Neurospine 2024;21(2):721-731.
https://doi.org/10.14245/ns.2448250.125

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

Corresponding Author
Dong-Ho Kang
https://orcid.org/0000-0002-9114-0150

Department of Orthopedic Surgery, Samsung Medical Center, 81 Ilwon-ro, Gangnam-gu, Seoul 06351, Korea
Email: kang9451@gmail.com

Received: March 10, 2024
Revised: April 16, 2024
Accepted: April 28, 2024

Comparison of Surgical Burden, Radiographic and Clinical Outcomes According to the Severity of Baseline Sagittal Imbalance in Adult Spinal Deformity Patients

Se-Jun Park[1], Jin-Sung Park[1], Dong-Ho Kang[1], Hyun-Jun Kim[1], Yun-Mi Lim[1], Chong-Suh Lee[2]

[1]Department of Orthopedic Surgery, Spine Center, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea
[2]Department of Orthopedic Surgery, Haeundae Bumin Hospital, Busan, Korea

Objective: To determine the clinical impact of the baseline sagittal imbalance severity in patients with adult spinal deformity (ASD).
Methods: We retrospectively reviewed patients who underwent ≥5-level fusion including the pelvis, for ASD with a ≥2-year follow-up. Using the Scoliosis Research Society-Schwab classification system, patients were classified into 3 groups according to the severity of the preoperative sagittal imbalance: mild, moderate, and severe. Postoperative clinical and radiographic results were compared among the 3 groups.
Results: A total of 259 patients were finally included. There were 42, 62, and 155 patients in the mild, moderate, and severe groups, respectively. The perioperative surgical burden was greatest in the severe group. Postoperatively, this group also showed the largest pelvic incidence minus lumbar lordosis mismatch, suggesting a tendency towards undercorrection. No statistically significant differences were observed in proximal junctional kyphosis, proximal junctional failure, or rod fractures among the groups. Visual analogue scale for back pain and Scoliosis Research Society-22 scores were similar across groups. However, severe group's last follow-up Oswestry Disability Index (ODI) scores significantly lower than those of the severe group.
Conclusion: Patients with severe sagittal imbalance were treated with more invasive surgical methods along with increased the perioperative surgical burden. All patients exhibited significant radiological and clinical improvements after surgery. However, regarding ODI, the severe group demonstrated slightly worse clinical outcomes than the other groups, probably due to relatively higher proportion of undercorrection. Therefore, more rigorous correction is necessary to achieve optimal sagittal alignment specifically in patients with severe baseline sagittal imbalance.

Keywords: Adult spinal deformity, Baseline severity, Sagittal imbalance, Clinical outcome, Radiographic outcome, Deformity correction

INTRODUCTION

Adult spinal deformity (ASD) is a debilitating condition associated with sagittal malalignment causing substantial pain and functional disability.[1-4] It is well known that increased sagittal deformity leads to worse health-related quality of life.[5-7] Therefore, the optimal restoration of spinopelvic malalignment has been a cornerstone of surgical management for ASD for

achieving good clinical outcomes.[8,9] Several authors have suggested the optimal surgical targets, including Scoliosis Research Society (SRS)-Schwab classification, age-adjusted sagittal alignment goals, and Global Alignment and Proportion (GAP) score.[10-12] Although these systems have their own correction targets, the common determinant factors are patient's age and pelvic incidence (PI). Therefore, the current guidelines will propose the same surgical target without considering of the severity of baseline sagittal imbalance in patients of the same age and PI.

ASD is a disease entity with a wide spectrum of severity. For patients with mild sagittal deformity, only a small gap exists between the current sagittal imbalance status and the surgical target. Therefore, less-morbid surgery may be sufficient to achieve optimal sagittal correction. In contrast, patients with severe sagittal imbalance will have a larger gap to the desired correction target from the current deformity status, frequently necessitating more complicated surgery, thereby increasing the perioperative surgical burden such as operation time, perioperative morbidity, and length of hospital stay.[13] However, it is undetermined how the effect of severity of baseline sagittal imbalance on the clinical outcomes after corrective surgery for ASD remained undetermined. We hypothesized the clinical outcomes would not be inferior, even in patients with severe baseline sagittal imbalance, if the correction was performed successfully. In the current study, we aimed to determine the clinical impact of the baseline sagittal imbalance severity by comparing various perioperative and postoperative outcomes among the patients with mild, moderate, and severe baseline sagittal imbalances.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Samsung Medical Center (2024-03-027). The requirement for informed consent was waived due to the retrospective nature of this study.

1. Study Cohort

This was a retrospective case series study based on records retrieved from a prospective ASD database at Samsung Medical Center. The study cohort included consecutive patients who underwent surgery for degenerative-type ASD between 2012 and 2021. Patient inclusion criteria were as follows: ≥60 years of age; ASD radiographically defined by C7 sagittal vertical axis (SVA) ≥50 mm, PI–lumbar lordosis (LL) mismatch ≥10°, or pelvic tilt (PT) ≥25° or coronal Cobb angle ≥30°; and ≥5 fused vertebral levels from the sacrum, all including the pelvis with iliac fixation. The severity of baseline sagittal imbalance was determined based on the SRS-Schwab classification. The SRS-Schwab classification consists of 3 sagittal modifiers of PI–LL mismatch, SVA, and PT.[12] Each sagittal modifier was graded as 0 (<10°), + (10°–20°), ++ (>20°) for PI–LL mismatch, 0 (<40 mm), + (40–95 mm), ++ (>95 mm) for SVA, and 0 (<20°), + (20°–30°), ++ (>30°) for PT. Scores were assigned to each item of the sagittal modifiers, for example, 0 points for grade 0; 1 point for grade +; and 2 points for grade ++. By modifying the previously reported categorization of baseline sagittal imbalance using the SRS-Schwab classification,[14,15] patients were classified into 3 groups: mild (score: 1 or 2 points), moderate (score: 3 or 4 points), and severe (score: 5 or 6 points). No patients had a total score of 0 point.

More than 2-years of follow-up with complete radiographic, and patient-reported outcome measure (PROM) data were required for inclusion. Patients were excluded if they lacked appropriate radiographs; had not completed the PROM questionnaire at the final follow-up; had undergone previous thoracic or lumbar fusion surgery; or had syndromic, neuromuscular, inflammatory, or other pathological, rather than degenerative, conditions.

2. Collected Data

The demographic data included age, sex, body mass index (BMI), T score, and American Society of Anesthesiologists (ASA) physical status classification grade. Variables related to the surgical technique included total fusion level, oblique lumbar interbody fusion (OLIF), anterior column realignment (ACR), usage of additional rods, cement augmentation in uppermost instrumented vertebra (UIV), and 3-column osteotomy. The perioperative variables included operation time, estimated blood loss, number of red blood cells (RBCs) transfused, intensive care unit (ICU) admission, length of hospital stay, incidence and causes of return to the operating room during the hospital stay, and postoperative medical complications.

Standing posteroanterior and lateral whole-spine radiographs were analyzed at baseline and immediately after surgery (approximately 1 week postoperatively) to measure the following radiographic parameters: PI, LL, PI–LL mismatch, sacral slope (SS), PT, thoracic kyphosis (TK), T1 pelvic angle (TPA), and SVA. For the posteroanterior and lateral whole-spine radiographs, all patients positioned their hands on their shoulders. In addition to postoperative comparison of absolute values of sagittal parameters, the appropriateness of surgical correction

 https://doi.org/10.14245/ns.2448250.125

was evaluated with regard to how much the postoperative sagittal alignment met the correction target of the legacy systems such as SRS-Schwab classification, age-adjusted sagittal alignment goals, and GAP score.[10-12] SRS-Schwab classification was previously described in study cohort section. The ideal age-adjusted PI–LL was calculated using a previously reported formula: PI–LL = (age–55 years)/2+3.[16] Then, based on the offset value between actual PI–LL and ideal PI–LL values, the patients were divided into the following 3 groups: undercorrection (offset $>10°$), matched correction (offset within $\pm 10°$), and overcorrection (offset $<-10°$). Finally, the GAP score is expressed as the total score of relative pelvic version, relative lumbar, lordosis distribution index, relative spinopelvic alignment, and age, ranging from 0 to 13 points.[10] Three groups were created according to the total score as follows: proportioned (score, 0–2), moderately disproportioned (score, 3–6), and severely disproportioned (score, ≥7).

Mechanical failures such as proximal junctional complications and rod fractures were recorded. Proximal junctional kyphosis (PJK) was defined as a proximal junctional angle (PJA) of $\geq 10°$ and increase of PJA $\geq 10°$ compared to preoperative PJA.[17] Proximal junctional failure (PJF) indicated fracture at the UIV or UIV+1, failure of UIV fixation, myelopathy, or any reasons of revision surgery.[17]

Clinical outcomes were compared using 3 PROM questionnaires, namely, the visual analogue scale (VAS) for the back pain, Oswestry Disability Index (ODI), and the SRS-22 questionnaire (SRS-22) scores. Preoperative and final PROM questionnaires were used for analysis. In addition, we compared the proportion of patients achieving minimal clinically important difference (MCID) in VAS, ODI, and SRS-22 at the last follow-up. The MCID values used in the current study were 1.2 for VAS, 12.8 for ODI.[18] For SRS-22, the MCID values were 1.05 for function, 0.85 for pain, 1.05 for appearance, 0.70 for mental, and 1.05 for subtotal, respectively.[19]

3. Statistical Analysis

Data are presented as frequencies with percentages for categorical variables and as means with standard deviations for continuous variables. Comparisons of variables among the 3 groups were performed using chi-square or Fisher exact tests for categorical variables and analysis of variance with a *post hoc* test (Tukey test) for continuous variables. Statistical analyses were conducted by professional statisticians using IBM SPSS Statistics ver. 27.0 (IBM Co., Armonk, NY, USA). A p-value <0.05 was considered statistically significant.

RESULTS

A total of 259 patients met the inclusion criteria and were included in the study cohort. The mean age was 69.0 years and 225 patients (86.9%) were female. There were 42, 62, and 155 patients in the mild, moderate, and severe groups, respectively (Table 1). There were more female patients, and the T score was significantly less, in the severe group. There were no differences in age, BMI, or ASA physical status classification grade among the 3 groups. With regard to operative variables, the number of fusion levels differed significantly among the 3 groups (6.1, 7.2, and 7.5, respectively; $p=0.001$). Significantly more patients underwent OLIF surgery at L5–S1, ACR, cement augmentation in UIV, and 3-column osteotomy as the severity of baseline sagittal imbalance increased ($p=0.048$, $p<0.001$, $p=0.041$, and $p=0.001$, respectively). The operation time, total number of RBC transfusion, and number of patients requiring ICU care were significantly greater in the severe group ($p=0.004$, $p=0.031$, and $p=0.027$, respectively). The length of hospital stay was significantly longer in the severe group than in the mild group ($p=0.049$). None of the patients in the mild group required revision surgery during their hospital stay; however, the inpatient revision rate was not statistically significant. There were no cases of revision surgery due delayed complication other than PJF or rod fracture after discharge in both groups. Moreover, there were no significant differences in postoperative medical complications among the 3 groups.

With regard to radiographic parameters, the PI was significantly smaller in the mild group than in the severe group (50.9° vs. 55.2°, $p=0.023$) (Table 2). Other preoperative sagittal parameters showed significant differences among the 3 groups in terms of LL, PI–LL, SS, PT, TK, TPA, and SVA. There were no significant differences in the postoperative LL, SS, PT, TPA, or SVA. However, the postoperative PI–LL mismatch was significantly greater in the severe group (2.6°, 4.9°, and 8.4°, respectively; $p=0.003$), and the postoperative TK was the smallest in the severe group. Postoperative changes in all sagittal parameters were significantly greater in the severe group. With regard to the SRS-Schwab classification, significantly more patients achieved a sagittal modifier grade 0 of PI–LL mismatch in the mild group than the other groups ($p=0.033$) (Fig. 1). However, there were no differences in number of patients with regard to sagittal modifier grades of PT or SVA. There were more patients with undercorrection relative to age-adjusted PI–LL targets in the severe group (Fig. 2). No significant differences were found in patient distribution relative to the GAP score (Fig. 3).

Table 1. Comparison of the demographics and operative variables among the 3 groups

Variable	Mild group (n = 42)	Moderate group (n = 62)	Severe group (n = 155)	p-value	p-value (subanalyses between groups)
Age (yr)	67.7 ± 7.5	69.5 ± 5.8	69.1 ± 6.2	0.312	NA
Female sex	29 (69.0)	49 (79.0)	147 (94.8)	< 0.001**	B: < 0.001**, C: 0.001**
BMI (kg/m^2)	24.9 ± 2.6	25.5 ± 2.8	25.6 ± 3.4	0.450	NA
T score (g/cm^2)	-1.1 ± 1.5	-1.1 ± 1.6	-1.7 ± 1.3	0.010*	B: 0.022*, C: 0.012*
ASA PS classification grade	1.9 ± 0.6	2.0 ± 0.4	2.1 ± 0.5	0.412	NA
No. of fused levels	6.1 ± 2.0	7.2 ± 2.0	7.5 ± 2.2	0.001**	A: 0.014*, B: < 0.001**
OLIF at L5–S1	14 (33.3)	27 (43.5)	82 (52.9)	0.048*	B: 0.036*
OLIF at or above L4–5	23 (54.8)	40 (64.5)	80 (51.6)	0.225	NA
ACR	2 (4.8)	15 (24.2)	78 (50.3)	< 0.001**	A: 0.013*, B: < 0.001**, C: < 0.001**
Additional rod	2 (4.8)	2 (3.2)	18 (11.6)	0.086	NA
Cement augmentation in UIV	4 (9.5)	10 (16.1)	40 (25.8)	0.041*	B: 0.025*
Three-column osteotomy	0 (0)	2 (3.2)	25 (16.1)	0.001**	B: 0.003**, C: 0.011*
Operation time (hr)	9.8 ± 2.5	10.8 ± 3.2	11.4 ± 2.7	0.004	B: 0.001**
EBL (L)	1.8 ± 1.1	2.1 ± 2.2	2.1 ± 1.3	0.497	NA
No. of RBC transfused intraoperatively	2.9 ± 2.4	3.8 ± 4.8	4.0 ± 3.4	0.208	NA
No. of RBC transfused postoperatively	1.8 ± 1.4	2.1 ± 1.2	2.2 ± 1.7	0.254	NA
No. of total RBC transfused	4.7 ± 2.9	5.9 ± 5.2	6.3 ± 4.1	0.097	B: 0.031*
ICU admission	6 (14.3)	14 (22.6)	52 (33.5)	0.027*	B: 0.021*
Length of hospital stay (day)	14.1 ± 7.2	15.4 ± 8.6	18.0 ± 13.3	0.082	B: 0.049*
Return to OR during hospital stay	0 (0)	3 (4.8)	7 (4.5)	0.363	NA
Motor weakness (n)	0	1	3		
Wound infection (n)	0	1	4		
Persistent CSF leakage (n)	0	1	0		
Medical complications†	5 (11.8)	7 (11.3)	21 (13.5)	0.889	NA
Arrhythmia (n)	1	2	6		
Cardiovascular shock (n)	1	1	6		
Pulmonary complications (n)	2	2	3		
Gastrointestinal complications (n)	0	2	3		
DVT	1	0	3		

Values are presented as mean ± standard deviation or number (%) unless otherwise indicated.
BMI, body mass index; ASA PS, American Society of Anesthesiologists physical status; OLIF, anterior lumbar interbody fusion; ACR, anterior column realignment; UIV, uppermost instrumented vertebra; EBL, estimated blood loss; RBC, red blood cell; ICU, intensive care unit; OR, operating room; CSF, cerebrospinal fluid; DVT, deep vein thrombosis; NA, not available; A, mild vs. moderate; B, mild vs. severe; C, moderate vs. severe.
*p < 0.05. **p < 0.01. †Postoperative medical complications included the events that required the consultation to the professionals.

There was a trend of increasing PJK and PJF as the baseline severity increased (Table 3). However, no statistically significant differences were found among the 3 groups in terms of PJK and PJF development or revision surgery for PJF (p = 0.270, p = 0.162, and p = 0.799, respectively). The incidence of rod fractures, as well as the revision rate for rod fractures, did not differ among the 3 groups (p = 0.569 and p = 0.265, respectively).

There were no significant differences in the preoperative VAS scores for back pain, ODI, or SRS-22 scores among the 3 groups (Table 4). There were also no differences in the scores at the last follow-up or their postoperative changes in the VAS scores for back pain and SRS-22 scores However, the ODI score at the last follow-up was significantly lower in the mild group than in the severe group (29.6 vs. 37.0, p = 0.019). ODI improvement was

https://doi.org/10.14245/ns.2448250.125

Table 2. Comparison of the radiographic parameters among the 3 groups

Variable	Mild group	Moderate group	Severe group	p-value	p-value (subanalyses between groups)
PI					
Preoperative (°)	50.9 ± 10.4	51.8 ± 10.2	55.2 ± 11.2	0.023*	B: 0.024*, C: 0.038*
Immediate PO (°)	50.8 ± 10.9	51.9 ± 10.8	55.2 ± 10.5	0.018*	B: 0.017*, C: 0.038*
LL					
Preoperative (°)	39.2 ± 11.1	27.2 ± 10.1	7.0 ± 15.9	< 0.001**	A: < 0.001**, B: < 0.001**, C: < 0.001**
Immediate PO (°)	48.1 ± 10.2	46.9 ± 11.1	46.9 ± 12.3	0.834	NA
Change (°)	8.9 ± 8.8	19.7 ± 9.7	39.9 ± 18.3	< 0.001**	A: 0.001**, B: < 0.001**, C: < 0.001**
PI–LL					
Preoperative (°)	11.7 ± 7.1	24.6 ± 2.8	48.2 ± 13.5	< 0.001**	A: < 0.001**, B: < 0.001**, C: < 0.001**
Immediate PO (°)	2.6 ± 7.6	4.9 ± 9.7	8.4 ± 11.5	0.003*	B: 0.002*, C: 0.029*
SS					
Preoperative (°)	28.9 ± 9.2	25.3 ± 9.3	19.0 ± 11.0	< 0.001**	A: 0.048*, B: < 0.001**, C: < 0.001**
Immediate PO (°)	33.1 ± 7.9	33.7 ± 8.1	35.4 ± 10.0	0.231	NA
Change (°)	4.1 ± 6.9	8.4 ± 7.5	16.4 ± 10.9	< 0.001**	A: 0.027*, B: < 0.001**, C: < 0.001**
PT					
Preoperative (°)	22.0 ± 7.1	26.5 ± 6.5	36.5 ± 9.8	< 0.001**	A: 0.011*, B: < 0.001**, C: < 0.001**
Immediate PO (°)	17.7 ± 7.2	18.1 ± 7.4	19.7 ± 9.3	0.277	NA
Change (°)	-4.3 ± 6.5	-8.4 ± 8.0	-16.8 ± 10.8	< 0.001**	A: 0.032*, B: < 0.001**, C: < 0.001**
TK					
Preoperative (°)	29.2 ± 10.2	21.4 ± 10.6	8.3 ± 12.2	< 0.001**	A: 0.001**, B: < 0.001**, C: < 0.001**
Immediate PO (°)	31.1 ± 8.3	28.8 ± 10.2	23.6 ± 10.6	< 0.001**	B: < 0.001**, C: 0.001**
Change (°)	1.9 ± 6.7	7.4 ± 9.4	15.3 ± 12.5	< 0.001**	A: 0.012*, B: < 0.001**, C: < 0.001**
TPA					
Preoperative (°)	19.7 ± 6.1	24.8 ± 5.5	36.0 ± 10.5	< 0.001**	A: 0.017*, B: < 0.001**, C: < 0.001**
Immediate PO (°)	14.3 ± 6.2	14.9 ± 8.3	15.8 ± 9.0	0.517	NA
Change (°)	-4.1 ± 5.7	-9.9 ± 7.6	-20.1 ± 11.8	< 0.001**	A: 0.016*, B: < 0.001**, C: < 0.001**
SVA					
Preoperative (mm)	35.7 ± 29.9	53.7 ± 42.9	88.5 ± 52.3	< 0.001	A: 0.045*, B: < 0.001**, C: < 0.001**
Immediate PO (°)	20.9 ± 34.0	17.0 ± 30.7	17.7 ± 29.4	0.751	NA
Change (mm)	-14.8 ± 40.2	-36.7 ± 50.3	-71.5 ± 52.7	< 0.001**	A: 0.030*, B: < 0.001**, C: < 0.001**

Values are presented as mean ± standard deviation.
PI, pelvic incidence; PO, postoperative; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; TK, thoracic kyphosis; TPA, T1 pelvic angle; SVA, sagittal vertical axis; NA, not available; A, mild vs. moderate; B, mild vs. severe; C, moderate vs. severe.
*$p < 0.05$. **$p < 0.01$.

also higher in the mild group then in the other groups (28.5, 17.8, and 20.4, respectively; $p = 0.029$). Regarding the MCID, there were no significant differences in the number of patients to achieve MCID in VAS, ODI, and all components of SRS-22 such as activity, pain, appearance, mental, and subtotal domains (Table 5). In subgroup analyses, a significantly higher proportion of patients in the mild group achieved the MCID in the ODI compared to the moderate group (78.6% vs. 56.5%, $p = 0.02$). Similarly, a greater percentage of patients in the severe group reached MCID in the appearance score of the SRS-22 questionnaire than in the moderate group (78.1% vs. 56.5%, $p = 0.025$). In the severe group without rod fracture, patients with undercorrection exhibited a higher ODI score at the last follow-up than those with matched or overcorrection; however, this difference was not statistically significant, likely due to the small sample size (41.8 vs. 34.0, $p = 0.063$), and the SRS-22 total score

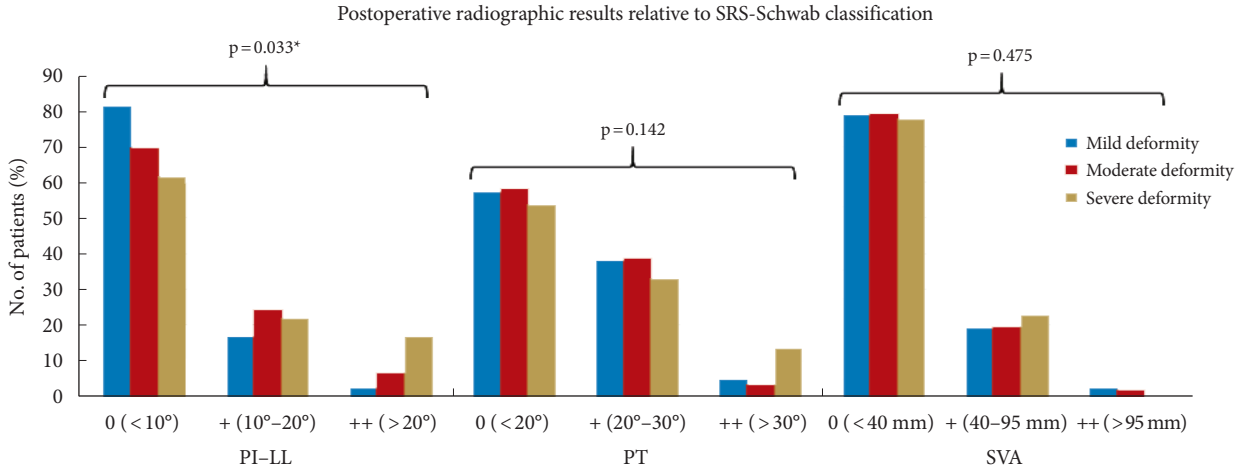

Fig. 1. Comparison of patient distribution relative to the postoperative SRS-Schwab classification among the 3 groups. SRS, Scoliosis Research Society; PI, pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis. *p<0.05.

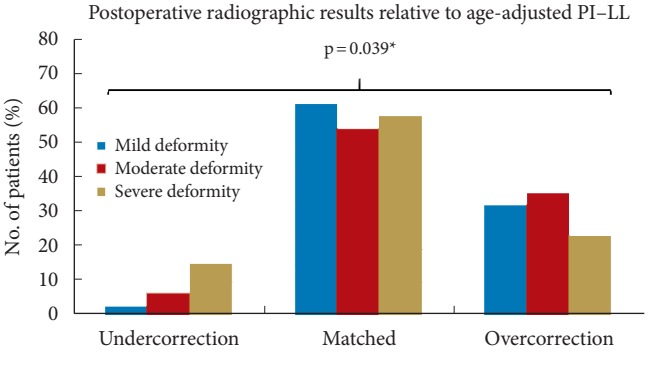

Fig. 2. Comparison of patient distribution relative to the postoperative age-adjusted PI–LL target among the 3 groups. PI, pelvic incidence; LL, lumbar lordosis. *p<0.05.

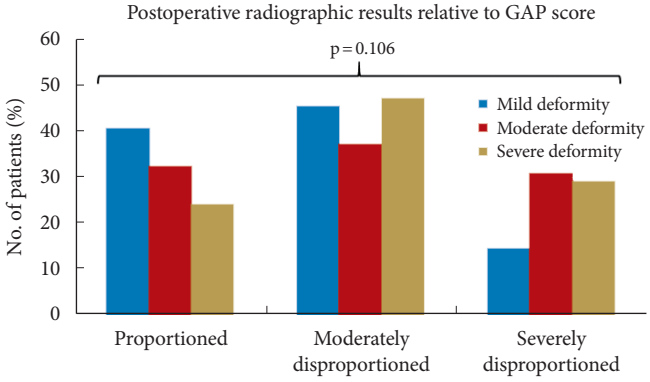

Fig. 3. Comparison of patient distribution relative to the postoperative Global Alignment and Proportion (GAP) score among the 3 groups.

Table 3. Comparison of the mechanical failure among the 3 groups

Variable	Mild group	Moderate group	Severe group	p-value	p-value (subanalyses between groups)
PJK	7 (16.7)	19 (30.6)	41 (26.5)	0.270	NA
PJF	5 (11.9)	15 (24.2)	40 (25.8)	0.162	NA
Revision surgery for PJF	4 (9.5)	7 (11.3)	13 (8.4)	0.799	NA
Time to revision for PJF (mo)	43.6±30.7	31.8±29.9	39.7±44.8	0.869	NA
Rod fracture	9 (21.4)	19 (30.6)	44 (28.4)	0.569	NA
Revision surgery for rod fractures	1 (2.4)	4 (6.5)	15 (10.3)	0.265	NA
Time to revision for rod fracture (mo)	29.5±21.9	37.4±33.9	34.5±31.3	0.664	NA

Values are presented as number (%) or mean±standard deviation.
PJK, proximal junctional kyphosis; PJF, proximal junctional failure; NA, not available.

at the last follow-up was significantly lower in patients with undercorrection compared to those with matched or overcorrection (2.8 vs. 3.5, p=0.013).

Representative cases for patients in the mild and severe groups are illustrated in Figs. 4 and 5, respectively.

https://doi.org/10.14245/ns.2448250.125

Table 4. Comparison of the clinical outcomes among the 3 groups

Variable	Mild group	Moderate group	Severe group	p-value	p-value (subanalyses between groups)
VAS for the back pain					
Preoperative	64.8 ± 24.4	68.2 ± 20.9	71.6 ± 22.4	0.185	NA
At the last follow-up	34.3 ± 26.1	36.5 ± 25.7	35.9 ± 26.3	0.914	NA
Change	-30.5 ± 35.3	-31.8 ± 30.7	-35.7 ± 30.7	0.525	NA
ODI					
Preoperative	58.1 ± 14.9	54.4 ± 16.4	57.4 ± 15.2	0.372	NA
At the last follow-up	29.6 ± 16.6	36.6 ± 18.2	37.0 ± 17.9	0.057	B: 0.019*
Change	-28.5 ± 22.2	-17.8 ± 20.0	-20.4 ± 20.5	0.029*	A: 0.010*, B: 0.025*
SRS-22 total					
Preoperative	2.5 ± 0.5	2.3 ± 0.5	2.3 ± 0.5	0.592	NA
At the last follow-up	3.5 ± 0.8	3.3 ± 0.8	3.4 ± 0.7	0.515	NA
Change	0.9 ± 0.9	0.8 ± 0.8	1.1 ± 0.7	0.163	NA

Values are presented as mean ± standard deviation.
VAS, visual analogue scale; ODI, Oswestry Disability Index; SRS-22, Scoliosis Research Society-22 questionnaire; NA, not available; A, mild vs. moderate; B, mild vs. severe.
*$p < 0.05$.

Table 5. Comparison of the number of patients achieving MCID for VAS, ODI, and SRS-22 at the last follow-up

Variable	Mild group	Moderate group	Severe group	p-value	p-value (subanalyses between groups)
VAS for the back pain (threshold = 1.2)	27 (64.3)	48 (77.4)	121 (78.1)	0.170	NA
ODI (threshold = 12.8)	33 (78.6)	35 (56.5)	106 (68.4)	0.055	A: 0.020*
SRS-22 activity (threshold = 0.85)	18 (42.9)	23 (37.1)	58 (37.4)	0.921	NA
SRS-22 pain (threshold = 0.90)	18 (42.9)	30 (48.6)	84 (54.2)	0.676	NA
SRS-22 appearance (threshold = 1.05)	30 (71.4)	35 (56.5)	121 (78.1)	0.065	C: 0.025*
SRS-22 mental (threshold = 0.70)	24 (57.1)	32 (51.6)	82 (52.9)	0.937	NA
SRS-22 subtotal (threshold = 1.05)	21 (50.0)	28 (45.2)	92 (59.4)	0.388	NA

Values are presented as number (%).
MCID, minimal clinically importance difference; VAS, visual analogue scale; ODI, Oswestry Disability Index; SRS-22, Scoliosis Research Society-22 questionnaire; NA, not available; A, mild vs. moderate; B, mild vs. severe; C, moderate vs. severe.
*$p < 0.05$.

DISCUSSION

Given that a positive sagittal imbalance leads to poor clinical outcome,[6,7] optimal restoration of spinopelvic malalignment is a key factor in achieving good clinical outcomes. Considering that the alignment target is largely determined by the patient's PI and age, patients with a more severe sagittal imbalance may require a more aggressive surgical strategy to reach the desired surgical target. In the current study, we observed that patients in the severe group had a higher probability of undergoing more invasive surgeries, such as OLIF at L5–S1, ACR, and 3-column osteotomy. Neuman et al.[13] reported a surgical invasiveness threshold to predict the odds of major complication. They found that surgical variables, such as 3-column osteotomy, anterior interbody fusion (vs. posterior interbody fusion), iliac fixation, and revision surgery, significantly increased the risk of surgical and medical complications. Samuel et al.[20] conducted a similar study to investigate perioperative morbidity. They observed that a longer operative time was a better predictor of inpatient complications than surgical invasiveness itself. Song et al.[21] also reported that operation time was associated with a higher rate of 30-day morbidity and blood transfusion.

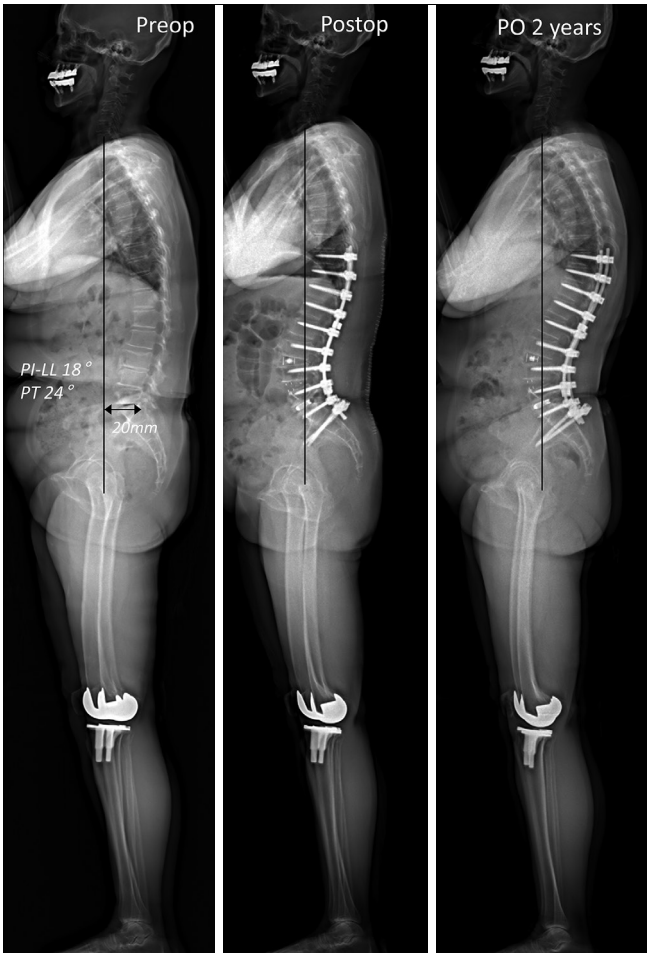

Fig. 4. Representative case of mild sagittal imbalance. A 69-year-old female presented with persistent back pain due to lumbar kyphoscoliosis. Her preoperative sagittal parameters are as follows: PI = 40, LL = 22, PI–LL = 18, PT = 24, SVA = 20 mm (sum of sagittal modifier score = 2). She underwent the corrective surgery using oblique lumbar interbody fusion at L3–5 and posterior lumbar interbody fusion at L5–S1 with T10-pelvis fixation. Her postoperative sagittal parameters are as follows: LL = 45, PI–LL = -5, PT = 6, SVA = 34 mm (sum of sagittal modifier score = 0). PI, pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

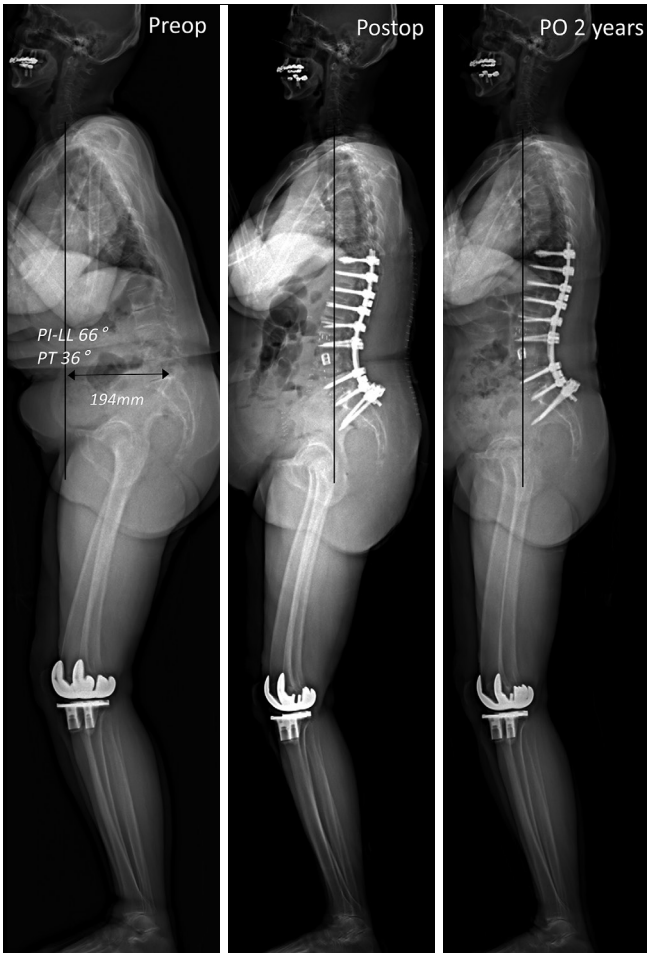

Fig. 5. Representative case of mild sagittal imbalance. A 73-year-old female presented with persistent back pain due to lumbar kyphoscoliosis. Her preoperative sagittal parameters are as follows: PI = 60, LL = -7, PI–LL = 67, PT = 36, SVA = 194 mm (sum of sagittal modifier score = 6). She underwent the corrective surgery using oblique lumbar interbody fusion at L2–3, L4–S1 and corner osteotomy at L3–4 with T10-pelvis fixation. Her postoperative sagittal parameters are as follows: LL = 49, PI–LL = 11, PT = 21, SVA = 24 mm (sum of sagittal modifier score = 2). PI, pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

In the current study, the operation time was significantly longer in the severe group than in the mild group, but the gap between groups was not large with just 1.6 hours. In the current study, there were no cases of return to the operating room due to inpatient surgical complications in the mild group. Although approximately 5% of patients in the moderate and severe groups required revision surgery during their hospital stay, all complications were treated successfully, leaving no permanent deficit. There were no significant differences in medical complications between the groups. Therefore, although surgery in the severe group increased the surgical burden with regard to surgical invasiveness and inpatient morbidity, the complication rate and its treatability were within acceptable ranges.

In the current study, the severity of baseline sagittal imbalance and postoperative changes of all sagittal parameters were clearly distinguished among the 3 groups. We observed that PJK and PJF developed less frequently in the mild group than in the other groups. However, no statistical significance was found for the development of PJK and PJF or revision surgery. The severity of baseline sagittal imbalance and subsequent

https://doi.org/10.14245/ns.2448250.125

postoperative greater change in sagittal deformity are known risk factors for PJK and PJF development.[22-25] However, the appropriateness of postoperative sagittal correction is equally crucial. Our findings indicate no significant differences in achieving matched correction postoperatively among mild, moderate, and severe groups. Furthermore, the severe group had a lower incidence of overcorrection, compared to mild and moderate groups. Considering that overcorrection increases PJF risk,[9,11,25] the lower rate of postoperative overcorrection in severe group could have decreased the incidence of PJF. However, several studies have published contradictory results showing that the amount of correction or the final sagittal alignment did not affect PJK or PJF development.[26,27] Further follow-up studies are required to clarify this discrepancy. The incidence of rod fractures showed a trend similar to that of PJK and PJF. The incidence of rod fracture and the revision rate were lowest in the mild group, but these results did not reach statistical significance in the Fisher exact test or in the intergroup subanalyses. It is currently understood that mechanical failure after ASD surgery is closely associated with the shape of sagittal alignment such as the GAP score, rather than the absolute value of radiographic parameters.[10,28,29] In the current study, we found that GAP score categories did not differ among the groups; therefore, our findings can explain the negative findings of mechanical complication occurrence among the 3 groups.

We observed the greatest postoperative PI–LL value, the fewest patients achieving grade 0 in the SRS-Schwab PI–LL modifier, and the more patients with undercorrection relative to the age-adjusted PI–LL in the severe group. It is well known that undercorrection has been associated with poor clinical outcomes in ASD surgery.[8,9,30] Our findings indicate that a higher proportion of patients in the severe group experienced undercorrection after surgery and had significantly elevated ODI scores and SRS-22 total scores at the final follow-up, consistent with previous studies. The optimal restoration of sagittal malalignment is crucial for success after ASD surgery. Lee et al.[8] reported that the strict correction relative to all sagittal modifiers of SRS-Schwab classification ensures better SRS-22 scores even in a long-term follow-up of 90.3 months. Park et al.[9,25] also demonstrated that matched correction relative to the age-adjusted PI–LL target is necessary to achieve good clinical outcomes and to reduce PJK development. Patients with severe sagittal imbalance are likely to be undercorrected compared to those with mild and moderate sagittal imbalance. Therefore, greater efforts are required to achieve adequate correction as the severity of baseline sagittal imbalance increases.

This study has a few limitations. First, an inherent limitation of this study is the retrospective nature, which allows for the possibility of selection bias. Second, the results of this study may lack the generalizability considering the heterogeneous nature of patients with ASD because we only included patients with degenerative-type ASD. However, we applied strict inclusion criteria, such as narrow age group (≥60 years), main preoperative diagnosis with sagittal imbalance, and pelvic fixation in all cases, during patient selection to reduce such heterogeneity. Third, there was no investigation regarding the history of lower limb joint replacement surgery. Severe knee arthritis and similar conditions necessitating lower limb joint replacement can impact compensatory mechanisms in patients with ASD. However, we routinely check the range of motion of hip or knee, and patients with severe flexion contracture in these joints, irrespective of undergoing total joint surgery, were not included. Finally, we adopted the SRS-Schwab classification to group patients according to the baseline severity of sagittal malalignment. Different results may be obtained if other criteria, such as an age-adjusted alignment target or GAP score, are applied. However, the SRS-Schwab classification is currently the most popular tool in the current literatures for defining the severity of sagittal deformity.[31-34]

CONCLUSION

Patients with more severe sagittal imbalance were treated with more invasive surgical methods, with an increased perioperative surgical burden. Regardless to severity of baseline sagittal imbalance, all patients exhibited significant radiological and clinical improvements after surgery. However, in term of ODI, the severe group demonstrated slightly worse clinical outcomes compared to the other groups, probably due to relatively higher proportion of undercorrection. Therefore, more rigorous correction is necessary to achieve optimal sagittal alignment specifically in patients with severe baseline sagittal imbalance.

NOTES

Conflict of Interest: The authors have nothing to disclose.

Funding/Support: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution: Conceptualization: SJP, JSP, DHK; Data curation: SJP, JSP, DHK, HJK, YML; Formal analysis: HJK, YML; Methodology: SJP, DHK; Project administration: JSP,

CSL; Visualization: SJP, JSP, HJK; Writing – original draft: SJP, DHK; Writing – review & editing: SJP, DHK.

ORCID

Se-Jun Park: 0000-0002-2412-9437
Jin-Sung Park: 0000-0001-6517-8609
Dong-Ho Kang: 0000-0002-9114-0150
Hyun-Jun Kim: 0009-0005-8151-1084
Yun-Mi Lim: 0000-0001-5007-8699
Chong-Suh Lee: 0000-0003-1373-4815

REFERENCES

1. Kim HJ, Yang JH, Chang DG, et al. Adult spinal deformity: a comprehensive review of current advances and future directions. Asian Spine J 2022;16:776-88.
2. Magcalas KJ, Oe S, Yamato Y, et al. Change in line of sight after corrective surgery of adult spinal deformity patients: a 2-year follow-up. Asian Spine J 2023;17:272-84.
3. Lee JK, Hyun SJ, Kim KJ. Reciprocal changes in the whole-body following realignment surgery in adult spinal deformity. Asian Spine J 2022;16:958-67.
4. Wang J, Ushirozako H, Yamato Y, et al. How is degenerative lumbar scoliosis associated with spinopelvic and lower-extremity alignments in the elderly. Asian Spine J 2023;17:253-61.
5. Glassman SD, Berven S, Bridwell K, et al. Correlation of radiographic parameters and clinical symptoms in adult scoliosis. Spine (Phila Pa 1976) 2005;30:682-8.
6. Glassman SD, Bridwell K, Dimar JR, et al. The impact of positive sagittal balance in adult spinal deformity. Spine (Phila Pa 1976) 2005;30:2024-9.
7. Schwab F, Patel A, Ungar B, et al. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. Spine (Phila Pa 1976) 2010;35:2224-31.
8. Lee CS, Park JS, Nam Y, et al. Long-term benefits of appropriately corrected sagittal alignment in reconstructive surgery for adult spinal deformity: evaluation of clinical outcomes and mechanical failures. J Neurosurg Spine 2021;34:390-8.
9. Park SJ, Lee CS, Park JS, et al. A validation study of four preoperative surgical planning tools for adult spinal deformity surgery in proximal junctional kyphosis and clinical outcomes. Neurosurgery 2023;93:706-16.
10. Yilgor C, Sogunmez N, Boissiere L, et al. Global Alignment and Proportion (GAP) score: development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery. J Bone Joint Surg Am 2017;99:1661-72.
11. Lafage R, Schwab F, Challier V, et al. Defining spino-pelvic alignment thresholds: should operative goals in adult spinal deformity surgery account for age? Spine (Phila Pa 1976) 2016;41:62-8.
12. Schwab F, Ungar B, Blondel B, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine (Phila Pa 1976) 2012;37:1077-82.
13. Neuman BJ, Harris AB, Klineberg EO, et al. Defining a surgical invasiveness threshold for increased risk of a major complication following adult spinal deformity surgery. Spine (Phila Pa 1976) 2021;46:931-8.
14. Kyrölä K, Repo J, Mecklin JP, et al. Spinopelvic changes based on the simplified SRS-Schwab adult spinal deformity classification: relationships with disability and health-related quality of life in adult patients with prolonged degenerative spinal disorders. Spine (Phila Pa 1976) 2018;43:497-502.
15. Kieser DC, Boissiere L, Cawley DT, et al. Validation of a simplified SRS-Schwab classification using a sagittal modifier. Spine Deform 2019;7:467-71.
16. Passias PG, Jalai CM, Diebo BG, et al. Full-body radiographic analysis of postoperative deviations from age-adjusted alignment goals in adult spinal deformity correction and related compensatory recruitment. Int J Spine Surg 2019;13:205-14.
17. Maruo K, Ha Y, Inoue S, et al. Predictive factors for proximal junctional kyphosis in long fusions to the sacrum in adult spinal deformity. Spine (Phila Pa 1976) 2013;38:E1469-76.
18. Copay AG, Glassman SD, Subach BR, et al. Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the Oswestry Disability Index, Medical Outcomes Study questionnaire Short Form 36, and Pain Scales. Spine J 2008;8:968-74.
19. Arima H, Carreon LY, Glassman SD, et al. Cultural variations in the minimum clinically important difference thresholds for SRS-22R after surgery for adult spinal deformity. Spine Deform 2019;7:627-32.
20. Samuel AM, Fu MC, Anandasivam NS, et al. After posterior fusions for adult spinal deformity, operative time is more predictive of perioperative morbidity, rather than surgical invasiveness a need for speed? Spine (Phila Pa 1976) 2017;42:1880-7.

 https://doi.org/10.14245/ns.2448250.125

21. Song J, Katz AD, Silber J, et al. Comparison of value per operative time between primary and revision surgery for adult spinal deformity: a propensity score-matched analysis. Asian Spine J 2023;17:485-91.
22. Hart RA, McCarthy I, Ames CP, et al. Proximal junctional kyphosis and proximal junctional failure. Neurosurg Clin N Am 2013;24:213-8.
23. Yagi M, Rahm M, Gaines R, et al. Characterization and surgical outcomes of proximal junctional failure in surgically treated patients with adult spinal deformity. Spine (Phila Pa 1976) 2014;39:E607-14.
24. Park SJ, Lee CS, Chung SS, et al. Different risk factors of proximal junctional kyphosis and proximal junctional failure following long instrumented fusion to the sacrum for adult spinal deformity: survivorship analysis of 160 patients. Neurosurgery 2017;80:279-86.
25. Park SJ, Lee CS, Kang BJ, et al. Validation of age-adjusted ideal sagittal alignment in terms of proximal junctional failure and clinical outcomes in adult spinal deformity. Spine (Phila Pa 1976) 2022;47:1737-45.
26. Im SK, Lee JH, Kang KC, et al. Proximal junctional kyphosis in degenerative sagittal deformity after under- and overcorrection of lumbar lordosis: does overcorrection of lumbar lordosis instigate PJK? Spine (Phila Pa 1976) 2020;45:E933-42.
27. Park SJ, Lee CS, Park JS, et al. Does the amount of correction of sagittal deformity really promote proximal junctional kyphosis? Multivariate analyses according to uppermost instrumented vertebra levels. World Neurosurg 2023:S1878-8750(23)00878-1. doi: 10.1016/j.wneu.2023.06.095. [Epub].
28. Ham DW, Kim HJ, Choi JH, et al. Validity of the global alignment proportion (GAP) score in predicting mechanical complications after adult spinal deformity surgery in elderly patients. Eur Spine J 2021;30:1190-8.
29. Jacobs E, van Royen BJ, van Kuijk SMJ, et al. Prediction of mechanical complications in adult spinal deformity surgery-the GAP score versus the Schwab classification. Spine J 2019;19:781-8.
30. Scheer JK, Lafage R, Schwab FJ, et al. Under correction of sagittal deformities based on age-adjusted alignment thresholds leads to worse health-related quality of life whereas over correction provides no additional benefit. Spine (Phila Pa 1976) 2018;43:388-93.
31. Hallager DW, Hansen LV, Dragsted CR, et al. A comprehensive analysis of the SRS-Schwab adult spinal deformity classification and confounding variables: a prospective, non-US cross-sectional study in 292 patients. Spine (Phila Pa 1976) 2016;41:E589-97.
32. Terran J, Schwab F, Shaffrey CI, et al. The SRS-Schwab adult spinal deformity classification: assessment and clinical correlations based on a prospective operative and nonoperative cohort. Neurosurgery 2013;73:559-68.
33. Smith JS, Klineberg E, Schwab F, et al. Change in classification grade by the SRS-Schwab Adult Spinal Deformity Classification predicts impact on health-related quality of life measures: prospective analysis of operative and nonoperative treatment. Spine (Phila Pa 1976) 2013;38:1663-71.
34. Zhu WG, Kong C, Zhang ST, et al. Different acute behaviors of pelvic incidence after long fusion to sacrum between elderly patients with severe and minor sagittal deformity: a retrospective radiographic study on 102 cases. Eur Spine J 2020;29:1379-87.