). The increase of FH and PDH showed a significant negative correlation with CPR, which meant that the more posteriorly the cage was placed, the greater the expected increase in FH and PDH. The posterior placement of the cage will have a more direct and local impact on the posterior disc space. As the position of the cage moves forward, the increase of FH and PDH is gradually decreasing. The amount of FH and PDH is less with the anterior cage position. Therefore, attention should be paid to excessive posterior compression causing stenosis of the foramina. However, we found that there was no significant correlation of CPR with the increase of ADH. This might be attributed to the intact anterior longitudinal ligament would limit the distraction of the anterior disc space. Moreover, the effect of posterior compression was weakened with a cage located in posterior portion of the disc space, resulting in the inability to further increase ADH.

Higher final disc height has been reported to be associated with improved clinical outcomes, indicating the importance of restoring these variables during TLIF[16]. Kepler *et al.*[16] found that patients with persistent leg pain at final follow-up had lower disc height than patients with pain relief at final follow-up. The reduction of disc height is usually accompanied by a decrease in FH and possible nerve root compression. Moreover, the change of PDH can indirectly indicate the change of FH. Therefore, the recovery of disc height can increase neuroforaminal height, potentially reducing nerve root compression.

Effect of Cage Height on Radiographic Results in Different Cage Positions

The subanalysis results based on the position of the cage showed that cage height had a positive correlation with ADH when the cage was located in the anterior and middle of the endplate ($r = 0.554$, $P < 0.001$, $r = 0.424$, $P < 0.001$). If the cage was located in the posterior, cage height had no significant correlation with ADH ($r = -0.007$, $P = 0.974$). Of note, the cage height had a positive correlation with SLL when the cage was located anteriorly ($r = 0.543$, $P < 0.001$) and had a negative correlation with SLL when the cage was located posteriorly ($r = -0.657$, $P < 0.001$). Therefore, a thick cage located in the anterior endplate may contribute to achieve maximum lordosis, and a thin cage located posteriorly would be conducive to optimize the lordosis. But our results showed that the improvement of SLL with anterior cage placement may be at the expense of the increase amount of FH and PDH. In a few patients, the absolute height of FH and PDH was reduced with the cage located anteriorly. Consequently, optimizing the lordosis with a thin cage located posteriorly was not a perfect solution. Because FH and PDH were positively correlated with cage height (Figs 5 and 6), a thick cage placed as anteriorly as possible may be preferable. The actual situation may be more complicated, so we need to choose the appropriate cage according to the actual situation in the operation. Cage heights should be chosen by attempting to achieve the same height as the disc above the surgical level, with adjustments made intraoperatively depending on the difficulty of cage insertion. This will contribute to the recovery of FH and PDH. If the main purpose of surgery is to restore SLL, then this cage should be placed as anteriorly as possible or used in conjunction with a posterior osteotomy.

The clinical significance of sagittal alignment recovery in spinal surgery has been paid more and more attention. This study suggested that changing the position of the cage was an effective way to reconstruct the lumbar lordosis. It is easier and more effective to restore lumbar lordosis with anterior cage placement. The biomechanical and finite element studies demonstrated that anterior cage placement would result in better load-sharing between the anterior cage and the posterior pedicle screws construct thus possibly enhancing stability and successful bony fusion[32,33]. In addition, it was reported that the improvement of lumbar lordosis was related to a lower incidence of adjacent segment diseases, and proper disc height and SLL restoration were essential for prevention of adjacent segment diseases[34]. Since the cage position is mainly determined by the surgeon during operation, this can guide the surgeon to place the cage in a suitable position to obtain satisfactory results.

Limitations

There are several limitations in this study. One of the limitations is that this was a retrospective study. Second, there is no attempt to relate radiographic results to improved clinical outcomes, yet this relationship is well-documented in the literature[16–18]. The length of follow-up is relatively insufficient to confirm the reduced incidence of adjacent segment diseases with improved SLL, and the longer follow-up is ongoing. Third, we used only one type of cage. Further studies will be needed to clarify the effects of various cage types on postoperative lordosis. Despite these limitations, to our knowledge, this is the largest series to focused on the effect of sagittal cage position on radiographic results of single-level TLIF, and all operations were performed by the same surgical team with consistent surgical protocols.

Conclusions

The increase of SLL, FH and PDH is correlated with cage position. The cage located in anterior portion of the disc space is conducive to the reconstruction of SLL. Conversely, posterior cage placement can contribute to the restoration of PDH and FH. In addition, cage height is a factor affecting radiographic results. The cage height should be chosen by attempting to achieve the same height as the disc above the surgical level. If the main purpose of surgery is to restore SLL, a thick cage placed as anteriorly as possible is recommended.

Authorship Declaration

All authors contributing to the manuscript have approved the final version to be published.

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