Predictors of Spontaneous Restoration of Lumbar Lordosis after Single-Level Transforaminal Lumbar Interbody Fusion for Degenerative Lumbar Diseases

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Abstract:

Introduction: Preoperative factors that predict postoperative restoration of lumbar lordosis (LL) are not well understood. To investigate whether preoperative postural correction of LL, sagittal malalignment, or lumbar flexibility are associated with the postoperative restoration of LL in patients treated with a single-level transforaminal lumbar interbody fusion (TLIF), a retrospective cohort study was conducted.

Methods: We enrolled 104 patients (mean age: 67.5±10.7 years old; 47 men and 57 women) with lumbar degenerative diseases treated with a single-level TLIF. The pre- and postoperative LL were examined using lateral radiographs in the standing position and computed tomography (CT) images in the supine position. The correlation between postoperative LL restoration and preoperative postural correction of LL (difference in LL between the standing and supine positions: D-LL), sagittal imbalance (pelvic incidence minus LL: PI-LL), and lumbar flexibility (difference in LL between the flexion and extension postures) were analyzed. Patients were divided into two groups according to the D-LL (D-LL≥0° and D-LL<0°). The rates of postoperative LL restoration (postoperative LL-preoperative LL in standing) were compared between the two groups.

Results: Multiple regression analysis performed after adjustment for age, gender, body mass index, and cage angle revealed that postoperative LL restoration was significantly correlated with D-LL ($p<0.001$), but not with PI-LL, and lumbar flexibility. Patients with a preoperative D-LL≥0° showed a significantly greater increase of LL after TLIF (7.1°±11.2°) than those with D-LL<0° (1.4°±6.6°) ($p=0.003$).

Conclusions: A preoperative evaluation of a lateral radiograph or CT taken in the supine position is useful in predicting postoperative improvement of sagittal alignment. Postoperative improvement of sagittal spinopelvic alignment would be expected when LL is corrected in the supine position preoperatively. Surgeons should pay attention to the postural correction of LL when performing short-segment fusion surgery for lumbar degenerative disease with sagittal malalignment.

Keywords:

sagittal alignment, lordosis, restoration, transforaminal lumbar interbody fusion (TLIF), spontaneous, lumbar degenerative disease, spondylolisthesis

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Introduction

Transforaminal lumbar interbody fusion (TLIF) is a commonly used procedure for treating lumbar degenerative diseases[1]. A circumferential intervertebral fusion can be obtained via a minimally invasive unilateral approach[1]. Favorable clinical and radiological outcomes of TLIF have been previously reported; however, a certain number of patients have postoperative residual symptoms, such as low back pain, lower extremity pain, or numbness[2-5].

The importance of sagittal spinopelvic alignment in the treatment of patients with adult spinal deformities has been widely recognized, particularly when long-segment fusion surgery is considered[6,7]. In such cases, balance between the pelvic incidence (PI) and lumbar lordosis (LL) is reported to be a key factor, and PI minus LL (PI-LL) ≤10° is the ideal spinopelvic alignment to achieve good clinical results after long-segment fusion surgery for adult spinal deformities[8]. Recently, several studies have suggested that sagittal alignment should be taken into consideration even when treating patients with short-segment fusion[9-11]. It was previously reported that surgical outcomes after short-segment TLIF are influenced by a high PI-LL[9]. Kong et al. studied surgical outcomes of single-level posterior lumbar interbody fusion for patients with L4 degenerative spondylolisthesis and concluded that the postoperative improvement of back pain is associated with the improvement of sagittal spinopelvic alignment[12]. Several studies have reported that LL tends to be restored following short-segment lumbar interbody fusion[10,13,14]; however, preoperative factors that predict postoperative restoration (or maintenance) of LL are not well understood.

Generally, sagittal spinopelvic alignment, such as LL and sacral slope (SS), show significant changes across positions in an individual, while PI remains unchanged[15]. In this study, we focused on the differences in LL between the standing and supine positions. We hypothesized that sagittal spinopelvic alignment should be corrected in the supine position when the lumbar spine of the patient is flexible and capable of being restored after surgery. Thus, we believed that the difference in LL between the standing and supine positions, which reflects postural correction of LL in the supine position, would be correlated with the spontaneous restoration of LL after short-segment TLIF. In addition, it is suggested that preoperative sagittal imbalance and lumbar flexibility are correlated with postoperative LL restoration. From these observations, this study was conducted to elucidate how the sagittal spinopelvic alignment changes after a single-level TLIF and whether preoperative postural differences in LL, PI-LL, and lumbar flexibility are associated with postoperative restoration of sagittal spinopelvic alignment.

Materials and Methods

We enrolled 124 consecutive patients with lumbar degenerative diseases treated with single-level (L3-L4, L4-L5, or L5-S1) TLIF with none or one-level decompression surgery at another level at our hospital between September 2014 and November 2019. Patients who needed additional decompression of two or more levels were excluded. To exclude the influence of miscellaneous factors related to sagittal spinopelvic alignment, the inclusion criteria were strictly limited to lumbar degenerative diseases with neurological symptoms treated with a single-level TLIF. We excluded patients with vertebral fracture at L3, L4, L5, or S1 and those requiring reoperation on their lumbar spine within 1 year after surgery. Finally, 104 patients were included in the final analysis. The preoperative characteristics of patients, including age, gender, and body mass index (BMI), were reviewed. Spinopelvic parameters, such as LL (the angle between the superior endplates of L1 and S1) and PI (the angle between a line perpendicular to the sacral plate at its midpoint and a line from the center of the femoral head to the sacral end plate midpoint) were measured using radiographs taken in the standing position (Fig. 1, 2). LL was also measured using sagittal reconstruction CT images taken in the supine position (Fig. 1, 2). The preoperative postural correction of LL in the supine position was evaluated by examining the differences in LL (D-LL) between the standing and supine positions and calculated as the value on supine CT minus that on the standing radiograph. Therefore, a positive D-LL represents an increase of LL in the supine position. Generally, LL in the standing position was used for the analyses in this study, except for the calculation of D-LL. Preoperative existing sagittal imbalance was evaluated by the value of PI-LL. Lumbar flexibility was evaluated preoperatively using the flexion-extension lumbar radiographs taken in the standing position. The difference in LL between the lumbar-flexed and lumbar-extended positions was defined as lumbar flexibility[16].

LL was evaluated using radiographs taken in the standing position at 1 year postoperatively. Postoperative LL restoration was evaluated by examining the difference in LL between preoperative and postoperative radiographs in the standing position (postoperative LL - preoperative LL). Therefore, a positive value represents an increase in LL postoperatively. The study was conducted in accordance with the Declaration of Helsinki, and the study protocol was approved by the Institutional Review Board of our medical center. All patients provided informed consent.

Surgical procedure

TLIF was performed in the prone position with general endotracheal anesthesia. The side for the unilateral approach was usually the side showing worse neurological symptoms. If symptoms were similar on both sides, the left side was selected as the approach side. A 5-cm midline incision exposed the posterior elements and the surface of the L4-L5 facet joint on the approach side. The surface of the intervertebral disc was exposed by unilateral laminotomy and partial facetectomy. Local bone removed during the decompression

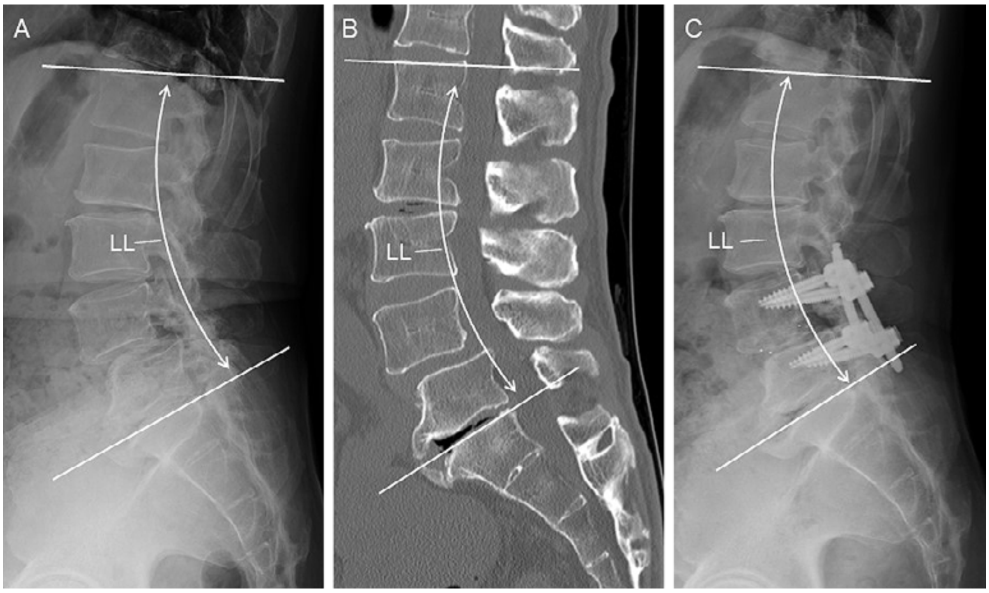

Figure 1. The preoperative lateral radiograph in the standing position (A) and computed tomography (CT) image in the supine position (B) of a 64-year-old man are shown. In this patient, no difference in lumbar lordosis (LL) was observed between the standing (A) and supine (B) positions. The postoperative lateral radiograph in the standing position (C) shows no remarkable change in LL when compared with the preoperative radiograph in the standing position.

Figure 2. The preoperative lateral radiograph in the standing position (A) and computed tomography (CT) image in the supine position (B) of a 63-year-old man are shown. In this patient, increases in lumbar lordosis (LL) are observed in the supine position (B) when compared with LL in the standing position (A). The postoperative lateral radiograph in the standing position (C) shows remarkable LL restoration when compared with the preoperative radiograph in the standing position.

procedure was utilized as a bone graft. After the removal of disc material and meticulous endplate preparation, the removed bone was milled and packed into the intervertebral disc space. One or two fusion cages packed with local milled bone were then inserted into the disc space. Following cage insertion, pedicle screws were placed on both sides. Using a percutaneous pedicle screw system, a 1-cm fascia incision allowed the insertion of pedicle screws transfascially. Adequate compressive force was applied to the disc space by the pedicle screws to establish stability of the fusion cages. In patients who required additional decompression surgery, unilateral laminectomy for bilateral decompres-

Table 1. Patient Demographic Data and Preoperative and Postoperative Lumbopelvic Parameters.

Age (years)		67.5±10.7
Gender (male/female)		47/57
Body mass index (kg/m^2)		24.8±3.7
PI-LL (°)	Radiograph (standing)	12.4±13.8
Lumbar flexibility	Preop	33.0±13.9
Preoperative LL (°)	Radiograph (standing)	39.1±14.2
	CT (supine)	36.5±11.6
Postural correction of LL	D-LL (preop)	−2.6±8.6
Postoperative LL (°)	Radiograph (standing)	42.5±13.3
Postoperative LL restoration	Postop and preop	3.4±9.3

Data are presented as the mean±standard deviation.
PI: pelvic incidence. LL: lumbar lordosis
D-LL: difference in lumbar lordosis between CT and radiograph (CT-radiograph)
Preop: before surgery. Postop: one year after surgery

sion was performed as previously reported[17].

Examining the correlation between preoperative spinopelvic parameters and postoperative restoration of global LL

To examine the influence of the preoperative values of D-LL, PI-LL, and lumbar flexibility on postoperative LL restoration, a correlation analysis was performed between each preoperative parameter and postoperative LL restoration. To exclude the influence of age, gender, BMI, and cage angle, a multiple regression analysis was performed after the appropriate adjustments.

Comparison of spinopelvic parameters between patients who showed an increase of LL in the supine position and patients who did not

Patients were divided into two groups depending on the value of D-LL (D-LL≥0° and D-LL<0°). Patients' age, gender, BMI, and angle of fusion cage were compared between the two groups. Preoperative values of PI-LL, lumbar flexibility, and LL, and postoperative value of LL were compared between the two groups. Postoperative LL restoration was calculated and compared between the two groups.

Data analysis

An unpaired t-test was used to compare the spinopelvic parameters between radiograph and CT and between preoperative and postoperative values. To investigate the correlation between the preoperative parameters (D-LL, PI-LL, and lumbar flexibility) and postoperative LL restoration, Pearson's correlation analysis was used, and multiple regression analysis was performed after adjustment for age, gender, BMI, and angle of fusion cage. To compare the age, BMI, cage angle, and lumbopelvic parameters between the two groups (D-LL≥0° and D-LL<0°), an unpaired t-test was used. To compare the gender between the two groups, a chi-square test was used. A p value<0.05 was considered statistically significant. Values were expressed as the mean±standard deviation.

Results

Table 1 shows the preoperative demographic data of patients (mean age: 67.5±10.7 years old; 47 men and 57 women; mean BMI: 24.8±3.7 kg/m^2). The mean preoperative PI-LL was 12.4°±13.8°. Of the 104 patients, 55 had a preoperative PI-LL>10° and 49 showed PI-LL≤10°. The mean value of lumbar flexibility was 33.0°±13.9°.

Preoperative postural correction of LL and postoperative LL restoration

As shown in Table 1, the mean LL was lower in the supine position than in the standing position, although no significant difference was found. The mean value of D-LL, which indicates postural correction of LL, was negative (−2.6°±8.6°). The mean LL in the standing position was 39.1°±14.2° preoperatively and 42.5°±13.3° postoperatively (Table 1). LL increased after surgery; however, there was no significant difference between preoperative LL and postoperative LL (p=0.078).

Correlation between postoperative LL restoration and preoperative D-LL, PI-LL, and lumbar flexibility

Postoperative LL restoration was significantly correlated with preoperative D-LL (r=0.4831, p<0.001) and PI-LL (r=0.4085, p<0.001); however, no significant correlation was observed between postoperative LL restoration and lumbar flexibility (Table 2). Multiple regression analysis performed after adjustment for age, gender, BMI, and cage angle revealed that postoperative LL restoration was significantly correlated with D-LL (p<0.001), but not with PI-LL (p=0.051), as shown in Table 3.

Comparison between patients with preoperative D-LL≥0° and D-LL<0°

There were 36 patients who had a preoperative D-LL≥0° and 68 patients who had a preoperative D-LL<0°. As shown in Table 4, no significant differences in age, gender, BMI, or cage angle were observed between the two groups. The preoperative PI-LL was significantly greater in the D-LL≥0° group (20.9°±13.9°) than in the D-LL<0° group (7.9°±11.4°) (p<0.001). No significant difference was found in preoperative lumbar flexibility between the two groups. Both pre- and postoperatively, LL was significantly lower in the D-LL≥0° group than in the D-LL<0° group (Table 4). Postoperative LL restoration in the D-LL≥0° group (7.1°±11.2°) was significantly greater than that in the D-LL<0° group (1.4°±6.6°) (p=0.003), as shown in Table 4.

Table 2. Correlation Between Postoperative LL Restoration and Preoperative D-LL, PI-LL, and Lumbar Flexibility.

Variables	Pearson's r	p
D-LL	0.4831	<0.001*
PI-LL	0.4085	<0.001*
Lumbar flexibility	0.0478	NS

Asterisks indicate statistically significant differences (*p*<0.05).
NS: not significant
D-LL: difference in lumbar lordosis between CT and radiograph (CT-radiograph)
PI-LL: pelvic incidence minus lumbar lordosis

Discussion

In this study, patients had a slightly decreased LL in the supine position when compared with the standing position, indicating that patients tended to have a smaller lordotic angle in the supine position. While these results are similar to those of previous reports examining LL in asymptomatic volunteers and patients with lumbar degenerative disease[15,18], recent studies have reported an increase in the LL and SS in the supine position in adult patients with spinal deformities[19,20]. In this study, one-third (36/104) of patients had an increase of LL in the supine position (Table 4), which may represent a different pathology than that in patients who had a decrease of LL in the supine position.

Several studies have examined the postoperative changes of LL, and most report that LL increases after TLIF[10,12-14,20,21]. This study is the first to report that patients in the D-LL≥0° group demonstrated greater restoration of LL than those in

Table 3. Correlation Between Postoperative LL Restoration and D-LL and PI-LL Adjusted for Age, Gender, Body Mass Index, and Cage Angle.

Dependent variables	Independent variables	Regression coefficient	Standardized regression coefficient	t value	*p*
Postoperative LL restoration	D-LL	0.4719	0.4361	4.1987	<0.001*
	PI-LL	0.1342	0.1993	1.9788	0.051

Asterisks indicate statistically significant differences (*p*<0.05).
D-LL: difference in lumbar lordosis between CT and radiograph (CT-radiograph)
PI-LL: pelvic incidence minus lumbar lordosis

Table 4. Demographic Data, Cage Angle, and Sagittal Spinopelvic Parameters of the Two Groups (D-LL≥0° and D-LL<0°).

		D-LL≥0°	D-LL<0°	p
Number of patients		36	68	-
Age (years)		68.8±9.3	66.9±11.3	0.39
Gender (male/female)		19/17	28/40	0.36
Body mass index (kg/m^2)		24.6±3.7	24.9±3.7	0.75
Cage angle (°)		5.1±1.4	5.3±1.5	0.50
PI-LL (°)	Preop	20.9±13.9	7.9±11.4	<0.001*
Lumbar flexibility	Preop	32.6±15.4	33.2±13.0	0.83
LL (°)	Preop	31.7±17.1	43.1±10.3	<0.001*
	Postop	38.8±16.1	44.5±11.2	0.040*
	Postoperative LL restoration	7.1±11.2	1.4±6.6	0.003*

Data are presented as the mean±standard deviation.
Asterisks indicate statistically significant differences (*p*<0.05).
PI: pelvic incidence. LL: lumbar lordosis
D-LL: difference in lumbar lordosis between CT and radiograph (CT-radiograph)
Preop: before surgery. Postop: one year after surgery

the D-LL<0° group. There have been only a few studies reporting preoperative factors that predict the postoperative improvement of sagittal spinopelvic alignment. Cheng et al. reported that patients with neurogenic claudication showed greater improvement of LL after a single-level TLIF than patients with low back pain and radiculopathy[14]. Their results suggest that greater improvement can be expected in patients with spinal stenosis and spondylolisthesis when compared with patients with discogenic pain and lumbar disc herniation. This may be due to the fact that patients with spinal stenosis may stand with their lumbar spine flexed preoperatively to relieve neurogenic symptoms.

A previous study has reported a relationship between PI and the postoperative restoration of LL[10]. In this study, we found a correlation between preoperative PI-LL and the postoperative restoration of LL, suggesting that preoperative existing spinal sagittal malalignment is a factor that predicts postoperative LL restoration. However, after the exclusion of the influences of age, gender, BMI, cage angle, and D-LL, no significant association was found between PI-LL and the postoperative LL restoration. In the present study, no correlation was found between preoperative lumbar flexibility and postoperative LL restoration. Regarding the preoperative postural correction of LL, there was a significant correlation of postoperative LL restoration with D-LL both before and after excluding the influences of age, gender, BMI, cage angle, and PI-LL, suggesting that the preoperative difference in LL between the two postures is the most reliable factor that predicts postoperative improvement of sagittal alignment. Our results show that greater LL was achieved postoperatively in patients who had a higher LL in the supine position than in the standing position preoperatively (D-LL≥0°). This suggests that postoperative improvement of sagittal spinopelvic alignment would be expected when lumbar lordotic angle is corrected in the supine position preoperatively. In other words, postoperative spontaneous restoration of LL cannot be expected when lumbar lordotic angle is not corrected in the supine position preoperatively.

The postoperative change in sagittal alignment varies depending on fusion level, number of surgically treated levels, and symptoms of patients. To exclude the influence of other factors related to sagittal alignment, we strictly limited the participants in this study to those with lumbar degenerative diseases with neurological symptoms treated with single-level TLIF. Moreover, patients with spinal stenosis requiring additional decompression surgery for two or more levels were excluded from this study. It is generally recognized that spinopelvic parameters vary depending on age, gender, and BMI[23-28]; therefore, multiple regression analysis was performed to exclude the influence of these factors.

The postoperative change of LL is affected by the angle of the fusion cage, and the shape of the fusion cage is related to postoperative segmental lordosis[29]. Kamlanathan et al. studied the postoperative change of segmental lordosis and global LL at 1 year after single-level fusion and found that reduction in lordosis at adjacent segments as a compensation occurs when greater segmental lordosis angles were achieved[22]. Thus, the postoperative change of global LL may not be strongly related to the cage angle. Moreover, we performed multiple regression analysis to exclude the influence of cage angle on postoperative restoration of LL in this study.

This study is not without limitations. First, the number of patients was limited due to the strict inclusion criteria, and the clinical characteristics of patients were highly homogenous. However, even with a limited number of patients, statistical significance was observed in our study, validating our results. Further studies are necessary to determine if patients with multilevel fusions have similar results to our patient population. Second, we did not examine the global spinal alignment, which is important when discussing spinal alignment. Unfortunately, some of our patients did not undergo whole spine radiography preoperatively. Further study is needed to clarify the correlation between postoperative restoration of sagittal alignment and global spinal alignment.

In conclusion, we found that postural correction of the preoperative sagittal spinal malalignment in the supine position when compared with the standing position can predict postoperative restoration of sagittal imbalance after single-level TLIF. These results are useful for spine surgeons who treat lumbar degenerative diseases using short-segment fusion surgery. Preoperative evaluation of postural correction of sagittal spinal malalignment is necessary when treating patients with spinal deformity[18]. In addition, when considering short-segment fusion surgery for patients with lumbar degenerative disease with kyphotic alignment, spine surgeons should pay attention to the postural correction of sagittal spinal malalignment preoperatively. A preoperative evaluation of a lateral radiograph or CT taken in the supine position is recommended, as postoperative restoration of LL can be predicted by comparing the sagittal spinopelvic alignment in the supine position with that in the standing position.

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