Simple Prediction of Reasonable Lumbar Lordosis Based on Patient's Postoperative Quality of Life Score

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Research Article

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Abstract

Background: Scarce information exists on the relationship between lumbar lordosis (LL) and health-related quality of life (HRQOL) after lumbar surgery. The aim of this study was to derive a predictive equation for lordosis using pelvic incidence and to establish a simple lumbar lordosis prediction method to improve the quality of life after surgery.

Methods: A number of 146 patients with lumbar surgery were included in the study. Spinopelvic parameters and Oswestry Disability Index (ODI) were measured at the final follow-up. At the 75^{th} percentile cut-off value, patients with ODI were assigned to a good HRQOL group. Stepwise multiple regression analysis was used to analyze the correlation between parameters and ODI, and simple linear regression analysis was conducted to deduce the predictive equation for the recovery of reasonable LL by posterior lumbar interbody fusion (PLIF).

Results: In the good HRQOL group, we included 108 patients with an ODI score less than 29 (75% cut-off value) at the last follow-up. All patients had had completed their posterior lumbar interbody fusion (L4-S1) by the same experienced surgeon. Multiple regression analysis revealed that LL ($P < 0.001$) was significantly associated with ODI as radiological parameters. The close relationship between PI and LL is highly evident from the value of the regression coefficient (r = 0.765, $P < 0.001$). Based on the correlation established between the above parameters, the following prediction equation for PI and LL was derived: LL = 0.59 × PI + 12 (r = 0.765, $P < 0.001$).

Conclusions: This simple calculation method can provide a more effective and simple prediction of lumbar lordosis in the Chinese population. This approach can be used as a decision-making tool for restoring LL in lumbar correction surgery and plays an important role in improving the quality of life of patients after lumbar surgery.

Introduction

Lumbar lordosis is a unique feature of the human spine that is the basis for erect, bipedal posture and gait development [1]. The sagittal alignment of the lumbar spine has an important impact on the pathogenesis of lumbar disease and the health-related quality of life. Lumbar curvature is essential to the bio-mechanical stability of the lumbar spine [2] and contributes to the bearing capacity and flexibility of the lumbar spine, which is very important for performing routine daily activities [3]. Glassman et al. [4, 5] established that global sagittal alignment correlated with HRQOL in patients with scoliosis and was greater than 30 degrees or other significant spinal deformities, including a primary deformity in the sagittal plane. Additionally, Schwab et al. [6] showed that the loss of lumbar lordosis was closely associated with lower SF-36 scores, and lumbar lordosis was an important predictor of disability and a significant factor affecting clinical outcomes. The postoperative lack of lordosis disturbs normal gait, imbalances the spine, and is compensated by hyperlordosis at the adjacent level, which in turn may leads to adjacent segment degeneration [7]. Therefore, a proper establishment of lordosis is important when considering lumbar fusion. The purposes of a spinal fusion may be to restore lordosis by instrumentation and to fuse the spine in a proper position. As two thirds of the lumbar lordosis occurs at L4–S1 [8] and two thirds of lumbar fusions are performed in this region, the ability to achieve a good lordosis of the lumbosacral spine represents the basis of surgery.

Considering the compensatory mechanisms, the concept of global spinopelvic alignment is important for maintaining an upright posture and a high HRQOL [4, 9, 10]. Therefore, determining the correlation between sagittal spinopelvic parameters and health-related quality of life (HRQOL) would provide useful information for treatment decision-making and planning. Previous studies have evidenced that pelvic incidence (PI) plays a leading role in regulating sagittal spine alignment and PI is involved in the sagittal lumbar curvature through a significant correlation between PI and LL [11–13]. Most importantly, PI is a pelvic anatomical parameter that remains unchanged in adults [11]. Therefore, in this study, we used PI as a key parameter to predict reasonable reconstruction of lumbar lordosis after lumbar fusion. Although many previous studies have reported predictions of LL, few of them have predicted reconstructed reasonable LL based on the postoperative patient quality of life scores [10, 14, 15]. The purpose of this investigation was to derive a predictive equation for reasonable lumbar lordosis based on the PI of patients with high quality of life after lumbar fusion and to establish a simple LL calculation method to predict the quality of life of patients after lumbar fusion.

Materials And Methods

The present trial had approval from the Institutional Review Board of Cangzhou central Hospital. A number of 146 patients (64 women and 82 men; mean age of 39.8 ± 13.6 years; range, 21–60 years) were included who underwent PLIF between May 2016 and December 2018. The inclusion criteria were as follows: (1) individuals aged between 18 and 60 years; (2) simple lumbar disc herniation or lumbar spinal stenosis (L4-S1); (3) complete imaging data and Health Related Quality of Life (HRQOL) questionnaire; (4) no underlying diseases, including hypertension, diabetes, and coronary heart disease. The following exclusion criteria were applied: (1) history of spinal surgery; (2) spinal deformities, including scoliosis, isthmic spondylolisthesis, sacralization, or lumbarization; (3) spinal trauma or tumors; (4) vertebral compression fractures; and (5) neuromuscular disorders.

All patients were followed up for at least six months and completed the final follow-up and the health-related quality of life questionnaire. ODI at the final follow-up was used for HRQOL assessment. Postoperative patients with ODI below the 75th percentile threshold were assigned to a good HRQOL group.

The spinopelvic radiographic parameters of an entire spine standing X-ray were measured. The final follow-up radiographic data included full-length standing coronal and sagittal radiographs obtained in the freestanding locations with fingers on the clavicle [16]. Spinopelvic radiographic measurements included thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS). The measurement methods are presented in Table 1 (Fig. 1). Mean absolute error (MAE) values were calculated, and analysis of variance based on the Student's test was used as a post-hoc test to determine the significant difference in MAE between the model developed in this analysis and the previously reported models.

Table 1
Preoperation and postoperation radiographic measurements.

Parameter	Radiographic measurements
Lumbar lordosis (LL)	the angle between the lower end plate of L1 and the lower end plate of L5 on frontal radiographs
Pelvic tilt (PT)	the angle between a line drawn from the S1 endplate to the center of the femoral heads drawn intersecting the femoral-heads
Sacral slope (SS)	the angle between a line drawn parallel to the S1 endplate and the horizontal plane
Pelvic incidence (PI)	the angle subtended by a line connecting the center of the femoral head to the center of the cephalad end plate of S1 and a second line drawn perpendicular to the S1 endplate at its center
Thoracic kyphosis(TK)	the angle between the upper end plate of the T5 and the lower end plate of the T12
Sagittal vertical axisthe (SVA)	the horizontal distance between the C7 plumb and the posterosuperior corner of the sacrum

Statistical analysis

All data were analyzed using statistical software SPSS 21.0 (SPSS Inc., Chicago, IL, USA). Statistical data are presented as mean ± standard deviation. Stepwise multiple regression analysis was conducted to determine the factors associated with good clinical outcomes. ODI scores were used as dependent variables and the above radiographic parameters as independent variables. In this group, Pearson correlation coefficients are used to examine the correlation between variables, and a simple linear regression analysis was applied to derive the equations to be predicted. A P-value < 0.05 was considered significant.

Results

All patients had their posterior lumbar interbody fusion (L4-S1) completed by the same experienced surgeon. The median ODI score for all patients increased from preoperative 55.5 points (range 20–70) to 19.0 points (range 0–35.6) at the follow-up. Patients with an ODI score below 29 (75% cutoff value) at the last follow-up were classified as a good HRQOL group. The study included 58 males and 50 females with a mean age of 36.7 years (SD 11.7 years; range 25–58 years).

The PLIF surgery caused an increase in LL (from 35° preoperatively to 40° at the last follow-up)and TK (from 20° preoperatively to 24° at the last follow-up), but a decrease in SVA (from 80 mm preoperatively to 40 mm at the follow-up). The preoperative PI was 48.0 ± 8.7°, whereas it was 48.1 ± 8.2°at the last follow-up (Table 2).

Table 2
All preoperative and last follow-up measurements of radiographically assessed variables (mean ± SD)

Variable	peroperation	Last follow-up
Lumbar lordosis (°)	35.4 ± 14.6	40.3 ± 9.2
Pelvic tilt (°)	19.2 ± 7.6	18.6 ± 6.8
Sacral slope (°)	28.9 ± 10.6	29.4 ± 7.7
Pelvic incidence (°)	48.0 ± 8.7	48.1 ± 8.2
Thoracic kyphosis (°)	19.9 ± 8.3	23.9 ± 9.4
Sagittal vertical axisthe (cm)	7.8 ± 2.1	4.4 ± 1.4
SD: Standard Deviation		

Table 3 displays the data compared between males and females in the good HRQOL group. We found significant differences in the PT of the different genders in this study (males vs. females, 16.4 ± 6.8 vs 21.1 ± 5.1; $P = 0.016$). Besides, the PI of the female subjects was slightly higher than that of the male subjects, whereas the difference was not statistically significant (47.2 ± 7.3 vs 50.2 ± 8.2; $P = 0.196$).

Table 3
“Gender” effects on patients in good HRQOL groups with ANOVA procedure

N = 47(29 Males and 18 Females)	Males	Females	P-value
Age	37.0 ± 14.0	36.3 ± 10.6	0.845
Body mass indx	25.1 ± 2.9	24.2 ± 3.3	0.319
Lumbar lordosis	34.8 ± 7.7	34.8 ± 5.3	0.981
Pelvic tilt	16.4 ± 6.8	21.1 ± 5.1	0.016*
Sacral slope	30.8 ± 7.7	29.1 ± 6.8	0.434
Pelvic incidence	47.2 ± 7.3	50.2 ± 8.2	0.196
Thoracic kyphosis	24.6 ± 8.9	24.1 ± 9.1	0.845
Sagittal vertical axisthe	4.7 ± 1.5	4.6 ± 1.5	0.899
* p < 0.05			
HRQOL: health-related quality of life;ANOVA: Analysis of Variance			

Multiple regression analysis revealed that lumbar lordosis (LL) (P< 0.001), sacral slope (SS) (P= 0.003), and thoracic kyphosis (TK) (P= 0.004) were significantly associated with ODI as radiological parameters (Table 4). The regression coefficients among all parameters confirmed the basic effect of pelvic incidence. The close relationship between the incidence and other pelvic and spinal parameters was completely evident from the value of the regression coefficient: lumbar lordosis (r = 0.765, P< 0.001), sacral slope (r = 0.610, P< 0.001), pelvic tilting (r = 0.490, P< 0.001), and thoracic kyphosis (r = 0.509, P< 0.001). A close correlation existed between LL and SS (r = 0.669, P< 0.001) and TK (r = 0.676, P< 0.001). Moreover, a strong correlation was found between the sacral slope and thoracic kyphosis (r = 0.561, P< 0.001), and between the SS and PT (r = -0.391, P= 0.007) (Table 5). Based on the correlation between the above parameters, the following prediction equation for PI and LL was derived (Fig. 2): LL = 0.59 × PI + 12 (r = 0.765, P< 0.001).

Table 4
Stepwise multiple regression analysis

Variable	P-vaule
Lumbar lordosis	0.000*
Pelvic tilt	0.845
Sacral slope	0.003*
Pelvic incidence	0.866
Thoracic kyphosis	0.004*
Sagittal vertical axisthe	0.287
* P < 0.05	

Table 5
Correlation of the parameters in patients

		LL	SS	PT	PI	TK	SVA
LL	r	1	0.669**	0.055	0.765**	0.676*	−0.110
SS	r		1	−0.391*	0.610*	0.561*	0.142
PT	r			1	0.490**	−0.013	0.023
PI	r				1	0.509**	0.192
TK	r					1	0.212
SVA	r						1
* Significant correlation was established at the 0.001 level							
** Significant correlation was established at the 0.05 level							
LL: lumbar lordosis, PI: pelvic incidence; PT: pelvic tilt; SS: sacral slope; TK: Thoracic kyphosisare; SVA: sagittal vertical axis;							

Table 6 lists the mean absolute errors (MAE) between the actual LL and the predicted ideal LL. Our present results showed that the tests in the validation queue exhibited a good correlation between the predicted and the actual LL (r = 0.522), with an average absolute error (MAE) of 5.6°. Compared with the other six formulas, we found that the current formula had the lowest MAE value. In addition to the current formula, the MAEs of all other prediction models of LL based on PI were greater than 11°.

Table 6
Comparison of Different Equations Regarding the analysis of error Between Actual Lumbar Lordosis and Predicted Ideal Lumbar Lordosis

Equations	Mean absolute error	Range	P-vaule
Yu et al.[33]	14.1 ± 6.0	0–26.8	< 0.001
Xu et al.[30]	11.1 ± 6.o	0.2–24.2	< 0.001
Le Huec and Hasegawa [28]	14.2 ± 5.9	0.6–27.1	< 0.001
Barrett et al.[22]	16.6 ± 5.9	2.7–29.7	< 0.001
Schwab et al.[24]	13.1 ± 5.9	0.8–25.9	< 0.001
Lee et al.[32]	17.5 ± 6.8	1.0–32.0	< 0.001
Present study	5.6 ± 5.4	0.1–29.7	0.988

Discussion

Currently, no recognized standard exists in lumbar fusion surgery for reconstruction and restoration of LL. In the past, LL reconstruction success was mainly based on the personal experience of the surgeon. In recent years, some authors have put forward prediction models for LL reconstruction, proposing methods to determine the degree of LL correction [10, 11, 14, 15, 17]. It is well known that maintaining global sagittal position is essential for a high quality of life and improving the postoperative outcomes of spinal surgery [9]. Lumbar lordosis is critical to maintaining the sagittal balance of the spine. The first step in reconstructing the sagittal balance of the spine is the restoration of a reasonable lumbar lordosis [18, 19]. Bernhardt and Bridwell [8] studied the alignment of the normal segments of the thoracic and lumbar spine to provide guidance for reorientation of the procedure. These researchers found significant differences in the lumbar lordosis between individuals. However, they recognized a progressive increase in lumbar lordosis from the upper to the lower lumbar segments, with two-thirds of the lumbar lordosis occurring from L4 to S1 segments. The notion that the lower two segments of the lumbar region are important areas for observation in lumbar reconstruction supports the strategy of adjusting the lower lumbar spine to restore the segmental lordosis to two-thirds of the total lordotic target. Therefore, the reconstruction of the lower lumbar vertebrae or segmental reduction of the lower lumbar spine is particularly important during the reconstruction of lumbar lordosis. Senteler et al. [20] found that recovery of sufficient lumbar lordosis during low lumbar fusion surgery (L4-S1) is beneficial to slow down the degeneration of the adjacent segments. Therefore, to restore sufficient lumbar lordosis during lumbar degenerative lesions and spinal deformity surgery, especially in the recovery of L4-S1 segmental lumbar lordosis, the avoidance of the occurrence of degeneration of adjacent segments after lumbar reconstruction is an important consideration.

Many studies have presented predictive models for LL and given input values of certain pelvic parameters; PI has been a primary focus in such investigations [10, 12, 14, 17, 21–23, 26]. Barrett et al.

[23] reported the use of PI to predict lumbar lordosis, but their findings do not apply to adults because the average age of their participants was 13 ± 2 years. On the other hand, previous studies have shown that PI in children and adolescents changes with age. This change not only affects the accuracy of any linear regression prediction model for LL based on PI, but also the validity of the use of adolescent prediction algorithms in adult patients. In this respect, Xu et al. [17] attempted to analyze the correlation between LL and PI, age, gender, and body mass index (BMI) in 296 asymptomatic Chinese adults and finally deduced an LL prediction model by the inclusion of PI and age: $LL = 0.508 \times PI - 0.088 \times age + 28.6$. Although their formula seems to be more accurate in predicting LL in Chinese, it cannot be used for patients with various diseases with sagittal deformities, and age has an important influence on the natural history of sagittal changes in adult spine. Boulay et al. [12] attempted to establish an equation for predicting LL by TK, SS, PI, and T9 tilt angles. This equation was more accurate in predicting lumbar lordosis in normal adults, but not in various diseases with sagittal contour abnormalities, because the tilt angles of TK, SS, and T9 change in degenerative lumbar disease. Nevertheless, incorporating more parameter variables into an LL prediction would increase its accuracy and improve the prediction ability of its equation. In addition, the inclusion of multiple variables would not only lead to difficulties in clinical application; the interaction between variables cause large deviations between predicted and actual values, which may affect surgical strategies and even the postoperative outcome. Therefore, Schwab et al. [14] revisited the multi-parameter prediction models for LL and suggested that these models could be simplified by relying only on PI and effectively predicting LL. They put forward the following formula: $LL = PI + 9°$ (± 9°). However, the Oswestry Dysfunction Index (ODI) of LL patients with PI higher than 9° was significantly higher than that of LL patients with PI greater than or less than 9°. Finally, the formula was simplified as follows: $LL = PI + 9°$ [10].

Although a significant correlation between PI and LL has been reported in several publications, including this study, PI may be affected by other parameters, such as PT, SS, and TK. In addition, LL may also be influenced by TK as a reciprocal mechanism [24]. In this study, we found that PI was significantly correlated with LL ($r = 0.765$, $P < 0.001$), SS ($r = 0.610$, $P < 0.001$), PT ($r = 0.490$, $P < 0.001$), and TK ($r = 0.509$, $P < 0.001$). There was a close correlation between LL and SS ($r = 0.669$, $P < 0.001$) and TK ($r = 0.676$, $P < 0.001$). Earlier studies showed that with aging, thoracic kyphosis and SS increase or decrease, but asymptomatic individuals can maintain the balance of sagittal alignment of the spine [11, 19]. Schwab et al. [14] revealed that the sacral slope may be affected by pelvic retroversion and knee flexion typical of patients with significant loss of lumbar lordosis. This is the reason why both TK and SS have a high correlation with LL and are not included as variables in the predicted equation. However, we also consider that the correlation between these data may have clinical implications for specific surgical plans aimed at the reconstruction of reasonable lumbar curvature. Therefore, this shortage might be a limitation of this study.

Here, we established that the tests in the validation queue showed a good correlation between the predicted and the actual LL ($r = 0.522$), with an average absolute error (MAE) of 5.6° (Table 6). We found that, compared with the other six aforementioned formulas, the current formula had the lowest MAE value. In addition to the current formula, the MAE of all other prediction models of LL based on PI was greater than 11° (Table 6). Overall, these results indicated that our predictive equation was stable and reliable in terms of clinical application.

This study has several other limitations in addition to the ones mentioned above. First, the sample size of this study was relatively small, which to some extent weakened the statistical power of the study and its ability to detect correlations. Second, other radiological measurements (e.g. sacral slope and thoracic kyphosis) that could affect HRQOL were not included. Third, we did not analyze the potential association between the lower extremity and lordosis shape. Finally, it could be considered that HRQOL was evaluated by only ODI, and thus our results may be biased. In particular, evaluation using multiple tools can lead to more detailed disability information in HRQOL determination. However, the reason for using ODI in this investigation is that non-pathological cut-off values of radiographic parameters (i.e., SS, SVA, and PT.) were assessed based on the ODI reported in a previous study [25]. Despite the limited sample size, we were able to find the relationship between pelvic anatomy and lumbar spine shape. The findings of thins study provide a new perspective in the surgical strategies for the reconstruction of a reasonable lumbar lordosis.

Conclusions

This simple calculation method can provide a more appropriate and simpler lumbar lordosis prediction for the Chinese population. It can be used as a decision-making tool for restoring lumbar lordosis in lumbar correction surgery and plays an important role in improving the quality of life of patients after lumbar surgery.

Abbreviations

PLIF: posterior lumbar interbody fusion; HRQOL: health-related quality of life; ODI: oswestry disability index; BMI: body mass index; LL: lumbar lordosis, PI: pelvic incidence; PT: pelvic tilt; SS: sacral slope; TK: Thoracic kyphosisare; SVA: sagittal vertical axis; MAE: mean absolute error

Declarations

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None

Conflict of interest

None

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Figures

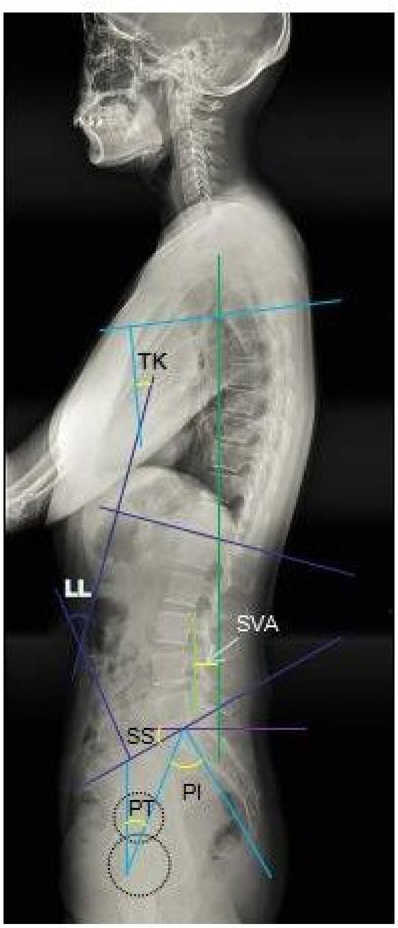

Figure 1

Illustration showing radiographic measurements of spinopelvic parameters.

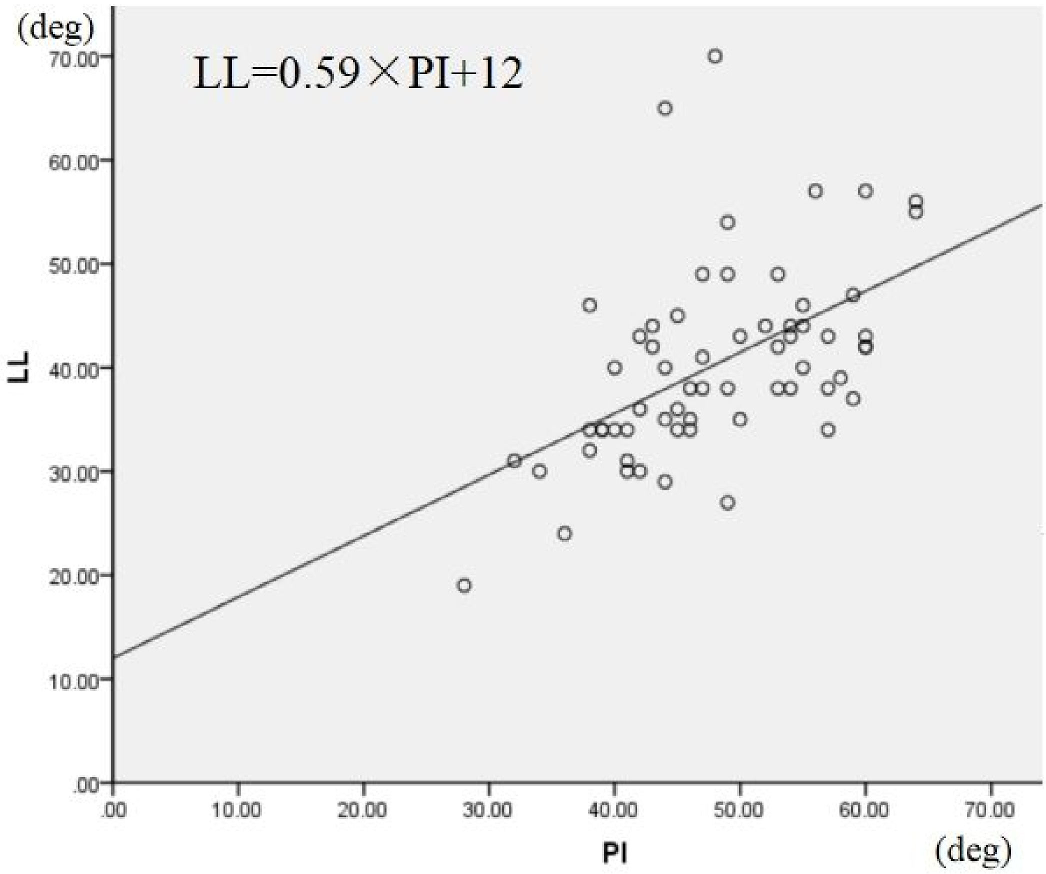

Figure 2

Relationship between the LL and PI in the good HRQOL group.