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

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Objectives: 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, L3-S1) and thoracolumbar levels (TLL, T10-L2) 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 χ2 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...
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 hyper-kyphosis, 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 \(\geq 45\) years) with diagnosis of de novo scoliosis or degenerative hyper-kyphosis based on imaging results with at least one of the following, (a) coronal curvature \(\geq 20^\circ\), (b) sagittal vertical axis (SVA) \(\geq 5\) cm, (c) pelvic tilt (PT) \(\geq 25^\circ\), and (d) thoracic kyphosis (TK) \(\geq 60^\circ\); (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 \(\geq 2\) 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 \(\geq 2\) 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 multi-level 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 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) or vertebral column decancellation (VCD) 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).

**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](image1.png)

**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 3 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](image2.png)

**Fig. 2** Pelvic parameters: sacral slope (SS): the angle between the horizontal line and the sacral 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 T4 and the lower endplate of T12, represents the thoracic feature. Thoracolumbar kyphosis (TLK), the Cobb angle between the upper endplate of T10 and the lower endplate of L2, is the transition from thoracic spine to the lumbar spine. Lumbar lordosis (LL), the Cobb angle between the upper endplate of L1 and the upper endplate of S1, represents the lumbar feature. Sagittal vertical axis (SVA), the offset between the center of C7 and the plumb line drawn from posterosuperior corner of S1, represents the global spine alignment. T1 pelvic angle (TPA), the angle between the line from the axis of the femoral head to the center of T1 and the line from the axis of femoral head to the midpoint of the S1 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 method26) 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 χ² 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 |
|--------------------------------------------------|
| General characteristic | LLL group (n = 53) | TLL group (n = 30) | t/χ² value | P value |
|------------------------|------------------|------------------|------------|---------|
| Age(years)             | 64.66 ± 7.65     | 65.27 ± 8.8      | −0.328     | 0.744   |
| Sex                    |                   |                  |            |         |
| Male                   | 8                 | 8                | 1.649      | 0.199   |
| Female                 | 45                | 22               |            |         |
| BMI(kg/m²)             | 26 ± 4            | 25 ± 6           | 0.336      | 0.767   |
| Comorbidities          |                   |                  |            |         |
| Diabetes               | 8                 | 4                | 1.103      | 0.294   |
| 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.
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](image1.png) **Fig. 3** The Scatter graph illustrates the negative relationship between pelvic incidence (PI) and thoracolumbar kyphosis (TLK) at pre-operation.

![Fig. 4](image2.png) **Fig. 4** The scatter graph illustrates the positive relationship between pelvic incidence (PI) and lumbar lordosis (LL) at pre-operation.
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).

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-pelvis-hip alignment improved significantly at immediate post-operation and the final follow-up. The imaging 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 3** The radiological parameters of the two groups at pre- and post-operation.

| Radiologic parameters | Pre-operation | Post-operation |
|-----------------------|---------------|----------------|
|                       | LLL group (n = 53) | TLL group (n = 30) | P value |
|                       | Mean | SD  | Mean | SD  |
| 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                    | 21.95 | 17.23 | 26.05 | 23.64 | 0.37 | 38.93 | 11.79 | 38.09 | 14.38 | 0.78 |
| SS                    | 23.17 | 15.43 | 19.50 | 16.36 | 0.28 | 29.79 | 9.03 | 28.67 | 13.53 | 0.69 |
| PT                    | 25.00 | 14.22 | 22.13 | 13.03 | 0.28 | 18.53 | 9.46 | 14.23 | 9.67 | 0.06 |
| 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 | 48.56 | 0.55 | 5.77  | 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                    | 48.47 | 11.22 | 41.96 | 12.37 | 0.02 | 48.47 | 11.78 | 42.93 | 11.65 | 0.04 |

The bold numbers indicate that the differences are significant \((P < 0.05)\), *, \(P < 0.01\); 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.

**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 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°(LLL), −24.6°(LLL), 22.1°(PT) and −22.9 mm (SVA). Those parameters were 33.2° (TK), 13.2°(TLK), −39.2°(LLL), −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 PT29, PI-LL21, 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 5 Comparison of the radiological parameters of 83 ASD patients at Pre- and Post-operation(1) |
|---------------------------------------------------------------|
| Radiological parameters                                      | Pre-operation | Post-operation | P value |
| Mean               | SD               | Mean               | SD               |           |
| 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                | 25.57             | 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             | 7.33          | <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 anteverision.

| TABLE 6 Comparison of radiographic parameters correction between the two groups |
|-----------------------------------------------|
| Operative variables                                    | LLL group (n = 53) | TLL group (n = 30) | t/χ² value | P value |
| Mean               | SD               | Mean               | SD               |           |
| 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     |
| ΔTLK               | 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 anteverision; 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 = pre-LL − post-LL; ΔPFA = pre-PFA − post-PFA; ΔPT = pre-PT − post-PT; ΔSAA = pre-SAA − post-SAA; ΔSS = pre-SS − post-SS; ΔSVA = pre-SVA − post-SVA; ΔTK = pre-TK − post-TK; ΔTLK = pre-TLK − post-TLK; ΔTPA = pre-TPA − post-TPA.
between PI and TLK ($r = -0.302, P = 0.005$). Therefore, DSD patients with low PI would be closer 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\textsuperscript{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\textsuperscript{10,11} and patients with spine or hip joint disorders\textsuperscript{33–35}. A previous study\textsuperscript{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

| 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     |          |          |
| 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.
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\textsuperscript{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\textsuperscript{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.\textsuperscript{39} and Yilgor et al.\textsuperscript{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 Zifang 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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