Spino-Pelvic Thresholds for Prevention of Proximal Junctional Kyphosis Following Combined Anterior Column Realignment and Short Posterior Spinal Fusion in Degenerative Lumbar Kyphosis

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Objective: To analyze ideal indication for combined anterior column realignment (ACR) with short posterior spinal fusion (PSF) and posterior column osteotomy (PCO) for preventing proximal junctional kyphosis (PJK) in adult spinal deformity (ASD) patients with lower lumbar kyphosis and compensatory thoracolumbar lordosis.

Methods: A retrospective study was conducted. This study included 27 ASD patients (average age of 66.6 years; one male and 26 females) with lower lumbar kyphosis and compensated thoracolumbar lordosis who underwent short PSF with PCO following ACR from 2006 to 2010. The minimum follow-up period was 5 years. The patients were divided into two groups based on the sagittal vertical axis (SVA) of the last follow-up radiographs, and a comparative analysis was performed evaluating spino-pelvic parameters and clinical outcomes including the Oswestry Disability Index (ODI), Visual Analog Scale (VAS), and complications.

Results: The mean follow-up time of included patients was 109.7 months, and the mean number of fused segments was 3.7. The uppermost instrumented vertebra was L2 in 18 patients or L3 in nine patients, and lowermost instrumented vertebra was sacrum in all patients. The mean lumbar lordosis (LL) values in the optimal SVA and suboptimal SVA groups were 4.4° and 4.2° preoperatively (P = 0.639), −48.1° and −35° postoperatively (P = 0.007), and −45.2° and −20.7° at the last follow-up (P < 0.05). Overcorrection was seen in seven patients in the optimal SVA group, whereas all of the patients of the suboptimal SVA group were in the category of undercorrection (P = 0.021). Pelvic incidence (PI) of optimal SVA group (<50 mm, n = 16) and suboptimal SVA group (≥50 mm, n = 11) was 44.1° and 53.8° (P = 0.009). The prevalence of PJK was significantly higher in the suboptimal SVA group (P = 0.008), and last follow-up VAS for back pain (P < 0.05), and postoperative and last follow-up ODI (P = 0.002 and P < 0.05) were statistically larger for the suboptimal group than the optimal group.

Conclusions: Combined ACR with short PSF and PCO could effectively prevent sagittal decompensation of PJK and help achieve sagittal balance in the treatment of ASD patients with lower lumbar kyphosis, compensatory thoracolumbar lordosis, and especially low PI (<50°).

Key words: Adult spinal deformity (ASD); Anterior column realignment (ACR); Kyphosis; Spinal fusion; Thoracolumbar lordosis

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**Introduction**

Adult spinal deformity (ASD) is a devastating condition that induces pain and disability because of spinal malalignment, which negatively affect a patient’s quality of life. The recent increase in the average life expectancy has increased the prevalence of ASD, and surgical treatment for senior patients with active lifestyles has drawn attention.

Restoration of sagittal balance following appropriate surgical correction is the main goal in the treatment of ASD with sagittal malalignment. Optimal lumbar lordosis (LL) is essential for prevention of sagittal decompensation and closely correlated with pelvic incidence (PI). According to several studies, correlations between pelvic parameters and normal sagittal plane alignment are helpful for making a preoperative plan to achieve postoperative optimal sagittal balance. In addition, based on these correlations, various mathematical formulae have been developed to improve the accuracy of predicting the sagittal balance after the correction of deformities.

Layegy and others demonstrated that the PI is an important anatomic parameter that is used to describe the anatomical shape of the pelvis, and it greatly affects the sagittal spino-pelvic alignment. It is widely accepted that the positive sagittal balance has a negative impact on patients with ASD. According to Farcy and Schwab, flatback and kyphotic decompensation syndrome might have a correlation with the amount of residual sagittal imbalance, and Booth and others reported a treatment failure to achieve the negative sagittal balance that might be the most reliable indicator of unsatisfactory surgical outcomes. Moreover, Glassman and others reported that sagittal balance was the most important predictive factor for 2-year clinical outcomes, and restoration of a more normal sagittal balance is the critical goal for any reconstructive spine surgery for ASD patients. Likewise, spino-pelvic alignment affects sagittal balance and should be considered during surgical decision making to decrease postoperative complications.

Therefore, optimal surgical correction in patients with ASD is necessary to improve clinical outcomes and prevent sagittal decompensation, and surgical techniques for sagittal balance correction involve complex and challenging deformity correction. Traditionally, osteotomy, such as anterior open wedge osteotomy (Smith-Petersen osteotomy [SPO]), polysegmental dorsal osteotomy (Ponte osteotomy, posterior column osteotomy [PCO]), pedicle subtraction osteotomy (PSO), and posterior vertebral column resection, have been used to recover spinopelvic harmony in patients with ASD. In particular, three column osteotomies are the most powerful methods for achieving optimal sagittal balance, but there are still problems originating not only from the complexity of the procedure itself but also from the complications that have been reported, with rates up to 37%. Among these complications, proximal junctional kyphosis (PJK) is one of the common complications in long-term follow-up with reported incidences of 0% to 61%, and it is still controversial with regard to determining the uppermost instrumented vertebrae (UIV) as well.

PJK is a common pathological entity and complication after instrumented spinal fusion surgery and is a potentially catastrophic complication that could lead to progressive decompensation in the sagittal plane, neurologic compromise, and worse clinical outcomes. Glatte and others reported medium-term follow-up studies that focused on PJK in the adult deformity with specific attention paid to patient outcomes; therefore, preventing sagittal decompensation of PJK is important for sagittal balance in the treatment of ASD.

There are various curve patterns according to the compensatory mechanism in ASD with sagittal malalignment and it is important to find an optimal indication of specific curve patterns for a short fusion level for achieving optimal correction with less complications; this is because all patients with ASD do not need to require long fusion from the sacrum to the thoracic spine and corrective three-column osteotomies for obtaining sagittal balance. Furthermore, there are various factors for deciding a proper surgical plan, including surgical approaches (staged anterior and posterior surgery vs single posterior), surgical procedures (three column osteotomy vs PCO), and level of UIV (upper thoracic, lower thoracic, upper lumbar). Recent advancements in minimally invasive spine surgery (MIS) have allowed ASD correction through posterior instrumentation of open or percutaneous techniques with interbody fusion grafts. Dakwar and others first evaluated recovery in sagittal balance after lateral lumbar interbody fusion in 2010, and the advancement in surgical techniques, including anterior longitudinal ligament release and ACR treatment, allowed for a significant correction of LL using a lateral approach.

Therefore, in this study, efforts have been made to analyze ideal indication for combined anterior column realignment (ACR) with short posterior spinal fusion (PSF) for preventing PJK in ASD patients with thoracolumbar (TL) compensation and lower lumbar kyphosis.

**Materials and Methods**

**Patient Selection**

In this study, 78 patients with ASD aged ≥60 years who were followed up for at least 5 years between 2006 and 2010 were retrospectively evaluated. The inclusion criteria were as follows: (i) patients were over 60 years with ASD accompanied by sagittal malalignment, and showed TL compensation and lower lumbar kyphosis; patients clearly showed atrophy of the back musculature on magnetic resonance imaging (a diagnostic criterion for degenerative lumbar kyphosis [DLK]) and...
clinical signs such as difficulty in walking with stooping, inability to lift heavy objects, difficulty in climbing slopes, and need for elbow support when working in the kitchen, with evidence of a corn on the extensor surface of the elbow; (ii) patients underwent short PSF and PCO to the sacrum combined with ACR as a surgical treatment performed by a single surgeon at a single institution; (iii) patients were divided into the following two groups based on the sagittal vertical axis (SVA) of the last follow-up radiographs: optimal SVA group (SVA < 50 mm) and suboptimal SVA group (SVA > 50 mm); (iv) we analyzed the radiographic and clinical outcomes inducing PJK parameters; and (v) patients were retrospectively reviewed in this study (retrospective cohort study).

And the exclusion criteria were as follows: patients with deformities resulting from (i) trauma, (ii) spinal infection, (iii) ankylosing spondylitis, (iv) rheumatoid arthritis, (v) neuromuscular disease, or (vi) tumors.

**Ideal LL**

The primary goal of surgical correction in all patients was to obtain the ideal LL. The ideal LL was the theoretical value calculated according to the Korean version of the Legaye formula (sacral slope [SS] = 0.80 + 0.74 × PI, and ideal [maximal] LL = 17.42 + 0.96 × SS)\(^3,37\). Based on the estimated ideal LL, patients with a postoperative LL more than the ideal were categorized as overcorrection, and patients with less were categorized as undercorrection.

**Radiographic Measurements**

Sagittal alignment was evaluated by lateral 14 × 36-inch full spine X-rays, for which the patients stood in a neutral unsupported position with their arms in the clavicle position. All the digital radiographs were measured using a picture archiving communication system (PACS) (Infinitt, Seoul, Korea): a software developed to accurately calculate parameters by magnifying anatomic landmarks of the spine and pelvis on lateral views. On radiography, we evaluated the PI, SS, pelvic tilt (PT), thoracic kyphosis (TK), TL, LL, lumbosacral junction (LS), and SVA.

**Sagittal Vertical Axis**

SVA was defined as the horizontal distance between the posterosuperior corner of the sacrum and the C7 plumb line. Optimal and suboptimal sagittal balances were defined as SVA ≤ 50 mm and >50 mm, respectively\(^39\).

**Pelvic Parameters**

PI was measured using a standing lateral radiograph of the pelvis, and the angle was defined between a perpendicular line from the sacral plate and a line connecting the midpoint of the sacral plate to the biacromial axis. SS corresponded to the angle between the sacral plate and horizontal plane, and PT corresponded to the angle between a line connecting the midpoint of the sacral plate to the biacromial axis and vertical plane\(^8\).

**Sagittal Cobb Angles**

Cobb angle is defined as the greatest angle at a particular region of the vertebral column when measured from the superior endplate of a superior vertebra to the inferior endplate of an inferior vertebra\(^40\). And a sagittal Cobb angle is one measured in the sagittal plane such as on lateral radiographs. Sagittal Cobb angles were measured for TK (T5–L2), TL (T10–L2), LL (T12–S1), and LS (L4–S1)\(^41,42\).

**PJK**

The proximal junctional angle (PJA) was measured from the inferior endplate of the UIV to the superior endplate of two vertebrae above the UIV, and PJK was defined by the following two criteria: (i) proximal junction sagittal Cobb angle greater than or equal to +10°; and (ii) proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement\(^25\).

**Clinical Outcome Assessment**

Clinical outcome assessment was done using the Oswestry Disability Index (ODI) and Visual Analog Scale (VAS) for the preoperative, postoperative, and last follow-up periods. Comparisons were done in optimal SVA group vs suboptimal SVA groups and low PI group vs high PI group.

**ODI**

ODI is the most commonly used indicator of the condition-specific outcome measure\(^34–46\), and it consists of 10 items that assess the level of pain and interference with several physical activities; pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. Each item asks how the pain affects the activities of daily living (ADL), and is scored. For each section of six statements the total score is 5. If all 10 sections are completed the score is calculated as follows: total scored out of total possible score × 100. If one section is missed (or not applicable) the score is calculated: (total score / [5 × number of questions answered]) × 100%. The scores are as follows: 0%–20% is considered mild dysfunction, 21%–40% is moderate dysfunction, 41%–60% is severe dysfunction, and 61%–80% is considered as disability. For cases with a score of 81%–100%, the person is either long-term bedridden or exaggerating the impact of pain on their life. The greater outcome percentage, the more extreme the disability.

**Visual Analogue Scale**

VAS is a simple and frequently used method of measuring pain intensity\(^37\), and the percentage of the pain relief measured by the VAS score is considered a method of the treatment efficacy\(^38\). The VAS pain scoring standard (scores from 0 to 10) was as follows: 0 = painless; less than 3 = mild pain that the patient could endure; 4–6 = patient was in pain that could be endured and was able to sleep; and 7–10 = patient had intense pain and was unable to tolerate the pain\(^49\).
### TABLE 1 Radiographic and PJK parameters between the optimal and suboptimal SVA groups

| Radiographic parameters | Optimal SVA (n = 16) | Suboptimal SVA (n = 11) | P-value |
|-------------------------|----------------------|-------------------------|---------|
| SVA (mm, mean ± SD)     |                      |                         |         |
| Preoperative            | 157.0 ± 61.6         | 116.7 ± 64.1            | 0.112   |
| IMPO                    | –0.4 ± 26.6          | 18.6 ± 44.5             | 0.176   |
| Last follow-up          | 20.9 ± 23.0          | 88.9 ± 53.0             | 0.016*  |
| Thoracic kyphosis (°, mean ± SD) |     |                         |         |
| Preoperative            | 4.0 ± 16.1           | –0.7 ± 12.3             | 0.505   |
| IMPO                    | 14.9 ± 14.8          | 9.3 ± 8.0               | 0.264   |
| Last follow-up          | 19.5 ± 13.2          | 5.4 ± 9.4               | 0.005*  |
| Thoracolumbar junction (°, mean ± SD) |     |                         |         |
| Preoperative            | –9.7 ± 6.7           | –9.7 ± 7.4              | 0.981   |
| IMPO                    | –3.9 ± 11.8          | –0.6 ± 11.6             | 0.479   |
| Last follow-up          | –4.2 ± 9.4           | 16.0 ± 16.1             | 0.004*  |
| LL (°)                  |                      |                         |         |
| Preoperative            | 4.4 ± 15.1           | 4.2 ± 23.2              | 0.639   |
| IMPO                    | –48.1 ± 4.6          | –35.0 ± 12.9            | 0.007*  |
| Last follow-up          | –45.2 ± 4.4          | –20.7 ± 14.7            | <0.001* |
| Estimated - ideal       | –49.6 ± 5.0          | –56.1 ± 8.0             | 0.015*  |
| Postoperative - ideal   | 1.5 ± 5.7            | 21.1 ± 10.3             | <0.001* |
| Fused segments angle (°, mean ± SD) |     |                         |         |
| Preoperative            | 2.2 ± 7.4            | 5.2 ± 20.6              | 0.088   |
| IMPO                    | –44.4 ± 5.4          | –40.3 ± 9.9             | 0.227   |
| Last follow-up          | –42.7 ± 5.3          | –38.1 ± 10.4            | 0.200   |
| Lumbosacral junction (°, mean ± SD) |     |                         |         |
| Preoperative            | 2.3 ± 8.8            | 1.3 ± 21.3              | 0.901   |
| IMPO                    | –35.3 ± 11.1         | –32.5 ± 12.7            | 0.556   |
| Last follow-up          | –34.3 ± 12.8         | –26.7 ± 15.0            | 0.168   |
| Pelvic incidence (°, mean ± SD) | 44.1 ± 6.9          | 53.8 ± 11.0             | 0.009*  |
| Pelvic tilt (°, mean ± SD) | 28.4 ± 14.1          | 42.5 ± 12.6             | 0.013*  |
| Preoperative            | 15.3 ± 8.1           | 21.4 ± 11.6             | 0.079   |
| IMPO                    | 17.2 ± 11.5          | 32.3 ± 11.7             | 0.001*  |
| PT ratio (PT/PI × 100%, mean ± SD) | 62.5 ± 23.9          | 83.0 ± 12.6             | 0.059   |
| Sacral slope (°, mean ± SD) | 31.9 ± 14.5          | 39.0 ± 22.4             | 0.328   |
| Preoperative            | 32.5 ± 18.6          | 54.8 ± 18.9             | 0.003*  |
| IMPO                    | 15.7 ± 10.0          | 10.8 ± 17.5             | 0.358   |
| Last follow-up          | 32.3 ± 8.0           | 35.5 ± 15.3             | 0.534   |
| PJK prevalence          | 32.7 ± 9.5           | 26.9 ± 11.3             | 0.159   |
| Patients with PJK (11 cases) | 12.6%              | 8 (72.7%)               | 0.008*  |
| Postoperative SVA (cases) |                      |                         |         |
| Optimal (25)            | 16                   | 9                       | 0.156†  |
| Suboptimal (2)          | 0                    | 2                       |         |
| Correction (cases)      |                      |                         |         |
| Overcorrection (7)      | 0                    | 0                       | 0.021*† |
| Undercorrection (20)    | 9                    | 11                      |         |
| PJK (°, mean ± SD)      |                      |                         |         |
| Preoperative            | –3.2 ± 7.7           | –4.1 ± 3.4              | 0.671   |
| IMPO                    | –2.7 ± 5.9           | 4.0 ± 11.1              | 0.152   |
| Last follow-up          | 1.5 ± 9.9            | 17.7 ± 11.6             | 0.001*  |

Data represent the mean values for each group; SVA, sagittal vertical axis; IMPO, immediate postoperative; PT, pelvic tilt; PI, pelvic incidence; PJK, proximal junctional kyphosis; PJA, proximal junctional angle; * Statistically significant (P-value <0.05); † Fisher’s exact test.

### Statistical Analysis

For continuous variables, analysis of variance with an unpaired t-test was used for variables with normality, and Wilcoxon’s rank sum test was used for variables without normality. Categorical variables were assessed using the Fisher’s exact test to evaluate every considerable risk factor (SAS 9.3, SAS Institute Inc., Cary, MC, USA). A P-value of <0.05 was considered statistically significant. Inter-observer reliability was calculated with Fleiss’ kappa statistics or intraclass correlation coefficient (ICC) as appropriate for each radiological measurement. ICC values for all radiographic parameters exceeded 0.90.
Results

Baseline Characteristics of the Patients
At the time of the study, the database included 78 surgical patients and, based on the inclusion criteria, 27 patients were selected for analysis. The average age at the time of surgery was 66.6 years, and the average follow-up period was 109.7 months. In these patients, combined ACR with short PSF were performed, and the mean number of fused segments was 3.7. The UIV was L2 in 18 patients or L3 in nine

| TABLE 2 Radiographic and PJK parameters between the low PI and high PI groups |
|--------------------------------------------------------------------------------|
| Radiographic parameters | Low PI (<50°) (n = 17) | High PI (> 50°) (n = 10) | P-value |
|--------------------------|-------------------------|--------------------------|---------|
| SVA (mm, mean ± SD)      |                         |                          |         |
| Preoperative             | 146.1 ± 59.9            | 131.1 ± 74.4             | 0.568   |
| IMPO                     | 3.84 ± 27.2             | 13.5 ± 47.5              | 0.566   |
| Last follow-up           | 42.0 ± 53.1             | 59.9 ± 46.1              | 0.167   |
| Thoracic kyphosis (°, mean ± SD) |             |                          |         |
| Preoperative             | 0.8 ± 12.6              | 4.2 ± 18.0               | 0.561   |
| IMPO                     | 12.2 ± 11.2             | 13.5 ± 15.2              | 0.796   |
| Last follow-up           | 16.2 ± 12.1             | 9.6 ± 15.5               | 0.166   |
| Thoracolumbar junction (°, mean ± SD) |             |                          |         |
| Preoperative             | −10.6 ± 8.2             | −9.7 ± 7.4               | 0.311   |
| IMPO                     | −4.2 ± 10.7             | −0.6 ± 11.6              | 0.321   |
| Last follow-up           | 0.5 ± 15.5              | 10.0 ± 15.6              | 0.138   |
| LL (°, mean ± SD)        |                         |                          |         |
| Preoperative             | 4.8 ± 15.1              | 3.5 ± 24.0               | 0.633   |
| IMPO                     | −42.1 ± 11.7            | −43.9 ± 10.2             | 0.979   |
| Last follow-up           | −36.4 ± 18.5            | −33.1 ± 9.6              | 0.093   |
| Estimated - ideal        | 48.0 ± 3.4              | 59.5 ± 5.4               | < 0.001* |
| Postoperative - ideal    | 5.9 ± 12.3              | 15.6 ± 10.8              | 0.019*   |
| Fused segments angle (°, mean ± SD) |             |                          |         |
| Preoperative             | 4.5 ± 9.2               | 1.6 ± 20.3               | 0.980   |
| IMPO                     | −40.6 ± 6.6             | −46.4 ± 8.5              | 0.058   |
| Last follow-up           | −38.8 ± 7.7             | −44.3 ± 7.6              | 0.082   |
| Lumbosacral junction (°, mean ± SD) |             |                          |         |
| Preoperative             | 5.7 ± 11.6              | −4.5 ± 17.9              | 0.901   |
| IMPO                     | −32.4 ± 10.5            | −37.1 ± 13.4             | 0.556   |
| Last follow-up           | −30.6 ± 12.3            | −32.2 ± 17.1             | 0.168   |
| Pelvic incidence (°, mean ± SD) |             |                          |         |
| Preoperative             | 41.8 ± 4.7              | 58.7 ± 6.6               | < 0.001* |
| Pelvic tilt (°, mean ± SD) |             |                          |         |
| Preoperative             | 28.4 ± 12.3             | 43.9 ± 14.7              | 0.006*   |
| IMPO                     | 16.2 ± 7.8              | 20.5 ± 12.8              | 0.288   |
| Last follow-up           | 18.1 ± 10.1             | 32.2 ± 14.8              | 0.007*   |
| PT ratio (PT/PI × 100%, mean ± SD) |             |                          |         |
| Preoperative             | 68.0 ± 30.0             | 75.6 ± 24.8              | 0.506   |
| IMPO                     | 35.8 ± 17.2             | 33.1 ± 20.3              | 0.709   |
| Last follow-up           | 36.5 ± 20.3             | 50.3 ± 19.8              | 0.102   |
| Sacral slope (°, mean ± SD) |             |                          |         |
| Preoperative             | 13.5 ± 12.4             | 14.2 ± 15.9              | 0.782   |
| IMPO                     | 29.4 ± 9.0              | 40.8 ± 11.7              | 0.009*   |
| Last follow-up           | 30.2 ± 10.4             | 30.6 ± 11.1              | 0.926   |
| PJK prevalence (cases)   |                         |                          |         |
| Patients with PJK (11)   | 4 (23.5%)               | 7 (70%)                  | 0.040*   |
| Postoperative SVA (cases)|                         |                          |         |
| Optimal (2S)             | 17                      | 8                        | 0.128*   |
| Suboptimal (2)           | 0                       | 2                        |         |
| Correction (cases)       |                         |                          |         |
| Overcorrection (7)       | 6                       | 1                        | 0.204*   |
| Undercorrection (20)     | 11                      | 9                        |         |
| PJA (°, mean ± SD)       |                         |                          |         |
| Preoperative             | −4.7 ± 6.3              | −1.7 ± 6.0               | 0.231   |
| IMPO                     | −2.5 ± 7.0              | 3.6 ± 10.3               | 0.119   |
| Last follow-up           | 4.7 ± 14.5              | 13.9 ± 8.4               | 0.023*   |

Data represent the mean values for each group; PI, pelvic incidence; SVA, sagittal vertical axis; IMPO, immediate postoperative; PT, pelvic tilt; PJK, proximal junctional kyphosis; PJA, proximal junctional angle; LL, Lumbar lordosis; * Statistically significant (P-value <0.05); † Fisher’s exact test.
patients. For the lowest instrumented vertebra (LIV), fusion was performed to the sacrum by using pedicle screws in all patients and sacropelvic fixation was performed by using iliac screws in three patients. Surgical correction included anterior lumbar interbody fusion (ALIF, \( n = 27, 99 \) segments) and PCO.

Radiographic Parameters: Optimal SVA Group vs Suboptimal SVA Group

There was no significant difference in the angle of fused segments between the two groups postoperatively \( (P = 0.227) \) and at the last follow-up \( (P = 0.200) \). The corrected LL was 1.5° less than the ideal LL in the optimal SVA group and was 21.1° less than the ideal LL in the suboptimal SVA group \( (P < 0.05) \). LL was significantly different between the two groups postoperatively \( (P = 0.007) \) and at the last follow-up \( (P < 0.05) \) (Table 1).

There were no significant differences in TK and TL between the two groups preoperatively, postoperatively; however, at the last follow-up there was a significant difference between the two groups (TK: \( P = 0.005 \); TL: \( P = 0.004 \)). TK and TL of the optimal SVA group improved at final follow-up, but TK and TL of the suboptimal SVA group decreased from 9.3° to 5.4° and from −0.6° to +16.0°, respectively.

Regarding pelvic parameters, there was significant difference in the preoperative PI and PT between the two groups (PI: \( P = 0.009 \); PT: \( P = 0.013 \)). There was no significant difference in PT postoperatively \( (P = 0.079) \), however there was a significant difference at the last follow-up \( (P = 0.001) \) showing that suboptimal SVA group was significantly greater PT by a greater postoperative increase compared to that of the optimal SVA group.

PJL Parameters: Optimal SVA vs Suboptimal SVA Groups

The overall prevalence of PJL was 41% (11/27 patients), and the prevalence was 19% (3/16) in the optimal SVA group.

Fig. 1 (A) Preoperative whole spine lateral radiograph of a 60-year-old female with degenerative sagittal malalignment (TK −20°, TL −14°, LL 8°, PI 50°, SVA 55 mm, estimated LL calculated by Korean version of Legaye formula −54°). (B) Postoperative whole spine lateral radiograph taken after ACR with posterior instrumentation and fusion at L2-S1 leading to a correction of lumbar lordosis (LL) of −44° (10° undercorrection compared to the estimated ideal LL) and a decrease in SVA (−51 mm). The preoperative PJA increased to −6° postoperatively (TK −3°, TL −14°). (C) Postoperative 5-year radiograph showing a hypokyphotic thoracic curve (TK −1°) and an increase in SVA (2 mm) with decrease in TL (−1°) and LL (−23°). (D) Postoperative 6-year radiograph showing a hypokyphotic thoracic curve (TK 2°) and an increase in SVA (172 mm) with decrease in TL (10°) and LL (−7°).
and 73% (8/11) in the suboptimal SVA group, which was significantly different ($P = 0.008$). There was no significant difference in PJA between the two groups preoperatively ($P = 0.671$), postoperatively ($P = 0.152$), however, there was a significant difference at the last follow-up ($P = 0.001$) with significant prevalence of PJK (Figure 1 and Table 1).

Oversstribution was seen in seven patients in the optimal SVA group (Figure 2), whereas all of the patients of the suboptimal SVA group were in the category of underscorrection with significant difference ($P = 0.021$).

**Spinopelvic Parameters: Low PI Group vs High PI Group**

As shown in Table 2, further evaluation was divided into the following two groups based on the preoperative PI: low PI group (PI <50°) and high PI group (PI >50°). There was no significant difference in fused segment angle between the two groups preoperatively ($P = 0.980$), postoperatively ($P = 0.058$), and at the last follow-up ($P = 0.082$).

The mean LL values in the low PI and high PI groups were $4.8°$ and $3.5°$ preoperatively, $-42.1°$ and $-43.9°$ postoperatively, and $-36.4°$ and $-33.1°$ at the last follow-up, respectively. The corrected LL was $5.9°$ less than the ideal LL in the low PI group and was $15.6°$ less than the ideal LL in the high PI group ($P = 0.019$). LL was not significantly different between the two groups preoperatively ($P = 0.633$), postoperatively ($P = 0.979$), and at the last follow-up ($P = 0.093$).

There was no significant difference in TK, TL, and LS between the two groups preoperatively (TK: $P = 0.561$; TL: $P = 0.311$; LS: $P = 0.901$), postoperatively (TK: $P = 0.796$; TL: $P = 0.321$; LS: $P = 0.556$), and at the last follow-up (TK: $P = 0.166$; TL: $P = 0.138$; LS: $P = 0.168$).
Comparison of Clinical Outcome Assessment

The preoperative ODI and VAS scores (back pain and leg pain) did not show differences between the optimal SVA group and suboptimal SVA group. And postoperative and last follow-up VAS for leg pain did not show differences between the two groups. But last follow-up VAS for back pain and postoperative and last follow-up ODI were statistically larger for the suboptimal group than the optimal group (P < 0.05) (Table 3).

The VAS scores (back pain and leg pain) did not show differences between the low PI group and the high PI group preoperatively, postoperatively, and at the last follow-up. The preoperative ODI did not show differences between the two groups, but postoperative and last follow-up ODI (P = 0.003 and P = 0.036) were statistically larger for the high PI group than the low PI group.

Complications

There were no permanent neurological, vascular, or visceral injuries including cerebrospinal fluid leakage, abdominal hernia, wound infection, or pseudarthrosis. However, there were transient complications including lower extremity symptoms related to sympathetic chain injury (one case), postoperative ileus (two cases), and ipsilateral psoas paresis (one case). After the conservative treatment, these transient complications have returned to normal over time (sympathetic chain injury 4 months, postoperative ileus 2 weeks, and ipsilateral psoas paresis 3 months).

Discussion

ACR and short posterior spinal fusion in ASD with degenerative causes (DLK) has not been reported in Western countries, but is one of the most common in Asian countries because of different lifestyles and working posture. DLK is a pure positive sagittal malalignment causing...
serious disability in daily life. Most patients revealed marked atrophy of the back musculature on magnetic resonance imaging and characteristic clinical features: stooping with walking difficulty; inability to lift heavy objects in front; difficulty in climbing slopes; and the need to support oneself with the elbow when working in the kitchen, resulting in the formation of a hard corn on the extensor surface of the elbow.54,50

Appropriate surgical correction of ASD with sagittal imbalance may affect arthrodesis of fused segments and contribute to adjacent segment degeneration of unfused mobile vertebrae, and proper correction of optimal LL is essential to prevent sagittal decompensation. A variety of reconstructive surgeries can be performed to restore normal sagittal balance in ASD patients, and some of these surgeries, such as three column osteotomies, are highly specialized and complex, with a high risk of complications.2,24,50

It is important to find an optimal indication for a shorter fusion level for achieving optimal correction with lesser complications; this is because every patient with lower lumbar kyphosis and compensatory TL lordosis does not need to undergo long fusion from the sacrum to the thoracic spine and does not require a UIV up to the thoracic spine or corrective osteotomies, such as PSO, for obtaining sagittal balance from correction of lower LL.23,36

Although surgeons can predict the postoperative sagittal balance based on the correlation between the PI and LL, which plays key roles in both achieving neutral or negative sagittal balance and preventing sagittal decompensation2,3,5, there are controversies in determining the amount of lordosis correction due to an increased risk of PJK.21,22,43 Thus, the LL obtained after a short PSF and PCO following ACR may be less or optimal considering the patient’s PI. In our study, considering the amount of LL correction from the ideal LL, overcorrection was seen in only seven patients in all patients that showed less deformity correction compared with three column osteotomies. However, ratio of over correction to under correction was significantly greater in the optimal SVA group than in the suboptimal group. Additionally, the optimal SVA group showed significantly lower prevalence of PJK and lesser PJA with greater postoperative LL, which correlates to previous studies with regard to the importance of postoperative LL in restoring normal sagittal balance and preventing sagittal decompensation.3,37

According to previous reports regarding ACR, the amount of LL correction ranges from 5° to 29°,54–56, which seems to be a limitation in surgically treating ASD with degenerative sagittal malalignment.55 In our study, however, a short PSF with PCO and ACR including anterior release allowed to achieve more LL correction (47.1°) than previous reports 59 with 46.1° of fused segment angle.

Optimal SVA Group vs Suboptimal SVA Group

Regarding the sagittal balance, postoperative sagittal balance showed no statistical difference in both groups; however, the suboptimal SVA group showed a significant increase in the ratio of PT to PI at the last follow-up, which demonstrated the insufficiency of LL correction resulting in delayed sagittal decancellation and compensatory pelvic retroversion at the last follow-up. Also, the hypokyphotic thoracic curve at the last follow-up of the suboptimal SVA group seems to be compensatory following delayed sagittal decompensation. Additionally, the optimal SVA group showed significantly greater TL lordosis and TK at the last follow-up, which seems to be a restoration of a natural thoracic kyphosis following an increase in LL as seen in the results of previous studies.36

Low PI Group vs High PI Group

In our study, the average postoperative lordosis angle of fused segments of the optimal SVA group was −44.4° and the preoperative TL lordosis was −9.7°, meaning that the maximal theoretical average LL that could be obtained would be 54.1°. The PI for an ideal LL of 54.1° was calculated to be approximately 50° by the Korean version of the Legaye formula (SS = 0.80 + 0.74 × PI, and ideal [maximal] LL = 17.42 + 0.96 × SS).37 Therefore, further evaluation was done by dividing the group into the low PI group (PI <50°) and high PI group (PI >50°). The high PI group showed significantly higher prevalence of PJK with greater PJA and a higher ratio of suboptimal balance compared to the low PI group, with no significant differences in postoperative and last follow-up for LL, TL junction, and TK. The results may be due to lesser correction of postoperative LL in the high PI group, which was insufficient to fulfill the required amount of LL considering higher PI.

Although the postoperative and last follow up PT ratio (PT/PI) showed no statistical difference between the low PI and high PI groups, there was a significant increase in the ratio of PT to PI in the high PI group in contrast to the low PI group, which may demonstrate insufficient LL correction in the high PI group compared to the low PI group. The insignificant results of comparing the ratio of PT to PI in both groups seems to originate from the relatively smaller proportion of overcorrection as a whole (7/27, 26%), and a lesser amount of postoperative LL compared to the estimated ideal LL.

Limitations

This study has some limitations. Previous studies revealed the possibility of short PSF combined with ACR as a treatment option in degenerative sagittal imbalance with compensated thoracic curve. However, the indication for this surgical correction should also include a PI less than 50°, and there is the limitation of obtaining sufficient LL after short level fusions, even with the addition of PCO other limitations of our study include the relatively small number of patients in both groups, which is expected that further future studies will remedy.

Conclusion

In conclusion, combined ACR with short PSF and PCO could effectively prevent sagittal decompensation of PJK and help achieve sagittal balance in the treatment of ASD patients with lower lumbar kyphosis, TL compensation, and especially low PI (less than 50°).
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