Simple prediction method of lumbar lordosis for planning of lumbar corrective surgery: radiological analysis in a Korean population

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Abstract

Purpose This study aimed at deriving a lordosis predictive equation using the pelvic incidence and to establish a simple prediction method of lumbar lordosis for planning lumbar corrective surgery in Asians.

Methods Eighty-six asymptomatic volunteers were enrolled in the study. The maximal lumbar lordosis (MLL), lower lumbar lordosis (LLL), pelvic incidence (PI), and sacral slope (SS) were measured. The correlations between the parameters were analyzed using Pearson correlation analysis. Predictive equations of lumbar lordosis through simple regression analysis of the parameters and simple predictive values of lumbar lordosis using PI were derived.

Results The PI strongly correlated with the SS ($r = 0.78$), and a strong correlation was found between the SS and LLL ($r = 0.89$), and between the SS and MLL ($r = 0.83$). Based on these correlations, the predictive equations of lumbar lordosis were found ($SS = 0.80 + 0.74 \text{ PI}$ ($r = 0.78$, $R^2 = 0.61$), $LLL = 5.20 + 0.87 \text{ SS}$ ($r = 0.89$, $R^2 = 0.80$), $MLL = 17.41 + 0.96 \text{ SS}$ ($r = 0.83$, $R^2 = 0.68$). When PI was between 30° to 35° , 40° to 50° and 55° to 60° , the equations predicted that MLL would be $PI + 10^\circ$, $PI + 5^\circ$ and PI, and LLL would be $PI - 5^\circ$, $PI - 10^\circ$ and $PI - 15^\circ$, respectively.

Conclusion This simple calculation method can provide a more appropriate and simpler prediction of lumbar lordosis for Asian populations. The prediction of lumbar lordosis should be used as a reference for surgeons planning to restore the lumbar lordosis in lumbar corrective surgery.

Keywords Adult spinal deformity · Alignment · Predictive lumbar lordosis · Pelvic incidence

Introduction

Recently, many authors have suggested the importance of the sagittal balance in spinal curvature [2, 3, 6]. In the treatment of lumbar degenerative diseases, lumbar fusion is an important option. Of these, achieving physiological lumbar lordosis is that is usually lost in lumbar degenerative disease is of prime importance [4, 10, 20, 29, 32]. If one fails to address the recovery of adequate lumbar lordosis during fusion surgery, particularly in multiple level fusion, a sagittal imbalance is the most likely result [5, 7, 17, 19, 23]. This will indeed hasten the degenerative changes in the adjacent level and the abnormal energy expenditure of the spine muscle [5, 28]. For the adequate restoration of lumbar lordosis, a proper estimation of lumbar lordosis for each patient is necessary. Indeed, lower lumbar lordosis of LLL 4–5 and L5–S1 comprises 70 % of the total lumbar lordosis [1, 13, 34]. Therefore, the restoration of LLL is most important for the adequate restoration of lumbar lordosis.

Few studies have examined methods for predicting the lumbar lordosis in lumbar corrective surgery [3, 18, 24, 27, 29, 33, 36]. Of these, the main subjects were Caucasians. Most published data shows that Caucasians have larger values of lumbar lordosis than Asians [1, 8, 9, 11, 15, 16,

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30, 35, 36]. Therefore, if there is a difference in the sagittal parameters between Caucasians and Asians, it would be inappropriate to use the prediction equations developed for Caucasians. Hence, it is important to develop prediction equations for Asians.

The initial purpose of this study was to derive a lordosis predictive equation using the PI in Koreans. The other purpose was to establish a simple calculation method of the MLL and LLL for planning lumbar corrective surgery.

Materials and methods

Study participants

Eighty-six volunteers (54 males and 32 females), who had pain-free interval of at least 6 months or had never sought medical advice for back pain, and reported no hip or knee joint deformities, were enrolled in this study. The subjects were mainly doctors, nurses and other allied health professionals affiliated with the medical center where the study was conducted. All subjects provided informed consent. The mean age, height, and weight of the subjects were 28.2 years (range 19–39 years), 168.6 cm (range 150.0–184.0 cm) and 64.1 kg (range 42.5–95.0 kg), respectively.

Radiographic measurement

Whole spine lateral radiographs on standing were taken using standard 37-inch-film. The hip joints and cervical spine were also included. The subjects were instructed to stand straight and relaxed with their knees fully extended. The elbows were flexed with both hands resting on a horizontal bar at the level of their shoulders. The film-to-focus distance was 2 m.

Three reference points were used: HA (hip axis: mid-point of the line between the geometric center of both femoral heads), JL (junctional level: most tilted thoracolumbar vertebra) and MSP (mid-sacral point: midpoint of the superior endplate of S1). As spinal and pelvic parameters, the MLL, LLL, PI and SS were measured (Figs. 1, 2).

Two observers (SK, SJ) measured all parameters twice with a 1-week interval at the same view box in scoliosis clinics. All parameters were measured by hand on X-ray film using a protractor and ruler. The angulations between the various pairs of vertebrae were measured using the Cobb method. Round plastic jar caps with a small hole in their centers were placed just under the superior domes of both acetabula, visualized on lateral radiographs, and used to mark the centers of the femoral heads. Vertical lines were drawn using a ruler parallel to the edge of the lateral radiograph or with the radiographs mounted straight up.

Fig. 1 Methods for measuring the spinal parameters. Maximal lumbar lordosis: angle between the *upper end plates* of the junctional level and first sacrum vertebra (S1). Lower lumbar lordosis: angle between the *superior end plates* of the fourth lumbar vertebra and S1

Statistical analysis

A professional medical statistical consultant performed the statistical analyses using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). The correlations between the variables were examined using the Pearson correlation coefficient. A predictive equation was derived from simple linear regression analysis. To evaluate the statistical significance of an equation, the beta coefficient standard error, coefficient of determination (R^2), F statistics, and P value were represented. The inter- and intra- observer intraclass correlation coefficients (ICC) were assessed for the levels, angles, and distances of the parameters. A p value <0.05 was considered significant.

Results

Table 1 lists the mean, minimum, maximum and standard deviation of the parameters. The first lumbar vertebra was

Fig. 2 Methods for measuring the pelvic parameters. Pelvic incidence: angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads. Sacral slope: angle between the superior plate of S1 and a horizontal line

the most common vertebra of the thoracolumbar junctional level.

The PI was strongly correlated with the SS, LLL and MLL ($r = 0.78$, $r = 0.66$, $r = 0.63$). A strong correlation was found between the sacral slope and lower lumbar lordosis ($r = 0.89$), and between the SS and MLL ($r = 0.83$). After simple linear regression analysis, the following predictive equations of the SS and lumbar lordosis were derived (Table 2):

$$SS = 0.80 + 0.74 PI,$$

$$LLL = 5.20 + 0.87 SS,$$

$$MLL = 17.42 + 0.96 SS.$$

Using this equation, the prediction values of the SS, and the MLL and LLL were estimated from the PI (Table 3). In

Table 1 Mean, minimum, maximum and standard deviation values of the parameters

Parameters	Mean (°)	Minimum (°)	Maximum (°)	Standard deviation
Pelvic incidence	47.8	24.0	66.5	9.3
Sacral slope	36.3	12.0	55.0	7.8
Maximal lumbar lordosis	52.3	32.0	78.5	9.1
Lower lumbar lordosis	36.8	19.0	57.0	15.2

Table 2 Simple correlations between the spinal and pelvic parameters

Linear regression models	Beta coefficient standard error	$R^{2\dagger}$	$F^\ddagger$	P value
$SS = 0.80 + 0.74PI$	Intercept: 3.13 PI: 0.06	0.61	132.10	< 0.01
$MLL = 17.42 + 0.96SS$	Intercept: 2.65 SS: 0.07	0.68	181.46	< 0.01
$LLL = 5.20 + 0.87SS$	Intercept: 1.76 SS: 0.05	0.80	335.45	< 0.01

PI pelvic incidence, *SS* sacral slope, *MLL* maximal lumbar lordosis, *LLL* lower lumbar lordosis

R^2 , the coefficient of determination; F , F statistics

addition, a simple calculation to estimate the lumbar lordosis (Table 3) may be useful in clinical practice. When the PI was between 30° to 35°, 40° to 50°, and 55° to 60°, the equations indicated that the MLL would be $PI + 10^\circ$, $PI + 5^\circ$, and PI , and that the LLL would be $PI - 5^\circ$, $PI - 10^\circ$ and $PI - 15^\circ$, respectively ($LLL = MLL - 15^\circ$).

All parameters were measured with good reproducibility (inter-observer: mean ICC, 0.92 (range 0.88–1.00); intra-observer: mean ICC, 0.97 (range 0.89–1.00)).

Discussion

Many studies reported that the PI plays a dominant role in determining the shape of the sagittal curvature [2, 3, 6, 9, 12, 23, 36]. The role of the PI in determining the sagittal curvatures is through the significant correlations between the pelvic incidence and SS, and between the sacral slope and lumbar lordosis. However, these sagittal parameters are changed by the position, aging process and deformity of the spinal column, which can lead to altered sagittal plane alignment. On the other hand, the PI is a unique anatomical parameter in individuals and is constant regardless of the pelvic position and age [6, 14, 21, 25]. Therefore, some studies suggested using the PI as the key parameter to estimate the ideal lumbar lordosis to be restored for lumbar fusion surgery in degenerative lumbar diseases.

Boulay et al. [3] evaluated the predictive value of lumbar lordosis based on thoracic kyphosis, SS, PI, and tilt angle of T9. This equation was more accurate in predicting the lumbar lordosis in normal adults, but could not be used in various disease states with an abnormal sagittal plane contour because the thoracic kyphosis, sacral slope and tilt angle of T9 were changed in degenerative lumbar disease. Although Mac-Thiong et al. [25] reported an equation to predict the lumbar lordosis using the PI, it was limited to adults because the mean age of their subjects was 12.1 years (range 3–18).

Table 3 Prediction values of the parameters by pelvic incidence and simple predictive lumbar lordosis

	Pelvic incidence (°)	Sacral slope (°)	Maximal lumbar lordosis (°)	Lower lumbar lordosis (°)
<i>n</i> the number of individuals (total = 86)	30 (<i>n</i> = 3)	23.07	39.61 (PI + 10)	25.28 (PI–5)
	35 (<i>n</i> = 6)	26.78	43.18 (PI + 10)	28.51 (PI–5)
	40 (<i>n</i> = 14)	30.49	46.74 (PI + 5)	31.74 (PI–10)
	45 (<i>n</i> = 22)	34.20	50.31 (PI + 5)	34.97 (PI–10)
	50 (<i>n</i> = 18)	37.91	53.88 (PI + 5)	38.20 (PI–10)
	55 (<i>n</i> = 14)	41.62	57.45 (PI)	41.43 (PI–15)
	60 (<i>n</i> = 9)	45.33	61.02 (PI)	44.66 (PI–15)

Table 4 Prediction value of the maximal lumbar lordosis by pelvic incidence

	Pelvic incidence (°)	MLL * of present study (SS = 0.80 + 0.74PI, MLL = 17.42 + 0.96SS)	MLL * of Vialle et al. [36] (SS = 7.3 + 0.63PI, MLL = 16 + 1.06SS)	MLL * of Legaye J and Duval-Beaupere [22] (SS = 12.7 + 0.55PI, MLL = 21.61 + 1.09SS)
	30	39.6	43.8	53.3
	35	43.2	47.1	56.3
	40	46.7	50.4	59.2
	45	50.3	53.7	62.2
	50	53.9	57.1	65.2
	55	57.5	60.4	68.2
	60	61.0	63.8	71.2

* MLL maximal lumbar lordosis (°), PI pelvic incidence, SS sacral slope

Table 5 Comparison of studies of the sagittal spinal alignment

	Asian			Caucasian			
Parameters	Current study	Kim et al. [15]	Eiji Itoi [11]	Vialle et al. [36]	Roussouly et al. [30]	Lafage et al. [16]	Gangnet et al. [8]
Maximal lumbar lordosis (°)	52.3	–	55.1	60.2	61.4	–	–
Lumbar lordosis (°)	–	47	–	–	–	57	50.7
Sacral Slope (°)	36.3	32	35.5	41.2	39.9	36	37.9
Pelvic incidence (°)	47.8	46	–	51.9	51.9	52	50.2

Vialle et al. [36] and Legaye J and Duval-Beaupere [22] reported the prediction equations of lumbar lordosis from simple and multivariable linear correlations, as described in this study. However, the lumbar lordosis predicted by these equations were from Western countries and showed higher values than those predicted in the present study (Table 4). Although no study has compared the sagittal parameters of the spine directly between Caucasians and Asians, most published data show that the mean values of the sagittal parameters (lumbar lordosis, PI and SS) are somewhat different between Asians and Caucasians (Table 5) [8, 11, 15, 16, 30, 36]. Therefore, there is a limitation to the application of Caucasian data to Asians. Previous predictive equations are complicated and are difficult to memorize and apply practically. Recently, Schwab et al. [31] suggested very simplistic formulae ($LL = PI + 9^\circ (\pm 9)$) to estimate the mean lumbar lordosis from the mean PI. Their results are

similar to those of the present study at low PI intervals, but show a much higher predicted lumbar lordosis at high PI intervals. The aim of this study was to derive a predictive equation from simple linear regression analysis based on the strong correlations between PI and SS, SS and LLL, and SS and MLL (Table 2). The predictive values of lumbar lordosis matching a PI were tabulated and expressed simply as “PI + 10, PI + 5, PI” (Table 3).

Figure 3 shows the clinical importance of an evaluation for the predictive value of lumbar lordosis. The preoperative lateral radiograph of a patient with a fixed sagittal imbalance showed that the PI and SS was 39.2° and 10.1° , respectively, instead of its theoretical value, which was predicted to be 30.1° , and L1-S1 lordosis was 0.1° instead of 46.4° . A L3 pedicle subtraction osteotomy and PLIF surgery aimed at restoring adequate lordosis and sagittal alignment was performed. The SS and L1-S1 lordosis were

Fig. 3 63-year-old female patient with severe back pain and stooping. **a** Preoperative whole spine lateral radiograph showed degenerative lumbar kyphosis and thoracic lordosis. **b** Postoperative radiograph showed that the sagittal alignment was well balanced

restored to 27.7° and 44.8° , respectively, which is close to their theoretical values. The postoperative lateral radiograph showed well-balanced sagittal alignment of the spine. Therefore, the prediction of lumbar lordosis can assist in the surgeon's decision for degenerative lumbar surgery in a patient with an abnormal sagittal plan contour and balance of the spine.

With the aging process, thoracic kyphosis, lumbar lordosis and SS are increased or decreased, but the balance of sagittal alignment of the spinal column can be maintained in asymptomatic individuals [9, 15, 26]. Therefore, during degenerative lumbar fusion surgery, the mean lumbar lordosis matching age could be considered. However, it is recommended that the ideal lumbar lordosis to restore be aimed at the mean lumbar lordosis in younger patients matching the pelvic incidence because the weakness of the gluteal and back muscles in the elderly might cause some loss of a deformity correction.

This study had several limitations. First, several normal patterns of sagittal alignment and the difference in PI according to gender and age were not considered. Second, there were a relatively small number of subjects who may not represent the general population. However, these were all healthy and young subjects without a history of spinal problems.

Conclusion

For Asian populations, it is inappropriate to use the predictive equations developed for Caucasians. The simple calculation method derived in this study can provide a more appropriate and simpler prediction of the lumbar lordosis for Asians. The prediction of lumbar lordosis can be used as a reference for surgeons planning to restore the lumbar lordosis in lumbar corrective surgery.

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Conflict of interest None.

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