CLINICAL ARTICLE

Association of Sagittal Spinopelvic Realignment with Correction in Lower Lumbar Lordosis after Surgical Treatment in Degenerative Lumbar Scoliosis

Zi-fang Zhang, MD, PhD[1,2], Deng-bin Qi, MD[2†], Tian-hao Wang, MD[2†], Chun-guo Wang, MM[2], Zheng Wang, MD[2], Yan Wang, MD, PhD[1,2], Guo-quan Zheng, MD[2]

[1]*The Medical College of Nankai University, Tianjin and* [2]*The Spine Surgery, The First Medical Center of the Chinese PLA General Hospital, Beijing, China*

Objective: To assess the effect that correction of lower lumbar lordosis (3L) has on global spine realignment due to the key role of 3L for scoliosis surgery in patients with degenerative lumbar scoliosis (DLS).

Methods: This study is a retrospective review performed between June 2018 and January 2020, including consecutive patients with DLS. Only patients age ≥ 45 years who had already undergone a selective root block operation and had the procedure of long-fusion extending to pelvis and posterior lumbar interbody fusion (PLIF) at lower lumbar spine (L_4-S_1) were retained for analysis. Spinopelvic parameters measured included thoracic kyphosis (TK), lumbar lordosis (LL), 3L, pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), T_1 pelvic angle (TPA), and sagittal vertical axis (SVA) at pre-operation and the third month follow-up. The mismatch (PI-LL) was calculated subsequently. Pearson correlation and linear regression analysis were performed to explore the association of the changes in global spinopelvic parameters with 3L correction.

Results: Thirty-nine patients (five males, 34 females) with the average age of 63.84 years (SD 7.53; range, 45–75 years) at the time of surgery were identified. All patients had the surgical procedure of long-fusion (≥4 vertebras) with PLIF at lower lumbar spine between L_4 and S_1 spine. Lower instrumented vertebras (LIV) fused to pelvis (S_1, 14; S_2, 18; ilium, 7) were operated in all patients. Seventeen patients were with upper instrumented vertebras (UIV) at thoracolumbar spine (L_2-T_{11}), and 22 patients at thoracic spine (T10 and above). The median of instrumented segments was 10 (5–14). 3L significantly increased ($P = 0.02$) after surgical treatment by mean change of 4.21° (range, −19.7° to +22.2°). Perioperatively, all spinopelvic parameters regarding to TK, LL, SS, PT, TPA, SVA, and mismatch (PI-LL) had significant changes ($P < 0.001$). The change in 3L correlated significantly with the changes in spinopelvic parameters ($r = 0.772$ for LL, −0.589 for SVA, −0.439 for TPA, and −0.428 for PI-LL). After linear regression analysis, the formulas were obtained: d-LL = 14.977 + 0.636 × d-3L, ($R^2 = 0.596$); d-(PI-LL) = 16.575 + 0.62 × d-3L, ($R^2 = 0.183$); d-TPA = −7.284 to 0.358 × d-3L, ($R^2 = 0.193$); d-SVA = −30.556–2.639 × d-3L ($R^2 = 0.347$).

Conclusions: Correction in lower lumbar lordosis, following the surgical procedure of long-fusion with PLIF at lower lumbar spine, could result in significant changes in full-spine parameters. The significant association of changes in

Address for correspondence Guo-quan Zheng, MD, The Spine Surgery, the First Medical Center of the Chinese PLA General Hospital, Fuxing Road 28, Beijing, China 100853; Tel: +86-01066938403; Fax; +86-01066938403; Email: zgq951@aliyun.com; Zheng Wang, MD, The First Medical Center of the Chinese PLA General Hospital, Fuxing Road 28, Beijing, China 100853; The First Medical Center of the Chinese PLA General Hospital, Fuxing Road 28, Beijing, China 100853; Tel: +86-01066938403; Fax; +86-01066938403; Email: wangzheng301@163.com; Yan Wang, MD, PhD, The medical College of Nankai University, Weijin Road 94, Tianjin, China 300071; Tel: +86-01066938403; Fax; +86-01066938403; Email: yanwang301spine@163.com

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each of global spine parameter with the correction of 3L perioperatively could provide important information for surgeons to make a surgical plan for spinal correction.

Key words: Degenerative lumbar scoliosis; Global spine alignment; Lower lumbar lordosis; Posterior lumbar interbody fusion; Spinopelvic parameter

Introduction

Degenerative lumbar scoliosis (DLS) is a 3-dimensional deformity of the spine with coronal deviation of greater than 10°. This kind of spinal disorder is a common condition affecting the older population[1], a section of our society which is continuing to grow rapidly[2]. The reported incidence of scoliosis in adulthood has varied from 1.5% to 29.4%[2–4]. The aging of the population, coupled with an increasing focus on quality of life, has rendered degenerative scoliosis a considerable health care concern. Moreover, DLS, compared with the scoliosis of children and adolescents, is more frequently encountered in the general spine practice[1].

The pathophysiology of degenerative scoliosis involves the asymmetric degeneration of the intervertebral disks and the facet joints at different levels, leading to unequal loading of the spinal column[5]. The asymmetric loading, together with degeneration, initiates a dynamic pattern of curve progression, producing a 3-dimensional deformity[6]. At a biological level, osteophytes are formed at the facet joint and vertebral end plates, further narrowing the spinal canal. This is compounded by ligamentum flavum hypertrophy and calcification[7]. Instability of the spinal column ensues secondary to the destruction of the facet joints and intervertebral discs. The instability can be manifested as a spondylolisthesis. The instability also leads to increasing axial rotation of the vertebral bodies in relation to one another. This is most visible in the frontal plane as a lateral translation of one vertebra in relation to the adjacent vertebra.

Therefore, in patients with degenerative lumbar scoliosis (DLS), scoliosis is primarily lumbar with distal fractional curves, moreover, lateral subluxation, or "lateralisthesis" is common and concurrent spondylolisthesis at lower lumbar spine can also be present[8]. Decreased lumbar lordosis, following significant degeneration of discs at lower lumbar spine (L_4-S_1), results in thoracolumbar hyperextension, pelvic tilt increasing, and accordingly an increased sagittal vertical axis[9]. Those compensatory mechanisms would be deployed to help re-center the body over the pelvis and maintain full-body balance[10].

It is well recognized that the restoration of a harmonious coronal and sagittal spinopelvic alignment is the main goal of the surgical treatment in spinal deformity[8,11,12]. Comparing with conservative treatment, operative interventions have been reporting statistically significant improvements in all health-related quality of life (HRQOL) for DLS patients[13]. Achieving a sagittal balanced spine by correcting the lumbar lordosis as close to the pelvic incidence as possible, reduces the energy requirements for ambulation[14]. Thus, if a patient undergoing surgical reconstruction has a low pelvic incidence, the surgeon must maintain a correspondingly low lumbar lordosis during reconstruction. Conversely, in a patient with a high pelvic incidence, the surgeon must aim to achieve a correspondingly high lumbar lordosis. Patients with DLS who have global spine imbalance in addition to a stiff large curve were often performed the procedures of osteotomies involving three-column and an anterior and posterior approach. Fixed sagittal imbalance or fixed kyphotic deformities have been treated with Smith-Petersen and pedicle subtraction osteotomies[15]. In a pedicle subtraction osteotomy, the vertebral body is decancellated through the partially resected pedicles and the lateral wall of the body by serially using curettes. Because degenerative scoliosis is a 3-dimensional deformity, an asymmetrical or biplanar pedicle subtraction osteotomy may be performed. These pedicle subtraction osteotomy variants may provide biplanar correction of deformity. However, those aggressive surgical techniques have been always bringing spinal surgeons and patients in great risks[16,17].

Patients with degenerative scoliosis who have coronal and sagittal imbalance in addition to a stiff large curve often require discectomies, which could reduce the stiffness of the spine, allowing for better deformity correction. Structural grafts placed in the anterior column support, achieve lordosis correction, and increase the rate of bony union[18]. The latest studies demonstrated that lumbar lordosis should not be overcorrected in those aging people with DLS[19,20], whereas realignment overcorrection was the most common results in the surgical treatment with three-column osteotomies[21]. The surgical procedure of long-fusion with instrumentation and posterior lumbar interbody fusion (PLIF) was safe and could result in good radiological and clinical outcomes, according to the results in recent study[22]. Especially, lower lumbar spine surgeries comprise the majority of those spinal correction surgeries performed by spinal surgeons. Barrey *et al.*[23] reposted that lower lumbar lordosis (3L) between L4 and S1 makes up two-thirds of the lumbar lordosis (LL). Zheng *et al.*[24] demonstrated that restoration in 3L correlated significantly with the adjacent segment disease. With the advent in technologies, the precise lordosis if it is known with preoperative planning can be introduced. Therefore, knowing the correction in 3L perioperatively and the relationships with the changes in other full-spine parameters would be considered to be an essential step in setting goals for the treatment of DLS.

However, there was a paucity of studies that revealed the association of the restoration of full-spinal alignment with the correction of 3L in the management of patients with

DLS. The purpose of this current study was to identify: (i) whether the effect that correction in 3L has on restoration of the lumbar lordosis (LL); (ii) the mismatch of pelvic incidence minus lumbar lordosis (PI-LL); and (iii) the global spinal alignment parameters regarding to sagittal vertical axis (SVA) and T_1 pelvic angle (TPA) during the surgical treatment?

Material and Methods

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (i) patients (age ≥ 45 years) with diagnosis of degenerative lumbar scoliosis (DLS) based on imaging results with at least one of the following: (a) coronal curvature ≥20°; (b) sagittal vertical axis (SVA) ≥ 5 cm; (c) pelvic tilt (PT) ≥ 25°; and (d) thoracic kyphosis (TK) ≥ 60°[1,25]; (ii) patients undergoing spinal sagittal deformity corrective procedures who were able to undergo erect, unsupported radiographs at baseline and discharge postoperatively. Adequate visualization of the upper 1/3 section of femoral shaft was necessary on the lateral view to measure the sagittal acetabular anteversion (SAA) and pelvic femur angle (PFA) accurately; (iii) all patients had undergone selective lumbar root block or lumbar facet joints injection with lidocaine (2 mL) prior to the spinal realignment procedure, which could identify the surgical segments; (iv) and would be performed the surgical procedure that multi-level (≥4 vertebras) fusion with instrumentation and pelvic fixation by posterior-only approach; and (v) the related data of patients were integrated.

The exclusion criteria were: (i) previous spinal surgery; (ii) history of spinal tumor; (iii) history of spinal infection such as tuberculosis; or (iv) ankylosing spondylitis; (v) suffered any hip disorders; or (vi) having differences ≥2 cm between two lower extremities.

This study is a retrospective analysis in a single institute, concerning consecutive database of patients with degenerative lumbar scoliosis (DLS) from June 2018 to January 2020. Institutional review board approval was obtained prior to the initiation of the study.

Surgical Technique

All surgical procedures were performed by two senior surgeons. After inducing general anesthesia, all of the patients were positioned prone. Then, somatosensory evoked potential (SEP) and transcranial motor evoked potential (MEP) monitoring of the spinal cord were initiated. The procedure that long-fusion extending to pelvis with posterior lumbar inter-body fusion (PLIF) at lower lumbar spine (L_4-S_1) was performed with posterior approach. Partial facetectomy and laminectomy were performed at interbody levels for those patients.

Outcome Measurements

Patients received standard standing full-length spine radiographic examinations preoperatively and the third month follow-up. All X-rays were scanned (View-Tec, Maisons-Alfort, France) and saved in JPG format (75 dpi). Spinopelvic variables were measured with valid Surgimap software (version 2.14.3, New York, USA). The accuracy of Surgimap was evaluated previously and is briefly summarized here: an interobserver and intraobserver reliability analysis revealed high agreement (intraclass correlation coefficient, >0.93) for all spinopelvic parameters, and the mean difference was <0.4° for PT, PI, and LL, and <0.3 mm for SVA[26].

Radiographic data collection consisted of full-length standing coronal and sagittal radiographs obtained in free-standing posture with the upper limbs resting on a support, the shoulders at 30° forward flexion, and the elbows slightly flexed[27]. The radiographic parameters of interest were as follows.

Spinopelvic parameters were measured before and after the spinal correction (Fig. 1A–C).

Sagittal spine parameters

Thoracic kyphosis (TK), the angle between the upper endplate of T_4 and the lower endplate of T_{12}, representing the thoracic feature, was measured with the Cobb method.

Lumbar lordosis (LL), the angle between the upper endplate of L_1 and the upper endplate of S_1, representing the lumbar feature, was measured with the Cobb method.

Lower lumbar lordosis (LLL), the Cobb angle between the upper endplate of L_4 and the upper endplate of S_1, a fraction of LL, was measured with the Cobb method.

Sagittal vertical axis (SVA), the offset between the center of C_7 and the plumb line drawn from posterosuperior corner of S_1 represents the global spine alignment.

T_1 pelvic angle (TPA), the angle between the line from the axis of the femoral head to the center of T_1 and the line from the axis of femoral head to the midpoint of the S_1 endplate, one of global spinal balance parameter, represents the global spine alignment..

Pelvic variables

Sacral slope (SS), the angle between the sacral endplate and the horizontal line correlates significantly with LL.

Pelvic tilt (PT), the angle between the line from the middle of the sacral plate to the middle of the hip axis and the vertical line has significant relationship with hip joints.

Pelvic incidence (PI), the angle between the line perpendicular to the midpoint of the sacral plate and the line connecting this to the midpoint of the hip axis is the pelvic morphology parameter.

Hip variables

Sagittal acetabular anteversion (SAA), the angle between the tangent line across the front and rear edge of the acetabulum and the horizontal line, represents the orientation of the acetabulum at sagittal plane, represents the orientation of the acetabulum at sagittal plane.

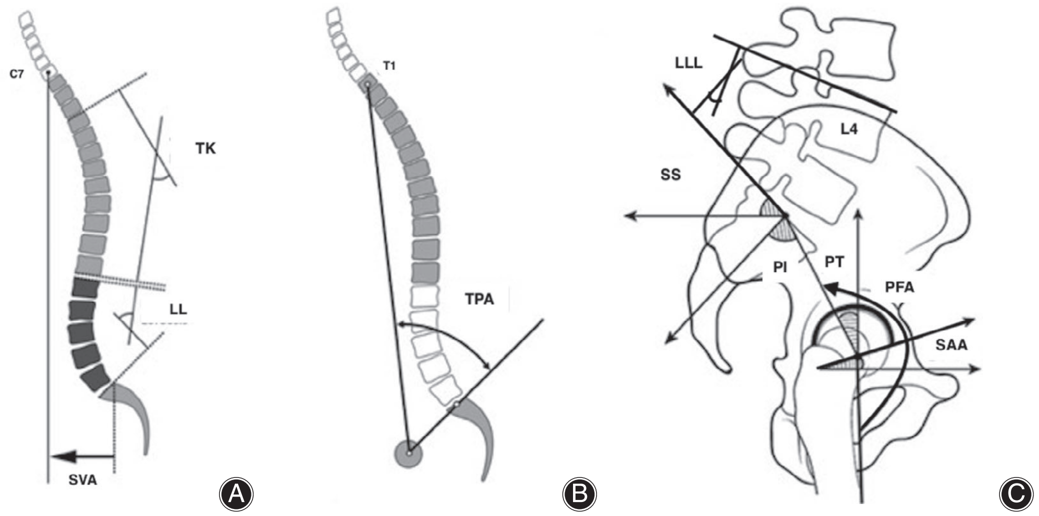

Fig. 1 Illustration of the measurement of spinopelvic parameters. SVA indicates sagittal vertical axis; TK, thoracic kyphosis; LL, lumbar lordosis; TPA, T1 pelvic angle; LLL, lower lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SAA, sagittal acetabular anteversion; and PFA, pelvic femur angle.

Pelvic femur angle (PFA), the angle between the line from the middle of the sacral plate to the middle of the hip axis and the parallel line of the longitudinal axis of the femur, represents the hip joints condition in the standing position, represents the hip joints condition in the standing position.

Kyphosis was recorded as positive (+), and lordosis as negative (−). Mismatch (PI-LL) were subsequently calculated by subtracting LL from PI, which is one of spinal balance parameter.

Statistical Analysis

Changes in spinopelvic parameters and global sagittal alignment parameters were compared with corrections in lumbar lordosis between preoperative and postoperative measurements. Statistical analysis was performed with SPSS software (Mac version 26.0, IBM, Armonk, NY, USA). Perioperative differences in spinopelvic parameter and global sagittal alignment parameters were calculated (mean, standard deviation, and range). The Pearson correlation coefficient was calculated *via* linear regression analysis. The slope of the line of best fit was used to predict the effect of LL on each radiographic variable.

Results

Demographic and Surgical Data

Thirty-nine patients suffered degenerative lumbar scoliosis (DLS) met inclusion criteria. The average age at the time of surgery was 63.84 years (SD 7.53; range, 45–75 years). The median of instrumented segments was 10 (5–14). All patients had the surgical procedure of PLIF at lower lumbar spine (L_4-S_1). Lower instrumented vertebras (LIV) fused to pelvis (S_1, 14; S_2, 18; ilium, 7) in all patients. Upper instrumented vertebra (UIV) was performed at thoracolumbar spine (L_2-T_{11}) in 17 patients, and at thoracic spine (T_{10} and above) in 22 patients. The analysis of the changes in spinopelvic parameters following the spinal realignment procedure was summarized in Table 1. This analysis revealed a significant increase in SS ($P < 0.001$), and a significant reduction in TK, PT, TPA, SVA, PFA, SAA, and PI-LL ($P < 0.001$). Lower lumbar lordosis (3L) significantly increased perioperatively ($P = 0.02$), and the mean correction of 3L was 4.21° (range, −19.7° to +22.2°).

In all, 28 (71.8%) suffered severe mismatch (PI-LL > 20°) at pre-operation. Postoperatively, 12 (30.8%) of 39 patients were still with severe imbalance (PI-LL > 20°). Of note, the ideal age-adjusted PI-LL alignment for patients

TABLE 1 Perioperative changes in spinopelvic variables perioperatively

Spinopelvic parameters	Perioperative changes*
Lower lumbar lordosis (°)	4.21 ± 10.49 (−19.7 to +22.2)
Lumbar lordosis (°)	17.65 ± 15.1 (−11.1 to +47.4)
Thoracic kyphosis (°)	−7.12 ± 7.62 (−12.1 to +20.7)
T_1 pelvic angle (°)	−7.79 ± 8.28 (−33.6 to +5.7)
Sagittal vertical axis (mm)	−38.14 ± 46.1 (−149.7 to +69.5)
Pelvic incidence minus lumbar lordosis (°)	18.87 ± 14.68 (−7.3 to +54.5)
Sacral slope (°)	7.0 ± 9.71 (−19.8 to +32.7)
Pelvic tilt (°)	−6.94 ± 8.56 (−30.8 to +9.1)
Sagittal acetabular anteversion (°)	−5.32 ± 6.72 (−19.6 to +19.2)
Pelvic femur angle (°)	−7.64 ± 7.24 (−7.3 to +25.5)

*The values were given as the mean and the standard deviation, with the range in parentheses.

TABLE 2 Changes in and Correlations between 3L and spinopelvic parameters perioperatively

	Change in spinopelvic parameters								
Change in 3L	TK	SS	PT	TPA	SVA	PI-LL	LL	SAA	PFA
Bivariable correlation									
R	0.046	0.235	−0.179	−0.439	−0.589	0.428	0.772	−0.208	−0.111
P value	0.787	0.161	0.288	0.007	<0.001	0.004	<0.001	0.216	0.519
Linear regression*									
R^2	N/A	N/A	N/A	0.193	0.347	0.183	0.596	N/A	N/A
P value	N/A	N/A	N/A	0.007	0.001	0.004	<0.001	N/A	N/A
Constant	N/A	N/A	N/A	−7.248	−30.556	16.575	14.977	N/A	N/A
Standard error	N/A	N/A	N/A	1.339	7.026	2.443	2.438	N/A	N/A
P value	N/A	N/A	N/A	<0.001	<0.001	<0.001	<0.001	N/A	N/A
Coefficient index	N/A	N/A	N/A	−0.358	−30.556	0.62	0.636	N/A	N/A
Standard error	N/A	N/A	N/A	0.12	0.629	0.219	0.218	N/A	N/A
P value	N/A	N/A	N/A	0.007	0.001	0.004	<0.001	N/A	N/A

3L indicates lower lumbar lordosis; LL, lumbar lordosis; N/A, not applicable; PFA, pelvic femur angle; PI-LL, mismatch pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SAA, sagittal acetabular anteversion; SS, sacral slope; SVA, sagittal vertical axis; TK, thoracic kyphosis; TPA, T1 pelvic angle.; * Linear regression analysis showed significant correlation changes in all spinopelvic parameters and lower lumbar lordosis.

with 45–54 years, >0.5°; for 55–64 years, >5.8°; for 65–74 years, >10.5°; and for older than 74 years, >17°[19]. Seventeen patients were with realignment overcorrection after surgery by the age-adjusted criteria for PI-LL.

Relationship Between 3L Correction and Changes in Other Global Spine Variables

The changes in 3L correlated most strongly with the changes in lumbar lordosis ($r = 0.772$, $P < 0.001$) and those global spine

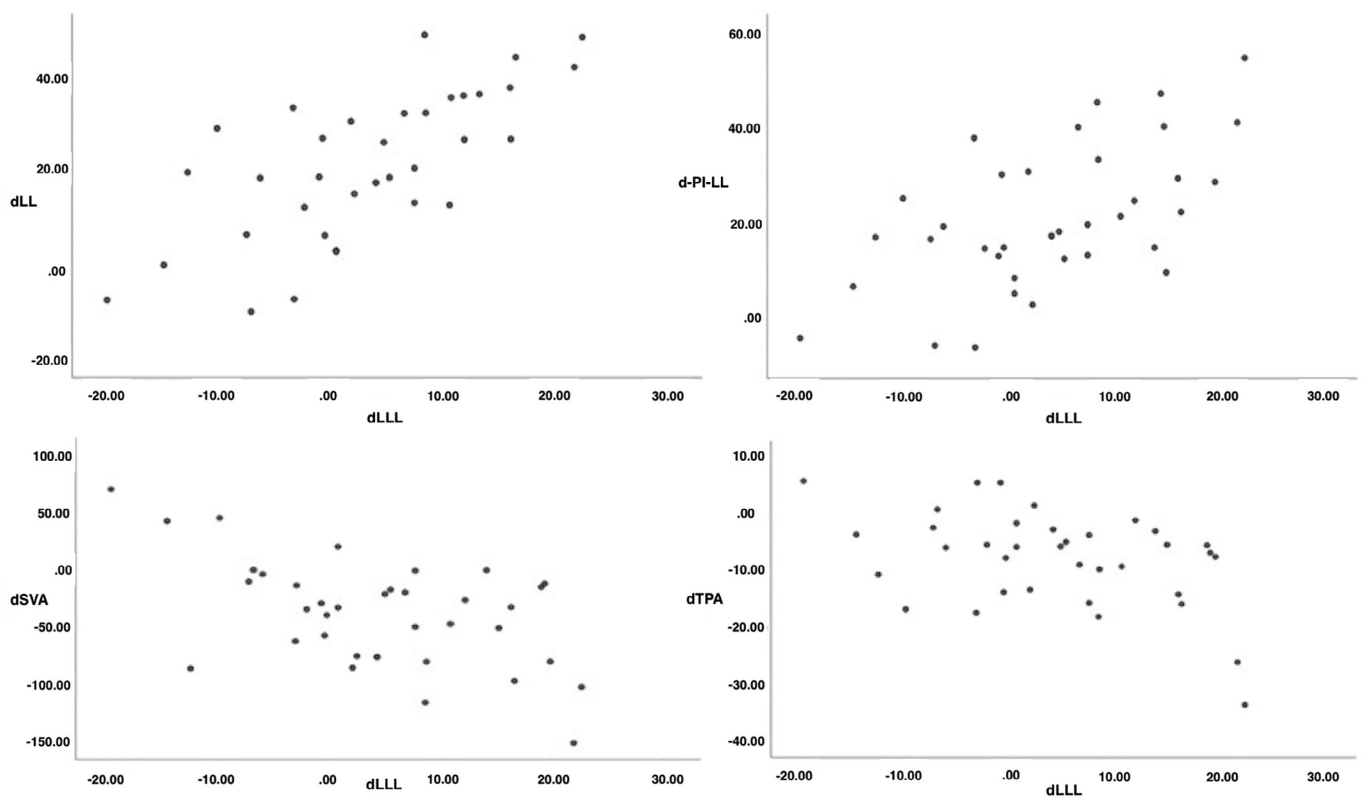

Fig. 2 Scatterplots showing the change in lumbar lordosis correlated with changes in spinopelvic parameters. d-LLL indicates changes in lower lumbar lordosis; d-LL, changes in lumbar lordosis; PI-LL, changes in pelvic incidence minus lumbar lordosis; d-SVA, changes in sagittal vertical axis; d-TPA, changes in T_1 pelvic angle.

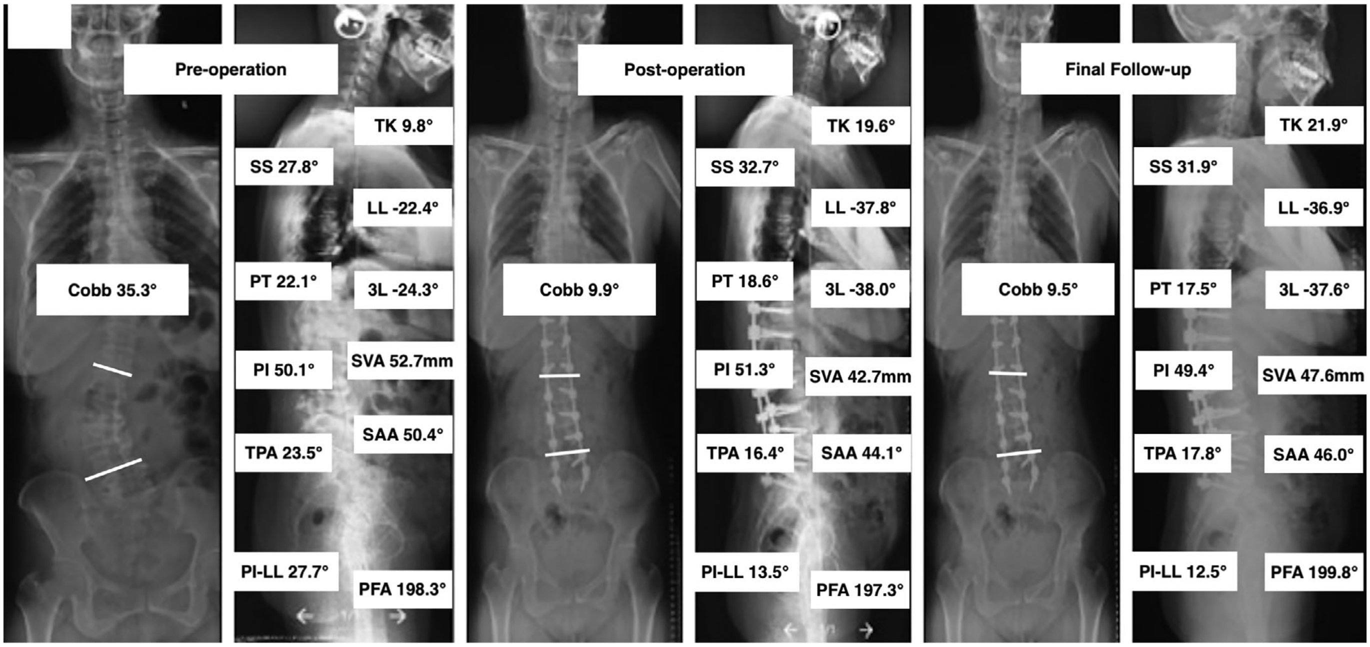

Fig. 3 Radiographs showing the changes in sagittal spinal parameters after the surgical procedure of long-fusion (T_{11}-S_2) with PLIF at L_4-S_1. Those parameters preoperatively, postoperatively and at the final follow-up were explicitly shown in those subfigures. Sagittal parameters had significant improvement from pre-operation to post-operation, however, the changes were little between post-operation and the final follow-up.

parameters involving PI-LL ($r = -0.428$, $P = 0.004$), TPA ($r = -0.439$, $P = 0.007$), and SVA ($r = -0.589$, $P < 0.001$). However, corrections in 3L had no correlation with changes in pelvic parameters regarding to PT and SS, as well as changes in hip joint variables including SAA and PFA. The results are summarized in Table 2. The scatterplot trends are shown in Fig. 2.

The linear regression equations were obtained after analyzing the regression enter method as follows:

$$\mathrm{d}-\mathrm{LL} = 14.977 + 0.636 \times \mathrm{d}-3\mathrm{L}, \left(R^2 = 0.596\right),$$
$$\mathrm{d}-(\mathrm{PI}-\mathrm{LL}) = 16.575 + 0.62 \times \mathrm{d}-3\mathrm{L}, \left(R^2 = 0.183\right),$$
$$\mathrm{d}-\mathrm{TPA} = -7.284 - 0.358 \times \mathrm{d}-3\mathrm{L}, \left(R^2 = 0.193\right),$$
$$\mathrm{d}-\mathrm{SVA} = -30.556 - 2.639 \times \mathrm{d}-3\mathrm{L}, \left(R^2 = 0.347\right).$$

A representative patient is shown in Fig. 3.

Discussion

The surgical procedure of long-fusion with instrumentation and posterior lumbar interbody fusion (PLIF) has been performed increasingly in degenerative lumbar scoliosis (DLS). The lower lumbar spine, defined as the upper endplate of the fourth lumbar vertebra to the sacrum, is the most important part of determining the lumbar lordosis[28,29]. Even if a single segment fixation is performed on the lower lumbar spine, the effect on the overall sagittal plane balance must be considered for optimal surgical planning. Therefore, we thought it would be important to see how 3L relates to the overall LL and other parameters. In this study, all patients had the surgical procedure of multi-level fusion extending to pelvis (S_1, S_2, or ilium) with PLIF at lower lumbar spine (L_4-S1). Osteotomies were just basic techniques rather than aggressive maneuvers[15]. All the radiographic measurements were performed at preoperative and immediate postoperative radiographs, which could eliminate the errors induced by mechanical complications of proximal junctional kyphosis or rod breakage during follow-up. Moreover, fusion of the pelvis would remove the effect that compensation of lumbosacral segments have on pelvic parameters postoperatively.

Lower lumbar lordosis (3L) significantly increased ($P = 0.02$) perioperatively, moreover, surgical correction in 3L could be increased by up to 22.2°, although the mean change was 4.21°. There was a strong correlation between changes in global spine variables, LL, and 3L. Changes of 3L had little effect on thoracic kyphosis correction and changes in pelvic parameters.

Association of Changes in LL and Global Spinal Parameters with 3L Correction

Patients with spinal degenerative disorders present with modifications of sagittal balance and are characterized by anterior sagittal imbalance, loss of lordosis, and increase of pelvic tilt[10]. In this study, lumbar lordosis (LL) increased significantly after surgical treatment ($P < 0.001$). 3L correction correlated strongly with the restoration of lumbar lordosis ($R = 0.772$). Furthermore, we obtained the formula: d-LL = 14.977 + 0.636×d-3L, ($R^2 = 0.596$). Correction of 1° in 3L would result in almost 16° changes in LL. The result data in our study showed the procedure of PLIF at lower lumbar spine between L_4 and S_1 made for an average correction of 4.21° in 3L, which could provide important information for surgeons to make an orthopedic plan for DLS patients.

The severe mismatch of PI minus LL would decrease the health-related quality of life (HRQOL) in patients with adult spinal deformity[30]. We observed that 28 (71.8%) suffered severe mismatch at pre-operation, according to the criteria for severe sagittal imbalance of mismatch (PI-LL) > 20°[25]. Postoperatively, 12 (30.8%) of 39 patients were still with severe imbalance. However, Iyer *et al.*[20] proposed that the spine has a natural tendency to increase the trunk inclination forward. Therefore, PI-LL realignment should be adjusted on the basis of age in DLS patients in order to reduce the incidence of mechanical complications[19]. The ideal age-adjusted PI-LL alignment for patients younger than 35 years is >−10.5°; for 35–44 years, >−4.6°; for 45–54 years, >0.5°; for 55–64 years, >5.8°; for 65–74 years, >10.5°; and for older than 74 years, >17°. In this current study, when stratifying all patients for every 10 years of age, we found the mean PI-LL were within normal criteria in each subgroup after surgical treatment. Additionally, we found the significant association of changes in PI-LL with 3L correction after Pearson correlation ($P = 0.004$).

The sagittal vertical axis (SVA) has been demonstrated as a commonly parameter to quantify sagittal balance[31]. Generally, the normal value of SVA for adult scoliosis patients is less than 40 mm[25]. Additionally, T1 pelvic angle (TPA) has recently been recognized as a parameter representing the global sagittal balance of adult scoliosis[32]. It allows for the measurement of the geometry of the spinopelvic deformity separate from pelvic and lower extremity compensation. Moreover, it correlates strongly with HRQOL in patients with adult spinal deformity[32,33]. As a preoperative planning tool, TPA was proposed a surgical target of 10°–20°[33].

In this study, the reduction in SVA and TPA were significant during perioperative period. We found a strong correlation of the changes in TPA ($R = -0.439$, $P = 0.007$) and SVA ($R = -0.589$, $P < 0.001$) with the correction of 3L. Postoperatively, the mean value of SVA and TPA decreased to 11.42mm (SD 32.71) and 16.78° (SD 9.45°), back into an ideal range as a result of the spinal surgical procedure demonstrates the important interplay between the SVA, TPA and 3L.

After linear regression, we obtained formulas as follows: $\text{d-SVA} = -30.556 - 2.639 \times \text{d-3L}$, $\text{d-TPA} = -7.284 - 0.358 \times \text{d-3L}$, and $\text{d-(PI-LL)} = 16.575 + 0.62 \times \text{d-3L}$. With each 1° of correction in 3L, the SVA would decrease by almost 33mm, about 7.5° reduction in TPA and 17° increase in PI-LL. Therefore, spinal surgeons could optimize the restoration in global spine alignment on the basis of the results revealed in our study. According to the ideal age-adjusted PI-LL alignment criteria[19], 17 patients were with realignment overcorrection after surgery. Then, just basic osteotomy performed between L4-S1 segments may result in overcorrection in full-spine alignment.

Correlations Among Changes in Pelvic Parameters and 3L Correction

The role of the pelvis in sagittal balance in upright stance is obvious to spinal surgeons, who take full account of SS, PT, and PI[34,35]. In spinal deformity, in order to maintain a horizontal gaze in the erect posture, patients develop several compensatory mechanisms for sagittal malalignment, including posterior pelvic rotation and hip extension[36,37]. PT can be thought of as a reservoir to compensate for sagittal balance. Moreover, PT strongly corelated with the HRQOL in patients with spinal deformity[25,31,37,38], and its value should be less than 20°[25]. However, surgical intervention does not directly change pelvis, rather, when restoring LL into normal value and the compensation of pelvis is no longer necessary, PT will improve as the hip reverts from terminal extension and pelvis rotates forward, SS increases accordingly due to the geometric relationship: $PI = PT + SS$[14]. In our study, the pelvis tilted posterior significantly at pre-operation (PT, 26.83° ± 10.8°; SS, 20.64° ± 11.19°), and restored anterior tilt as a result of the lumbar lordosis correction surgery. However, there was no correlation between 3L correction and changes in pelvic parameters, much less to changes in hip variables involving sagittal acetabular anteversion (SAA) and pelvic femur angle (PFA).

Masquefa *et al.* performed pedicle subtraction osteotomy (PSO) at lumbar spine in 19 patients with adult spinal deformity[39], and demonstrated that PSO significantly increases SS, thus inducing anterior pelvic tilt with significant acetabular retroversion. Additionally, they revealed the significant relationship between changes in LL and acetabular anteversion ($R = 0.34$). Buckland *et al.* performed a prospective study with adult spinal deformity patients in the setting of total hip arthroplasty, which demonstrated the significant relationships between LL correction and changes in acetabular anteversion[40]. Then, we suggest that the changes in pelvis and hip joints probably be induced by the comprehensive effect involving advanced osteotomy, correction in whole lumbar spine, and changes in global spine alignment.

Limitation of this current study include its sample size. These results were based on the techniques of surgeon from a single institute and may not be extrapolated to other centers. Because we defined that all patients underwent the procedure with long-fusion extending to pelvis with posterior lumbar inter-body fusion (PLIF) at lower lumbar spine (L_4-S_1) and performed with the posterior approach, only 39 patients suffering degenerative lumbar scoliosis (DLS) met inclusion criteria. Therefore, prospective studies including larger samples from multiple medical centers should be performed in the future. Furthermore, the measurement of spinopelvic variables was taken on full- body radiographs at pre-operation and the third month follow-up rather than long-term follow-up. As a result, there should be studies aiming to identify the effect that correction of lower lumbar lordosis (3L) has on global spine realignment during the long-term follow-up. Lastly, studies, aiming to explore the relationships between health-related quality of life (HRQOL) questionnaires and the correction in 3L, should be performed in the future, for the loss of that in this current study. Despite these limitations, this study identified significant correlation of full-spine realignment parameters with the correction in lower lumbar lordosis.

Conclusions

The correction of 3L following the surgical procedure of long-fusion with PLIF at lower lumbar spine have significant relationships with the global spine parameter, which could provide important information for surgeons to make surgical plans for spinal correction. Spinal correction surgery even with basic osteotomy at lumbosacral segments may result in overcorrection in full-spine alignment.

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