CLINICAL ARTICLE

Spine-Pelvis-Hip Alignments in Degenerative Spinal Deformity Patients and Associated Procedure of One-Stage Long-Fusion with Multiple-Level PLIF or Apical-Vertebra Three Column Osteotomy–a Clinical and Radiographic Analysis Study

Zi-fang Zhang, PhD, MD[1,2], Deng-bin Qi, MD[2], Tian-hao Wang, MD[2], Zheng Wang, MD[2], Yan Wang, MD, PhD[1,2]

[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 explore the spine-pelvis-hip alignments in degenerative spinal deformity (DSD) patients, and compare the outcomes in the procedure of long-fusion with posterior lumbar inter-body fusion (PLIF) or single-level three-column osteotomy (STO) at lower lumbar level (LLL, L_3-S_1) and thoracolumbar levels (TLL, T_{10}-L_2) for those patients.

Methods: This is a retrospective study. Following institutional ethics approval, a total of 83 patients (Female, 67; Male, 16) with DSD underwent long-fusion with PLIF or STO surgery between March 2015 and December 2017 were reviewed. All of those patients were assigned into LLL and TLL groups. The average age at surgery was 65.2 years (SD, 8.1). Demographic (age, gender, BMI, and comorbidities), radiographs (both coronal and sagittal parameters) and health-related quality of life (HRQOL) assessments were documented. The radiographic parameters and HRQOL-related measurements at pre- and post-operation were compared with paired-samples *t* test, and those variables in the two groups were analyzed using an independent-sample *t* test. The relationships between pelvic incidence (PI) and other sagittal parameters were investigated with Pearson correlation analysis. The Pearson χ^2 or Fisher's exact was carried out for comparison of gender, incidence of comorbidities and post-operative complications.

Results: There were 53 and 30 patients in the LLL and TLL groups respectively. Those spino-pelvic radiographic parameters had significant improvements after surgeries ($P < 0.001$). The patients in the two group with different pre-operative thoracolumbar kyphosis (TLK, $P = 0.003$), PI ($P = 0.02$), and mismatch of PI minus lumbar lordosis (PI-LL, $P = 0.01$) had comparable post-operative radiographic parameters except PI ($P = 0.04$) and pelvic-femur angle (PFA, $P = 0.02$). Comparing the changes of those spine-pelvic-hip data during surgeries, the corrections of TLK in TLL group were significant larger ($P = 0.004$). Pearson correlation analysis showed that there were negative relationship between PI and TLK ($r = -0.302$, $P = 0.005$), positive relationship between PI and LL ($r = 0.261$, $P = 0.016$) at pre-operation. Those patients underwent the surgical procedure that long-segment instrumentation and fusion with STO would have higher incidence of complications involving longer operative timing ($P = 0.018$), more blood loss ($P < 0.001$), revision

Address for correspondence Wang Yan, MD, PhD, The Spine Surgery, The First Medical Center of the Chinese PLA General Hospital, Fuxing Road 28, Beijing, China 100853; The Medical College of Nankai University, Weijin Road. 94, Tianjin China, 300071; Tel: +86-01066875503; Fax: +86-01066875503; Email: yanwang301spine@163.com; Wang 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: wangzheng301@163.com

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surgery ($P = 0.008$), and cerebrospinal fluid leakage ($P = 0.001$). All the HRQOL scores significantly improved at final follow-up ($P < 0.001$), with no difference of intra-group.

Conclusion: Patients suffered de-novo scoliosis or hyper-kyphosis with low PI would be vulnerable to significant thoracolumbar degeneration, and have more changes of spine-pelvis-hip data after long-fusion surgery, however, those with high PI would be closed to significant lumbar degeneration. Although spine-pelvis-hip alignments in DSD patients can be restored effectively after long-fusion with PLIF or STO, the incidence of complications in patients underwent STO was significant higher than that in patients performed multi-level PLIF.

Key words: De-novo scoliosis; Health-related quality of life; Hyper-kyphosis; Posterior lumbar inter-body fusion; Three-column osteotomy

Introduction

With a growing population of elderly people worldwide[1], the incidence of degenerative spinal deformity (DSD), including de novo scoliosis (DS) and degenerative hyperkyphosis, has persistently increased[2,3]. DSD, is a kind of very complicated disorder, which concerns not just the pathophysiological changes of musculoskeletal and nervous systems, but also human body biomechanics[2,4,5]. Global spine imbalance, either sagittal or coronal plane, has significant negative relationship with health-related quality of life (HRQOL) assessments in those patients[6,7]. Roussouly *et al.*[8,9] described the classification of the spinal sagittal alignment in asymptomatic human beings, and suggested there would be significant relationships between pelvic morphology (such as pelvic incidence, PI) and spinal degenerative disorders. Recently, Zhou *et al.*[10,11] proposed the associations among spinal alignments and hip joints during position changes from standing to sitting. Accordingly, It is necessary for us to investigate hip changes at pre- and post-operation for the DSD patients. Unfortunately, there have been few studies on that.

Previous studies[12,13] have demonstrated that DSD patients who underwent surgical treatments can obtain satisfactory spinal alignment and improved quality of life, which are more evident in patients who are willing to receive the surgical treatment[14]. Previous studies demonstrated that surgeries should be prior to the treatment of nonoperation for those patients[2,14]. There were kinds of operative procedures for the patients with variable symptoms respectively[2,15], however, the procedure of long-segments with instrumentation and fusion was an effective treatment for the patients suffered global spine imbalance. Furthermore, the procedure of long-fusion with three-column osteotomy would reconstruct spinal alignment and acetabular orientation more effectively[15,16], which have always borne the greatest risk to both surgeons and patients alike[2,17,18]. Therefore, there have been plenty of studies on surgical procedure of long-fusion without advanced osteotomy for DSD patients[19,20]. But there has been a paucity of papers on the comparison between the results of long-fusion with STO operations and that in procedure of long-fusion without advanced osteotomy.

Those patients suffered DS or hyper-kyphosis would have different spine-pelvis-hip alignments, and osteotomy or inter-body fusion should be performed at different segments. The study on spinal alignment description showed that the structure curve in most of DSD patients appeared in the lumbar spine[21]. Then, according to previous studies[19,20], long-level fixation was performed with multiple-level posterior lumbar interbody fusion (PLIF) or single-level three-column osteotomy (STO) for DSD patients.

Consequently, we performed this retrospective study to explore: (i) were there differences of spine-pelvis-hip alignments between DSD patients with severe spine degenerations at lower lumbar and those at thoracolumbar segments at pre-operation? And (ii) were there differences in post-operative spine-pelvis-hip alignments and clinical results for DSD patients underwent PLIF or STO at lower lumbar and thoracolumbar segments?

Materials and Methods

Inclusion and Exclusion

The inclusion criteria were as follows: (i) patients (age ≥ 45 years) with diagnosis of de novo scoliosis or degenerative hyperkyphosis 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°[2,21]; (ii) all patients were operated on by the procedure that instrumented fusion of four or more segments by posterior-only approach; (iii) the related data of patients were integrated; and (iv) follow-up duration ≥2 years. The exclusion criteria were: (i) previous spinal surgery; (ii) history of spinal tumor; (iii) history of spinal infection such as tuberculosis; (iv) history of ankylosing spondylitis; (v) suffered any hip disorders; or (vi) having differences ≥2 cm between two lower extremities.

We reviewed retrospectively patients with DSD who received long-segment posterior instrumentation and fusion surgery in our hospital between March 2015 and December 2017. Eighty-three DSD patients were included after appropriate Institutional Review Board approval, and divided into the LLL and TLL groups, according to those segments of PLIF or STO performed at thoracolumbar level or lower lumbar levels. All the patients were followed up for at least

2 years and the average follow-up was 34.2 ± 9.88 (range 24–82) months.

Surgical technique

All surgical procedures were performed by two senior surgeons. After inducing general anesthesia, all of the patients are positioned prone. Then, somatosensory evoked potential (SEP) and transcranial motor evoked potential (MEP) monitoring of the spinal cord are initiated. The procedure that long-fusion with multilevel posterior lumbar inter-body fusion (PLIF) or single-level three-column osteotomy (STO) were performed with posterior approach. The segments of instrumented and interbody fusion were determined by the clinical symptoms, physical signs, and the Pfirrmann[22] grade of intervertebral disc in those DSD patients. Partial facetectomy and laminectomy were performed at interbody levels for those patients underwent PLIF, and pedicle subtraction osteotomy(PSO)[23] or vertebral column decancellation (VCD)[24] at apical vertebra of main curve were performed in the patients suffered hyper-kyphosis (Cobb ≥ 60°).

Outcome measurements

Patients received standard standing full-length spine radiographic examinations preoperatively, postoperatively, and at final follow-up. All X-rays were scanned (View-Tec, France) and saved in JPG format (75 dpi). Spinopelvic variables were measured with valid Surgimap software (version 2.14.3, New York, NY, USA)[25].

Radiologic variables

Coronal plane

The major Cobb angle, representing the main feature of spine deformity on the coronal plane, was the angle between the upper endplate of the superior vertebra and the lower endplate of the inferior vertebra in the structure curve. Pre- and postoperative measurements were presented as Pre-Cobb and Post-Cobb respectively (Fig. 1A).

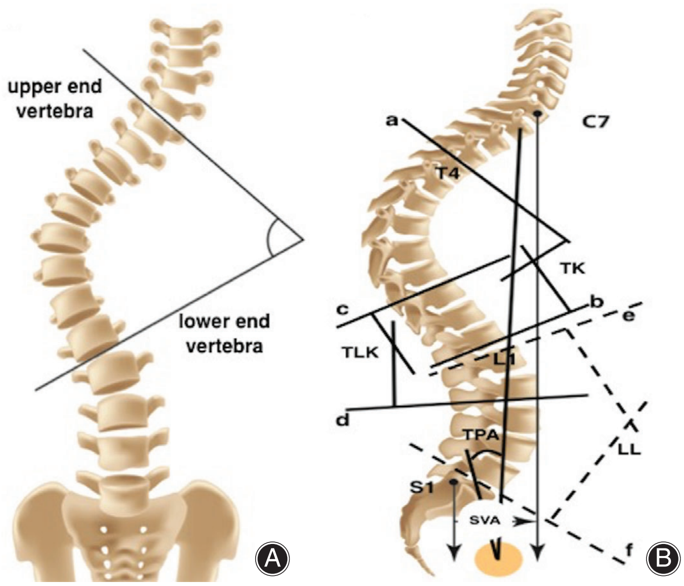

Fig. 1 Main curve angle measured from the superior endplate of the proximal most tilt vertebra to the inferior endplate of the distal most tilt vertebra by Cobb method (A). Sagittal radiologic parameters, thoracic kyphosis (TK) measured from the superior endplate of T_4 to the inferior endplate of T_{12} by Cobb method; thoracolumbar kyphosis (TLK) measured from the superior endplate of T_{10} to the inferior endplate of L_2 by Cobb method; lumbar lordosis (LL) measured from the superior endplate of L_1 to the inferior endplate of S_1 by Cobb method. Sagittal vertical axis (SVA) defined as the horizontal offset from the posterosuperior corner of S_1 to the vertebral body of C_7. T_1 pelvic angle (TPA) defined as the angle between the line from the femoral head axis to the center of T_1 vertebra and the line from the femoral head axis to the middle of the S_1 superior end plate (B).

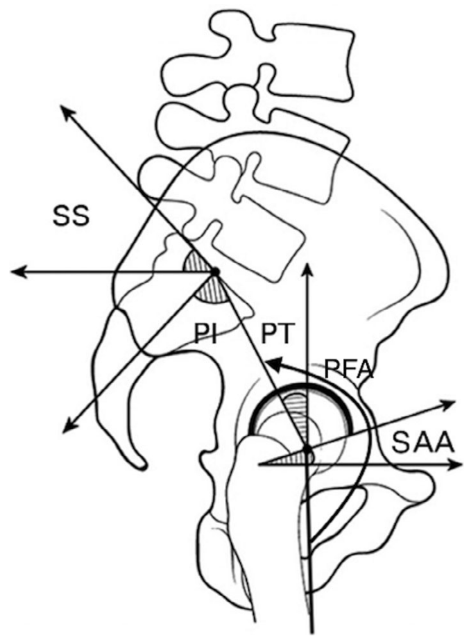

Fig. 2 Pelvic parameters: sacral slope (SS): the angle between the horizontal line and the sacarl endplate. Pelvic tilt (PT): the angle between the vertical and the line through the midpoint of the sacral endplate to the femoral heads axis; pelvic incidence (PI): the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral heads axis. Sagittal acetabular anteversion(SAA): the angle between the horizontal line and the line tangent to the anterior and posterior edges of the acetabulum. Pelvic femoral angle (PFA): the angle between the line from the center of the S1 endplate to the center of femoral head and the line that parallels the femoral diaphysis.

Sagittal plane

Thoracic kyphosis (TK), the Cobb angle between the upper endplate of T_4 and the lower endplate of T_{12}, represents the thoracic feature. Thoracolumbar kyphosis (TLK), the Cobb angle between the upper endplate of T_{10} and the lower endplate of L_2, is the transition from thoracic spine to the lumbar spine. Lumbar lordosis (LL), the Cobb angle between the upper endplate of L_1 and the upper endplate of S_1, represents the lumbar feature. 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, is one of global spinal balance parameter.

Additionally, kyphosis was presented as the positive angle and lordosis as the negative angle, the details were shown in Fig. 1B.

Pelvic variables

Sacral slope (SS), the angle between the sacral endplate and the horizontal line. 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. 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.

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.

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.

Those pelvic and hip parameters were shown in Fig. 2.

Data Collection

Clinical and radiographic measurements were documented preoperatively, postoperatively, and at final follow-up. Demographic (age, gender, body mass index, medical history), surgical, and radiographic data as well as health-related quality of life (HRQOL) including lower lumbar and lower extremity visual analogue scale (VAS), Oswestry Disability Index (ODI), and SF-36 scores (divided into physiological and mental scores based on the McHorney and Ware method[26]) were documented.

Additionally, operation timing, blood loss, grade and segment of osteotomy, fusion segments, post- operative complications involving infection, proximal junctional kyphosis (PJK)[27], proximal junctional failure (PJF)[28], and rod breakage were recorded.

Statistical analysis

Continuous data are presented as Means ± standard deviation. Pre- and post-operative variables were compared by paired *t* tests. Intra-group comparisons were performed by independent samples *t* tests. The Pearson χ^2 or Fisher's exact was carried out for comparison of gender, incidence of comorbidities and post-operative complications, and differences of upper and lower instrumented vertebra. The correlations between PI and other parameters were analyzed by the Pearson Pearson correlation tests. All statistical analyses were performed in SPSS (version 23.0, IBM, Armonk, NY, USA). A two tailed *P*-value of 0.05 was considered statistically significant.

Results

This study concerns a populations of 83 patients, 16 men (19.28%) and 67 women (80.72%), with de novo scoliosis or degenerative hyper-kyphosis. The average age at surgery was 65.2 years (SD, 8.1). In all, 69 patients had

TABLE 1 General characteristics of the two groups

	LLL group ($n = 53$)		TLL group ($n = 30$)			
General characteristic	Mean	SD	Mean	SD	t/χ^2 value	*P* value
Age(years)	64.66	7.65	65.27	8.8	−0.328	0.744
Sex					1.649	0.199
Male	8		8			
Female	45		22			
BMI(kg/m^2)	26	4	25	6	0.336	0.767
Comorbidities					1.103	0.294
Diabetes	8		4			
Hypertension	16		12			
Heart disease	8		5			
Pulmonary disease	12		1			
No comorbidities	9		8			

BMI, body mass index; LLL, lower lumbar level; TLL, thoracolumbar level.

TABLE 2 Operative variables of the two groups

	LLL group ($n = 53$)		TLL group ($n = 30$)			
Operative variables	Mean	SD	Mean	SD	t/χ^2 value	*P* value
Time (min)	266.17	55.11	298.5	57.92	−2.411	0.018
Blood (mL)	440.85	124.69	618.93	191.18	−4.402	<0.001
FL	7.85	2.44	8.57	1.87	−1.396	0.167
OL	2.21	0.67	2.4	1.13	−0.832	0.41
OG	2.02	0.14	2.5	0.51	−5.078	<0.001
UIV					0.185	0.667
Above T_{10}	7		5			
Not	46		25			
LIV					2.779	0.096
Pelvis or sacrum	33		13			
Not	20		17			
Revision operation	2		3		1.31	0.25
Infection	2		1		0.01	0.92
CSF	2		4		2.61	0.11
Break rods			3			
PJF	2					
PJK	4		2		0.02	0.88
Complications	6		7		2.09	0.15
	PLIF($n = 69$)		STO($n = 14$)		χ^2	P
Revision operation	2		3		7.06	0.008
CSF	2		4		11.44	0.001

CSF, cerebrospinal fluid leakage; FL, fixed levels; LIV, lower instrumented vertebra; LLL, lower lumbar level; OG, osteotomy grades; OS, osteotomy segments; PJF, proximal junction failure; PJK, proximal junction kyphosis; PLIF, posterior lumbar interbody fusion; STO, single-level three-column osteotomy; TLL, thoracolumbar level; UIV, upper instrumented vertebra.

procedure of long-fusion with multi-level PLIF, and 14 patients with single-level three column osteotomy (STO). There were 53 and 30 patients in the LLL and TLL groups respectively, all of those patients with STO were belonging to the TLL group. There were no differences in age ($P = 0.744$), gender ($P = 0.199$), BMI ($P = 0.767$), and comorbidities ($P = 0.294$) between the two groups (Table 1).

The measurements of the surgical operations are listed in Table 2. Patients in the LLL group had shorter operation timing ($P = 0.018$), less blood-loss ($P < 0.001$) and less grade of osteotomies ($P < 0.001$). There were no difference in

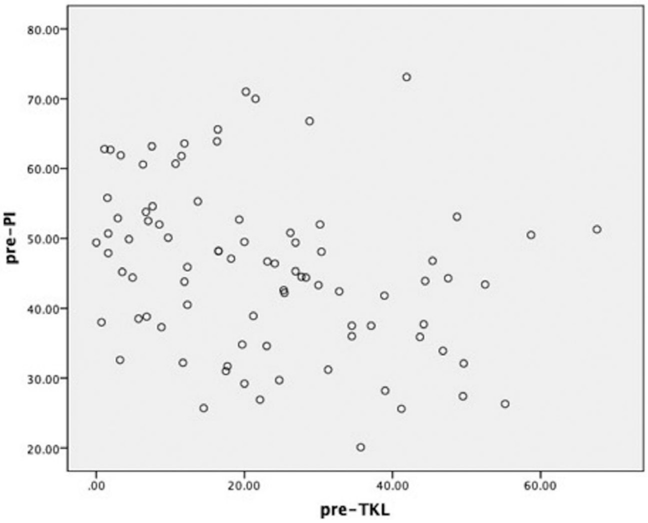

Fig. 3 The Scatter graph illustrates the negtive relationship between pelvic incidence (PI) and thoracolumbar kyphosis (TLK) at pre-operation.

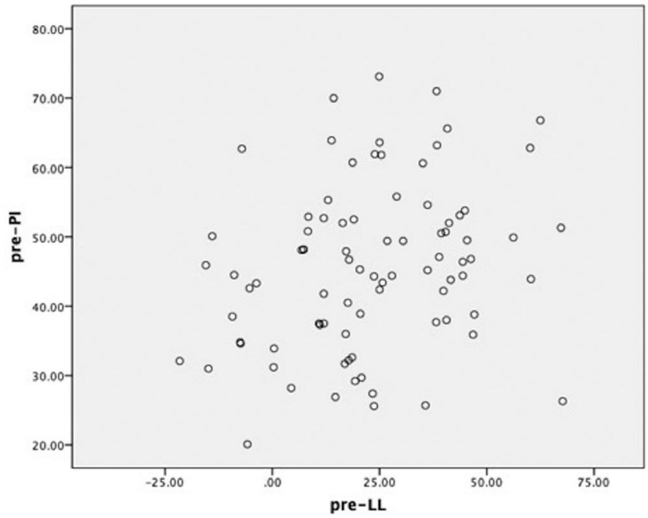

Fig. 4 The scatter graph illustrates the positive relationship between pelvic incidence (PI) and lumbar lordosis (LL) at pre-operation.

TABLE 3 The radiological parameters of the two groups at pre- and post-operation

	Pre-operation					Post-operation				
	LLL group ($n = 53$)		TLL group ($n = 30$)		*P* value	LLL group ($n = 53$)		TLL group ($n = 30$)		
Radiologic parameters	Mean	SD	Mean	SD		Mean	SD	Mean	SD	*P* value
Cobb	24.14	12.31	22.27	19.04	0.75	0.58	10.82	1.85	15.1	0.66
TK	16.49	12.53	17.15	14.22	0.83	22.68	9.38	22.64	12.1	0.99
TLK	17.97	13.42	29.81	18.16	**0.00** *	9.68	9.00	11.56	8.79	0.36
LL	21.55	17.23	26.05	23.64	0.37	38.93	11.79	38.09	14.38	0.78
SS	23.17	10.43	19.50	16.36	0.28	29.79	9.03	28.67	13.53	0.69
PT	25.00	10.42	22.13	13.03	0.28	18.53	9.46	14.23	9.67	0.06
PI	48.18	11.22	41.96	12.37	**0.02**	48.47	11.78	42.93	11.65	**0.04**
SAA	44.52	7.39	45.28	11.48	0.75	38.45	7.88	38.22	7.61	0.89
PFA	199.99	9.87	198.43	12.57	0.54	192.76	9.41	187.81	9.40	**0.02**
SVA	46.03	53.35	56.93	45.56	0.55	7.57	33.75	17.49	30.84	0.19
TPA	23.02	11.96	22.92	13.87	0.97	15.74	9.46	12.81	8.36	0.17
PI-LL	27.33	18.93	15.91	20.95	**0.01**	9.42	13.82	4.84	12.19	0.14

The bold numbers indicate that the differences are significant ($P < 0.05$). *, $P < 0.001$; LL, lumbar lordosis; LLL, lower lumbar level; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; TLL, thoracolumbar level; TPA, T1 pelvic angle.

fusion segments, the number of sacroiliac fixation, and the proportion of the upper instrumented vertebra (UIV) above T10 between the two groups. There were three patients in the LLL group and one patient in the TLL group suffered deep infections, and the incidence of infection in this study was about 4.8%. Two patients in the LLL group and four patients belonging to the TLL group had cerebrospinal fluid leakage (CSFL). At the final follow-up, there were four patients had PJK without any clinical symptom and two patients with PJF in the LLL group. For patients in the TLL group, three patients had rod breakage, two patients suffered PJK without any clinical symptoms. All of the patients with PJF and rod breakage recovered after reconstruction surgery.

Although comparisons of radiographic data involving spine (TK, LL, and main curve), pelvis (SS and PT), and hip (PFA and SAA) between the two groups showed no differences at pre-operation, patients in the TLL group had smaller mismatch (PI-LL, $P = 0.015$) and PI ($P = 0.023$), as well as much larger TLK ($P = 0.003$) (Table 3). Additionally, the Pearson correlations analysis showed that there were negative- relationships between PI and TLK ($r = -0.302$, $P = 0.005$), positive-relationships with LL ($r = 0.261$, $P = 0.016$) in all of those 83 patients at pre-operation (Table 4, Figs 3 and 4).

Comparisons of those radiographic data including main curve ($P < 0.001$), TK ($P < 0.001$), TLK ($P < 0.001$), LL ($P < 0.001$), SS ($P < 0.001$), PT ($P < 0.001$), SAA ($P < 0.001$), PFA ($P < 0.001$), SVA ($P < 0.001$), and TPA ($P < 0.001$) at pre- and post-operation showed significant differences (Table 5). Comparing sagittal radiographic data between the two groups during operations, the results showed that patients in the TLL group had much larger correction degree of TLK ($P = 0.004$). Patients in the LLL and TLL groups had comparable spine-pelvis-hip radiographic parameters at post-operation except PI ($P = 0.04$) and PFA ($P = 0.026$). (Table 6).

TABLE 4 The correlation between PI and other parameters at pre-operation

	PI	
	r	*P*
TLK	−0.302	0.005
LL	0.261	0.016

LL, lumbar lordosis; PI, pelvic incidence; TLK, thoracolumbar kyphosis.

The quality of life evaluations showed significant improvements after surgery ($P < 0.001$). There were no inter- and intra-group differences at pre-, post-operation and final follow-up respectively (Table 7).

Two representative patients underwent long-fusion with three-column osteotomy or PLIF are shown, and the spine-pelvic-hip alignment improved significantly at immediate post-operation and the final follow-up. The imagings of patient belonging to the LLL group were shown in Fig. 5A–F. The major Cobb angle preoperatively, immediate postoperatively and at the final follow-up was 19.2°, 9.0°, and 8.5° respectively. The parameters at sagittal plane at pre-operation were 21.2°(TK), 22.4°(TLK), −7.8°(LL), −25.6°(LLL), 18.9° (PT) and 65.5 mm (SVA), which were improved significantly after surgery, 32.9°(TK), 1.3°(TLK), −41.2°(LL), −33.9°(LLL), 10.5°(PT) and −50.7 mm (SVA). Those parameters were 34.5°(TK), 3.5°(TLK), −43.5°(LL), −34.5°(LLL), 14.7°(PT) and −40.5 mm (SVA) at the final follow-up. The images of a patient belonging to the TLL group were shown in Fig. 5A–F.

TABLE 5 Comparison of the radiological parameters of 83 ASD patients at Pre- and Post-operation(°)

	Pre-operation		Post-operation		
Radiological parameters	Mean	SD	Mean	SD	*P* value
Cobb	23.82	13.53	9.98	7.56	<0.001
TK	16.99	13.36	22.03	10.17	<0.001
TLK	21.32	15.99	10.25	8.19	<0.001
LL	22.57	20.74	39.18	12.39	<0.001
SS	22.35	13.04	30.26	10.69	<0.001
PT	23.51	11.79	16.0	9.33	<0.001
PI	46.06	11.55	46.44	12.07	0.513
SVA	48.53	51.99	12.35	36.72	<0.001
TPA	22.45	12.34	14.22	9.12	<0.001
PFA	199.8	10.92	190.78	9.67	<0.001
SAA	44.67	9.03	38.17	7.73	<0.001

Abbreviations: TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; SVA, sagittal vertical axis; TPA, T1 pelvic angle; PFA, pelvic femur angle; SAA, sagittal acetabular anteversion.

TABLE 6 Comparison of radiographic parameters correction between the two groups

	LLL group (n = 53)		TLL group (n = 30)			
Operative variables	Mean	SD	Mean	SD	t/χ^2 value	*P* value
ΔCobb	14.74	9.2	10.18	8.28	1.591	0.116
ΔTK	5.83	5.06	4.54	11.27	0.543	0.588
ΔTLK	7.84	11.53	18.02	15.34	3.035	0.004
ΔLL	17.77	14.64	13.38	15.05	1.245	0.217
ΔSS	6.82	9.06	9.14	9.26	−1.06	0.292
ΔPT	6.88	7.99	7.87	9.26	0.488	0.627
ΔSVA	37.91	51.25	36.89	51.16	−0.084	0.933
ΔTPA	7.68	8.21	8.97	8.06	0.655	0.515
ΔPFA	7.53	6.84	10.04	6.35	−2.627	0.008
ΔSAA	6.15	6.99	5.96	8.63	−0.108	0.915

LL, lumbar lordosis; LLL, lower lumbar level; PFA, pelvic femur angle; PI, pelvic incidence; PT, pelvic tilt; SAA, sagittal acetabular anteversion; SS, sacral slope; SVA, sagittal vertical axis; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; TLL, thoracolumbar level; TPA, T1 pelvic angle; ΔCobb = pre-Cobb – post-Cobb; ΔLL = |post-LL – pre-LL|; ΔPFA = |post-PFA – pre-PFA|; ΔPT = |post-PT – pre-PT|; ΔSAA = |post- SAA – pre-SAA|; ΔSS = |post-SS – pre-SS|; ΔSVA = |post-SVA – pre-SVA|; ΔTK = |post-TK – pre-TK|; ΔTLK = |post-TLK – pre-TLK|; ΔTPA = |post-TPA – pre-TPA|.

The major Cobb angle preoperatively, immediate postoperatively and at the final follow-up was 2.4°, 2.0°, and 2.1° respectively. The parameters at sagittal plane at pre-operation were 12.1°(TK), 39.5°(TLK), 12.4°(LL), −19.3°(LLL), 41.8°(PT) and 97.6 mm (SVA) respectively, which were improved significantly after surgery, 30.3°(TK), 10.7°(TLK), −38.4°(LL), −24.6°(LLL), 22.1°(PT) and −22.9 mm (SVA). Those parameters were 33.2° (TK), 13.2°(TLK), −39.2°(LL), −23.8°(LLL), 23.2°(PT) and 13.8 mm (SVA) at the final follow-up.

Discussion

It is well known that patients with degenerative spinal deformity (DSD), including de novo scoliosis (DS) and degenerative hyper-kyphosis, having biomechanics pathologies involving PT[29], PI-LL[21], and global spinal alignment (GSA)[30] would have significant lower quality of their life. Therefore, recognition of the spine-pelvis-hip alignments would be essential for the treatment in those patients. Sebaaly *et al.*[31] described the classifications of spinopelvic alignments in patients with spinal degenerative disorders first, which demonstrated that the incidence of DSD was much higher in patients with low PI. Moreover, there were significant correlations between PI and SS, and no correlation between pelvic and spinal parameters. But there were different results in this current study. Patients with smaller PI (P = 0.023) had larger degree of TLK (P = 0.003) and smaller degree of PI-LL (P = 0.015) at pre-operation. Moreover, there were negative correlations

TABLE 7 Comparison of clinical outcomes between two groups at pre-operation and final follow-up

	VAS			ODI			SF-36 PCS			SF-36 MCS		
	Pre-op	*F/U*	*P*	Pre-op	*F/U*	*P*	Pre-op	*F/U*	*P*	Pre-op	*F/U*	*P*
L	6.92	3.2	**0.001**	46.31	27.96	**0.001**	35.26	44.32	**0.011**	47.68	52.85	**0.007**
T	7.26	2.96	**0.001**	45.67	28.10	**0.001**	35.36	43.89	**0.009**	46.90	53.12	**0.006**
P	0.429	0.125	-	0.597	0.612	-	0.819	0.725	-	0.851	0.89	-

L indicates the LLL group; T, the TLL group; The bold numbers indicate that the differences are significant ($P < 0.05$).; F/U, final follow-up; ODI, oswestry disability index; Pre-op, pre-operation; SF-36 MCS, short form-36 mental component score; SF-36 PCS, short form-36 physical component score; VAS, visual analogue scale.

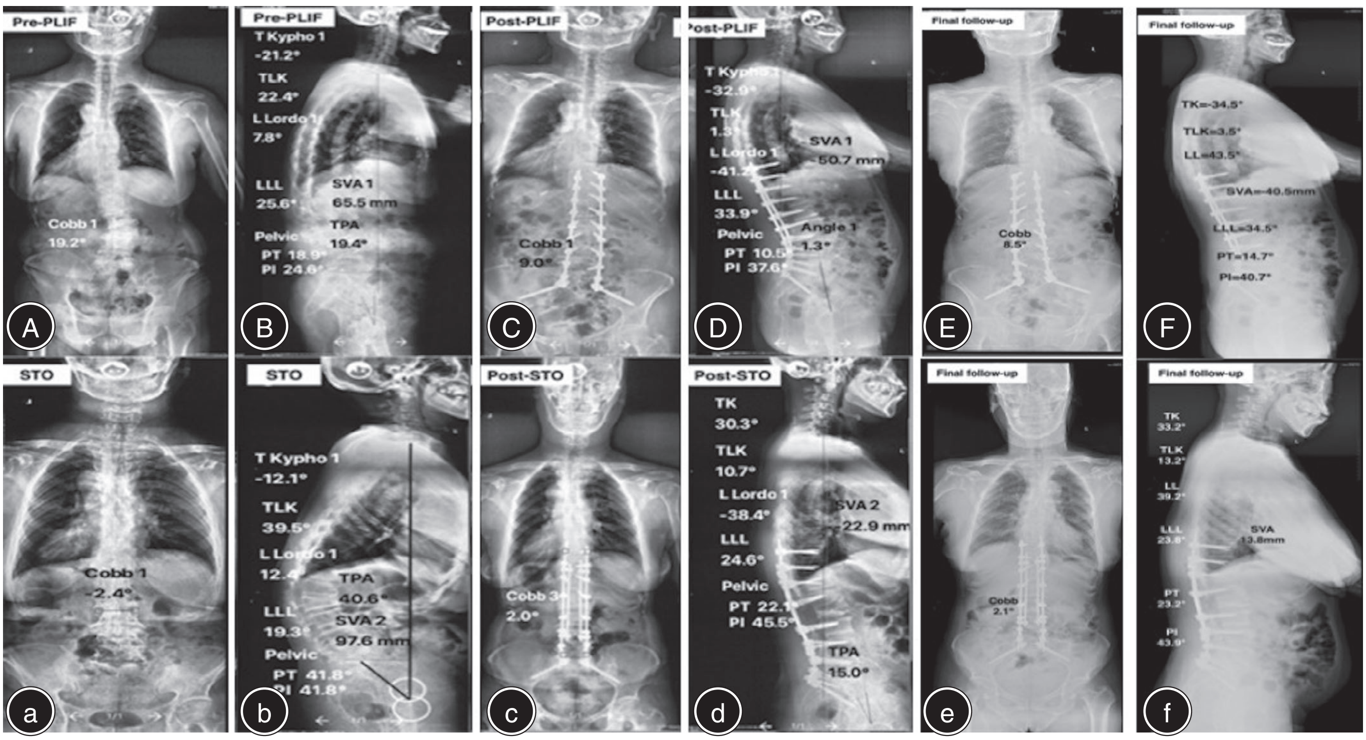

Fig. 5 Two representative patients underwent long-fusion with three-column osteotomy or PLIF are shown, and the spine-pelvic-hip alignment improved significantly after surgery.

between PI and TLK ($r = -0.302$, $P = 0.005$). Therefore, DSD patients with low PI would be closed to developing hyper-kyphosis at thoracolumbar spine for the less compensation potential of lumbar spine, and those with high PI may be vulnerable to significant degeneration at lumbar spine.

Long-fusion with osteotomy surgery can prevent DSD progression, decompress nerves and restore the spinal alignment effectively[13,32]. In this current study, all of the sagittal spinopelvic parameters were improved significantly after surgeries ($P < 0.001$).

There were significant connections among spine, pelvis, and hip joints during position changes in healthy human beings[10,11] and patients with spine or hip joints disorders[33–35]. A previous study[16] demonstrated that sagittal acetabular version would change significantly after PSO at lumbar spine. Both SAA and PFA of patients in our study had significant changes ($P < 0.001$) during surgery, and the PFA in the LLL group was much larger ($P = 0.02$) at post-operation. Additionally, The changes of TLK ($P = 0.004$) and PFA ($P = 0.008$) were significant larger in patients belonging to the TLL group. Therefore, the procedure of long-fusion with single-level three-column osteotomy (PSO or VCD) or PLIF at thoracolumbar spine would restore spinopelvic alignments effectively for patients with hyper-kyphosis. According to previous study[36], the lower the level of osteotomy in adult spinal deformity (ASD) patients, the greater the impact on pelvis. In this current study, although patients in the TLL group had osteotomies at thoracolumbar segments, there were much more influences on their hip joints. DSD patients with lower PI are probably much more vulnerable to hip joints changes after the procedure of long-fusion with PLIF or STO.

Although single-level three-column osteotomy (STO) at the apical vertebra would get excellent correction outcomes, the aggressive surgical approaches have been always posed the greatest risk to both surgeons and patients[37,38]. In this study, comparison of the complication of CSFL in the LLL and TLL groups showed no difference, however, the incidence of CSFL in patients who underwent STO was much higher (2/67 *VS* 4/10, $P = 0.001$). Additionally, although the incidence of revision surgery had no difference between the LLL and TLL groups (2/53 *VS* 3/30, $P = 0.25$), patients underwent STO had greater risk at mechanical failure (i.e. implant breakage) (2/67 *VS* 3/11, $P = 0.008$). With the comparable surgical data involving fusion segments, the number of sacroiliac fixation, and the proportion of the upper instrumented vertebra (UIV) above T10, patients in the LLL group had shorter operation timing ($P = 0.018$), less blood-loss ($P < 0.001$) and less grade of osteotomies ($P < 0.001$), probably for the reason that 14 patients received single-level three-column osteotomy (PSO or VCD) were all included in the TLL group.

Studies performed by Lafage *et al.*[39] and Yilgor *et al.*[40] suggested that a less aggressive alignment goal should be applied for patients with ASD. We performed lower grade osteotomies and inter-body fusion in the larger number of patients (69/83) to restore satisfactory spinal alignment and reduce the incidence of complications, as well as improve quality of life, which was confirmed by the improvement of VAS, ODI, and SF-36 scores.

Limitations of our study included the single center and retrospective study design, which has inherent difficulties encountered for studying degenerative spinal deformity patients. Further studies would be necessary to validate the conclusions in this study in the future, which would provide guidelines for spinal surgeons to perform surgical procedure for patients with adult spinal deformity. Moreover, subgroup comparative analysis probably has bias due to the small sample size; hence, a larger number of subjects should be included in future studies. Lastly, the radiographic data in this current study were measured in standing full-length spine plain radiographs, however, some parameters such as PFA and SAA, representing hip joints function, should be future investigated in position changes from standing to sitting.

Conclusions

According to the results in this study, degenerative spinal deformity (DSD) patients with low PI would be liable to thoracolumbar significant degeneration, and high PI probably be vulnerable to severe degeneration at the lower lumbar spine. The surgical procedure that long-segment instrumentation and fusion with multiple-level posterior lumbar interbody fusion or single-level three-column osteotomy in the severe degeneration segments can effectively restore the spine-pelvis-hip alignments and improve quality of life in patients with DSD. However, the procedure with PSO or VCD would bring higher incidences of complications, involving longer operative timing, more blood loss, and more revision surgery. Moreover, the radiographic data of hip joints in DSD patients with lower PI would be restored much easier after the procedure of long-fusion with PLIF or STO.

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Each author of this article certifies that the Chinese PLA general hospital approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research. This work was performed at the Chinese PLA general hospital, Fuxing Road, Beijing, China.

Authors' contributions

Zhang Z-ifang wrote this article completely; Zhang Zi-fang and Qi Deng-bin measured and recorded all the data for this article. Wang Tian-hao analyzed and interpreted the data. Professor Wang Zheng and Wang Yan designed and supervised this study. All authors read and approved this final manuscript.

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