Original Article

Posterior instrumented fusion surgery for adult spinal deformity: Correction rate and total balance

ABSTRACT

Background: The primary radiological goal of surgery for adult spinal deformity (ASD) is the restoration of lumbar lordosis (LL). Radiological parameters were analyzed to determine the surgical indications for ASD using posterior side-loading spinal instrumentation system.

Materials and Methods: This retrospective study included 31 patients of ASD who underwent posterior instrumented fusion surgery. Imaging parameters included spinal tilt angle (STA), LL, and thoracic kyphosis (TK). The ideal LL was estimated based on the normal value.

Results: Of 16 patients with sagittal imbalance, 10 patients demonstrated sagittal balance postoperatively. All six patients with frontal imbalance showed frontal balance postoperatively. STA improvement well correlated with change of LL. On univariate analysis, preoperative TK was significantly associated with preoperative sagittal imbalance and postoperative lack of LL with postoperative sagittal imbalance.

Conclusions: The surgical concept of ASD focusing on correction of LL was demonstrated. Although the surgery of ASD is still challenging, posterior instrumented fusion surgery using posterior side-loading system may be well applied for mild or moderate ASD without hyper-TK. The posterior side-loading system is practical and can be one of the surgical choices.

Keywords: Adult spinal deformity, posterior instrumented fusion surgery, sagittal balance, split tilt angle

INTRODUCTION

Adult spinal deformity (ASD) is a secondary process of degenerative lumbar disc and/or facet joints and represents a major social problem in modern aging societies.[1] ASD may cause back pain and/or nerve compression symptoms, leading to significant impairment of activities of daily living (ADL) and quality of life (QOL). ASD is characterized as a spinal sagittal or coronal imbalance, often accompanied by lumbar spondylolisthesis, instability, or stenosis. Conservative treatment is generally recommended and is effective for pain relief and maintaining ADL. The surgery should be indicated for severe back pain and/or progressive neurological symptoms refractory to conservative treatment.[1-4] The primary goal of surgery is correction of the spinal sagittal or coronal imbalance and subsequent achievement of better ADL and QOL.[5-7] Posterior spine fusion surgery using pedicle screw instrumentation with or without osteotomy or anterior reconstruction such as lateral lumbar interbody fusion has become the gold standard for maintaining stability or achieving correction of ASD.[1-4,8-16] However, complex surgeries may carry a high risk of surgery-related complications, and conventional open approaches have reported complication rates exceeding 30%.[3,8,14-17]

The present study applied the technique of posterior side-loading spinal instrumentation system with monoblock pedicle screws that can easily adapt implants to accommodate

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various pathologies of ASD. Radiographic parameters before and after surgery were carefully analyzed regarding risk factors for postoperative sagittal imbalance in ASD.

MATERIALS AND METHODS

Patients population

This retrospective study included 31 consecutive patients between 2008 and 2013 who had undergone posterior fusion surgery for ASD using posterior side-loading spinal instrumentation system (Easyspine®; LDR, Troyes, France). The specific features of this posterior side-loading spinal instrumentation system included side-opening monoblock pedicle screw with integrated multiaxial connections, a partial flattened rod with flat-on-flat locking connection, and a reduction forceps [Figure 1]. The inclusion criterion for the present study was a Cobb angle of the lumbar spine >10°. Exclusion criteria were the past medical history of lumbar surgery or adult scoliosis with an idiopathic etiology. Participants comprised 3 men and 28 women with a mean age of 67.2 ± 9.3 years (range, 49–84 years). The mean duration of postoperative follow-up was 4.2 ± 1.4 years (range, 3.0–8.8 years). All medical records, including patient demographics, operative records, postoperative course, surgery-related complications, and imaging analysis, were retrospectively reviewed using a computerized medical records system. Radiological examinations were conducted before surgery and at the recent follow-up after surgery.

Radiographic analysis

Plain radiographs before and after surgery were carefully examined to determine the imaging parameters, as demonstrated in Figure 2. Cobb angle was measured from the angle formed between the superior endplate of the upper tilted vertebra and the inferior endplate of the lower tilted vertebra. The C7 plumb line-central sacral vertical line (C7PL-CSVL) was recognized as a radiographic indicator of frontal balance. The frontal imbalance was defined as C7PL-CSVL >3 cm.[18] Spinal tilt angle (STA) was measured as the angle subtended by the vertical line at the center of the upper sacral endplate and line from the center of the C7 vertebral body to the center of the upper sacral endplate and was recognized as the radiographic indicator of sagittal global balance. The sagittal imbalance was defined as STA >7°.[19] Lumbar lordosis (LL) was measured as the angle formed between the superior endplate of L1 to the superior endplate of S1. The ideal angle was estimated based on the analysis by Legaye *et al*.[20] The lack of pre- or post-operative LL was defined as the difference between the ideal LL and pre- or post-operative LL. Thoracolumbar kyphosis (TLK) was measured as the angle formed between the superior endplate of Th10 and the superior endplate of L2. Thoracic kyphosis (TK) was measured as the angle formed between the superior endplate of Th2 to the superior endplate of Th12. Sacral slope (SS) was measured from the superior sacral endplate to the horizontal reference line. Pelvic tilt (PT) was measured as the angle between the line through the midpoint of the superior sacral endplate to the center of the femoral head and the vertical reference line. Pelvic incidence (PI) was measured as the angle between the line through the

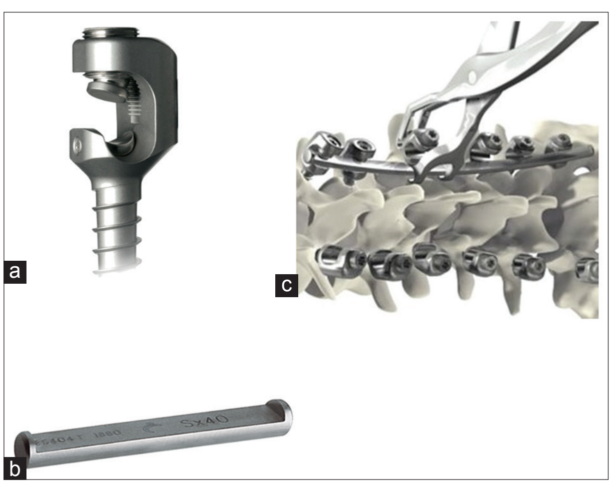


Figure 1: (a) Side-opening monoblock pedicle screw with multi-axial connections, (b) flattened rod (b and c) reduction forceps (permission to reprint Easy Spine images was confirmed)

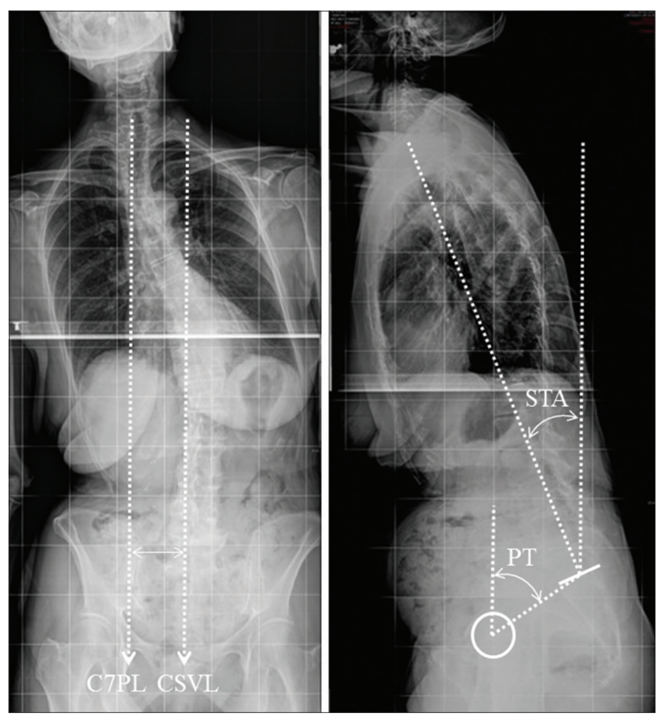


Figure 2: Imaging parameters of C7 plumb line-central sacral vertical line and spinal tilt angle. C7 plumb line-central sacral vertical line as a radiological indicator of coronal balance; spinal tilt angle subtended by the vertical line at the center of the upper sacral endplate and the line from the center of C7 vertebral body to the center of the upper sacral endplate, as a radiological indicator of sagittal global balance

midpoint of the superior sacral endplate to the center of the femoral head and the line perpendicular to the midpoint of the superior sacral endplate. Sagittal balance before and after surgery was further divided into four grades of A–D based on the values of STA and PT [Figure 3]: type A, STA ≤7° without retroversion of the pelvis (PT ≤25°); type B, STA ≤7° with retroversion of pelvis (PT >25°); type C, STA > 7° and PT ≤25°; and type D, STA >7° and PT >25°.

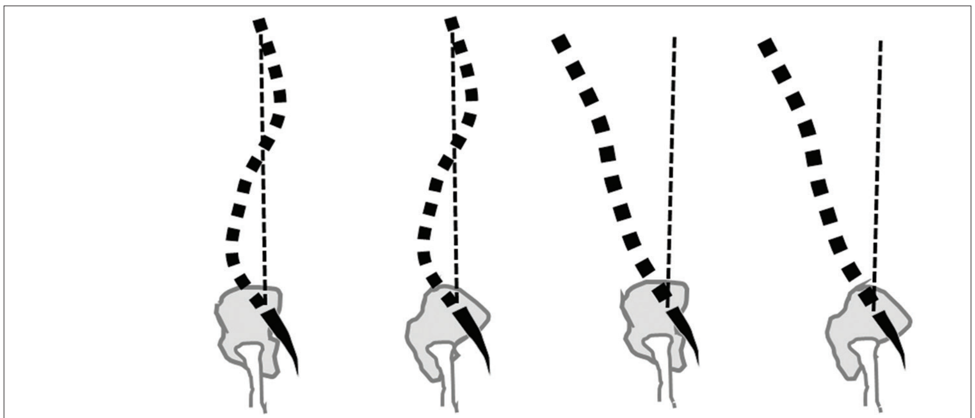
Surgical methods

In the present study, all surgeries were performed using only an open posterior spine approach to achieve correction of the spinal deformity. Basic correction procedures included bilateral facetectomy of Smith–Petersen Grade 1 osteotomy,[21] translation, and posterolateral fusion. Inferior fusion level was determined at L5 when the L5/S disc showed no collapse or instability. The fusion was extended caudally to the sacrum when the L5/S disc documented instability. In patients with significant sagittal imbalance, the fusion was also extended caudally to the sacrum because sagittal imbalance was more likely to cause subsequent disc degeneration at L5/S. The superior fusion level was determined based on coronal and sagittal imbalances. In cases of a double curve, the surgery was conducted only for lower-curve scoliosis. The primary goal of surgery was the surgical restoration of LL. Pedicle subtraction osteotomy was performed for cases of severe sagittal imbalance of type C or D with STA >14°. When kyphotic deformity was evident at the thoracolumbar junction, proximal fusion was extended enough to stabilize the thoracolumbar junction, usually up to Th10. Interbody fusion was indicated at the healthy lower lumbar disc to enhance fusion. Iliac screws or additional sacropelvic fusion was indicated in the case of long fusion from the upper or middle thoracic level and in cases of type C or D sagittal imbalance.

Patients were positioned prone under general anesthesia. Exposure of the posterior spine was achieved with a subperiosteal approach. Side-opening monoblock pedicle screw placement was carried out according to the preoperative plan. After the placement of all pedicle screws, bilateral facet release was carried out. Rods that had been bent according to the preoperative plan were applied to the upper and lower screws. The rod was slid into the side-opening monoblock pedicle screws by gradual capture of subsequent screws. Complex reduction forceps proved highly useful for achieving tight connection of rod and screws. All the screws on both concave and convex sides were captured and fully tightened. All corrections were performed under motor-evoked potential monitoring. Bone grafting from local bone with bone marrow from the iliac crest and calcium phosphate ceramic substitute were used to ensure adequate fusion. Postoperatively, the patient was mobilized without a brace.

Statistical analysis

All data are expressed as mean ± standard deviation. Statistical comparisons of pre- and post-operative radiographic parameters between the two study groups were performed using the paired *t*-test. JMP version 9.0 software (SAS Institute, Cary, NC, USA) was used for all statistical analyses in the present study. Spearman rank correlation test was used to search for correlations between parameters. Univariate analysis was performed to examine for the presence of an association between study variables and sagittal imbalance before or after surgery. Pearson's Chi-square test was used to test the relationship between study variables and sagittal



Type	Type A	Type B	Type C	Type D
Balance	Sagittal balance		Sagittal imbalance	
STA	≤ 7 degrees	≤ 7 degrees	> 7 degrees	> 7 degrees
PT	≤ 25 degrees	> 25 degrees	≤ 25 degrees	> 25 degrees

Figure 3: Four grades of sagittal global balance defined by spinal tilt angle and pelvic tilt

imbalance before or after surgery. $P < 0.05$ was considered statistically significant.

Statement of ethics

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Research Committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

RESULTS

Fusion length

Pedicle subtraction osteotomy was performed in two cases (L3, 1 case and L4, 1 case) and transforaminal interbody fusion in six cases (L4/5, 1 case; L5/S1, 3 cases; and L4/L5/S1, 2 cases).

The mean number of fusions was 7.3 ± 2.1 segments (range, 5–13 segments). The upper instrumented vertebra (UIV) ranged from T5 to L1. The most common UIV was T10 in 9 patients, followed by Th11 in 6 patients. The lower instrumented vertebra (LIV) ranged from L5 to S1. The most common LIV was L5 in 19 patients followed by S1 in 6 patients. Fixation range in all cases was demonstrated in Figure 4.

Radiographic parameters

Mean Cobb angle was 27.8° ± 12.9° preoperatively, improving significantly to 6.1° ± 6.7° postoperatively [Figure 5a and b]. Mean LL was 35.5° ± 8.9° preoperatively,

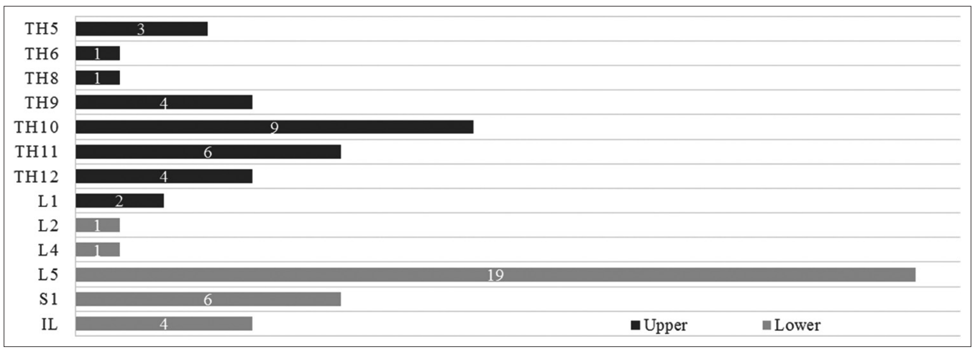


Figure 4: Summary of fusion range. Upper: Upper instrumented vertebra; Lower: Lower instrumented vertebra

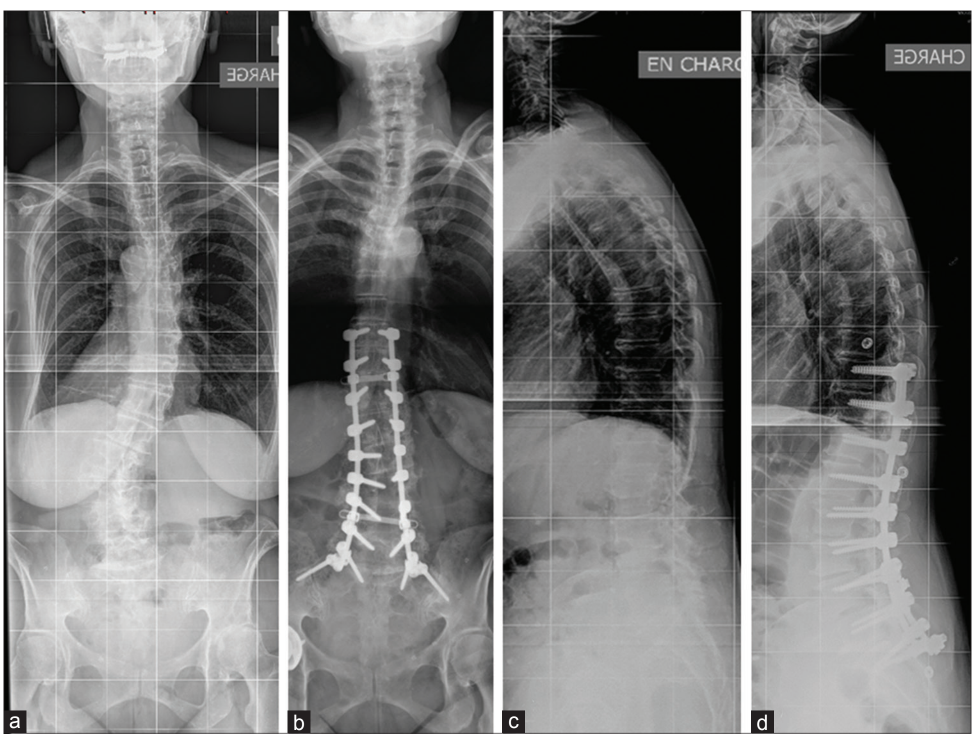


Figure 5: Illustrative case of satisfactory correction of coronal and sagittal balance. (a and b) Coronal balance before and after surgery. (c and d) Sagittal balance before and after surgery

and improved significantly to 47.7° ± 11.9° postoperatively [Figure 5c and d]. Mean TLK was 9.8° ± 16.7° preoperatively and reduced significantly to 1.6° ± 12.6° postoperatively. Mean TK was 44.6° ± 18.4° preoperatively and was maintained at 41.7° ± 13.2° postoperatively. Radiological parameters are summarized in Table 1. Ten of the 16 cases with sagittal imbalance preoperatively, including 2 PSO, showed sagittal balance postoperatively, and all six cases with frontal imbalance preoperatively achieved frontal balance postoperatively.

Preoperative image analysis suggested that preoperative STA did not correlate with preoperative lack of LL (r_s = 0.2625). Eight cases were type A, seven cases were type B, eight cases were type C, and eight cases were type D. All eight cases of preoperative type A were still classified as type A postoperatively. The seven cases of preoperative type B were reclassified postoperatively as type A in two cases and type B in five cases. The eight cases of preoperative type C were reclassified as type A in six cases and type C in two cases postoperatively. Eight cases of preoperative type D were reclassified as type A in three cases, type B in one case, type C in one case, and type D in three cases postoperatively. All patients demonstrated improvement or maintenance of sagittal balance postoperatively. Image analysis suggested that STA improvement degree correlated well with change in LL in successful realignment cases without PSO (r_s = 0.9087, $P < 0.05$) in Figure 6. Postoperative correction of the spinal sagittal deformity is summarized in Table 2.

Pre- and post-operative radiological parameters in all patients are expressed in the graphical visualization of the respective relationships of SS, LL, and TK [Figure 7].

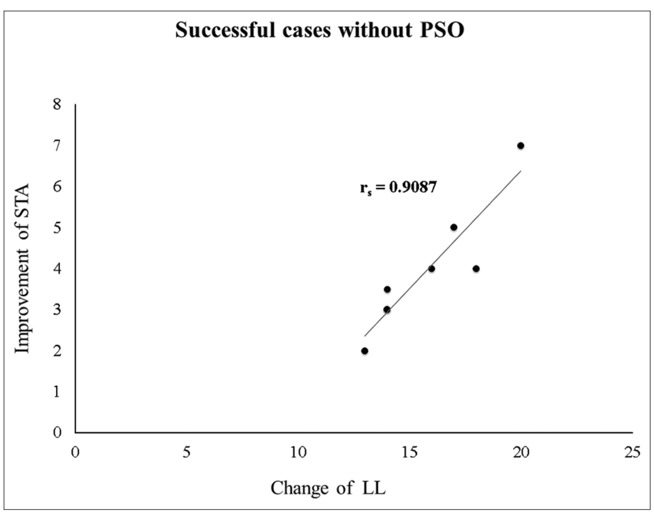


Figure 6: Correlation between the improvement of spinal tilt angle and change in lumbar lordosis in successful realignment cases without PSO (rs = 0.9087, *P* < 0.05)

Patients were divided into three groups with preoperative sagittal balance, preoperative sagittal imbalance with the improvement of sagittal imbalance postoperatively, and preoperative sagittal imbalance without improvement of sagittal imbalance postoperatively. The majority of patients demonstrated improvement of TK after surgery, and radiographic parameters tended to converge on the line proposed by Legaye *et al*.,[20] which is considered to represent normal spinal sagittal alignment. A total of six patients were judged to show preoperative sagittal imbalance without improvement of sagittal imbalance postoperatively (black triangle), comprising three cases of postoperative type C and three cases of postoperative type D. These six patients tended to demonstrate preoperative hyper-TK and maintained TK postoperatively. The postoperative sagittal imbalance was mainly attributed to preoperative hyper-TK. The radiographic parameters of these six patients are demonstrated in Figure 8.

Perioperative complications and postoperative follow-up

No mortality was encountered in the present study, and no screw misplacement required revision surgery early after surgery. Eight perioperative complications were identified, including dural tear in one case, sepsis in one case, neurological deterioration in two cases, and mechanical implant failure in four cases. Revision surgeries during the follow-up were performed for a total of three patients. Proximal junctional kyphosis was confirmed in two patients, at Th10/11 and Th11/12. Proximal extension of fusion was performed in one of these two patients. Distal extension of fusion was performed in two patients because of distal junctional kyphosis or pseudoarthrosis. The latest analysis indicated no evidence of pseudoarthrosis or instrumentation failure.

Table 1: Radiological parameters

	Preoperative	Postoperative	*P*
Coronal angle	27.8±12.9	6.1±6.7	<0.001
LL	35.5±8.9	47.7±11.9	<0.001
TLK	9.8±16.7	−1.6±12.6	0.0106
TK	44.6±18.4	41.7±13.2	0.1379

TLK - Thoracolumbar kyphosis; TK - Thoracic kyphosis; LL - Lumbar lordosis

Table 2: Correction of spinal sagittal deformity

Preoperative	Number of cases	Postoperative			
		Sagittal balance		Sagittal imbalance	
		A	B	C	D
Sagittal balance					
A	8	8			
B	7	2	5		
Sagittal imbalance					
C	8	6		2	
D	8	3	1	1	3

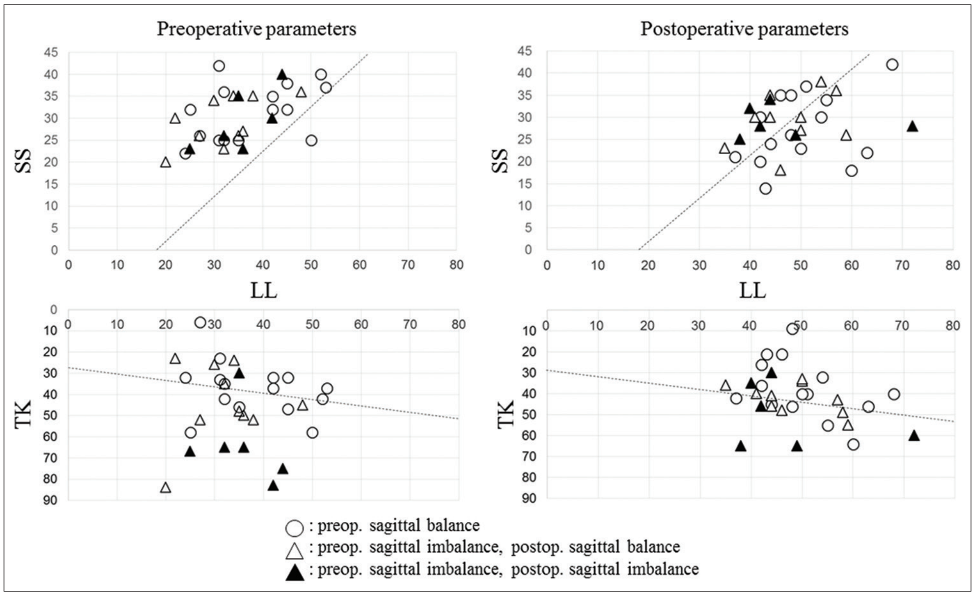
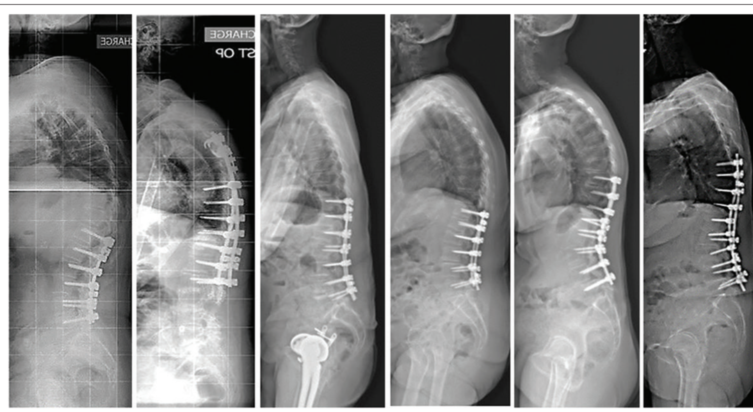


Figure 7: Graphical visualization of pre- and post-operative radiological parameters in all patients with the line suggesting the normal value proposed by Legaye and Duval-Beaupere 20



Case	1	2	3	4	5	6
Preoperative type	C	D	D	C	D	D
Postoperative type	C	C	D	C	D	D
Preoperative TK	75	65	30	65	83	67
Postoperative lack of LL	1	26	32	20	20	25

Figure 8: Summary of six cases of postoperative types C and D. The main cause of postoperatively sagittal imbalanced may be preoperative hyper-TK

Risk factors for sagittal imbalance before and after the surgery

On univariate analysis, only preoperative TK was significantly associated with preoperative sagittal imbalance [Table 3], and postoperative lack of LL was significantly associated with postoperative sagittal imbalance [Table 4].

DISCUSSION

The incidence of medical comorbidities increases with age and the prevalence of ASD. The worse the mismatch of spinopelvic parameters compared to normal values, the worse the pain and disability associated with ASD. The degenerative process of the aging spine leads to the progression of TK. The progression of TK is usually compensated by a decrease in TK and furthermore by PT and flexion of the hip and/or knee joints to maintain spinal alignment.[22,23] However, when such compensatory mechanisms reach their limitations with aging, spinal alignment finally shows sagittal global imbalance. The present analysis suggested that preoperative STA appeared not to correlate with preoperative lack of LL and sagittal global imbalance may result from multiple factors of not only loss of LL but also unsatisfactory compensation of the pelvis, hip joints, and knee joints. The present analysis also suggested that preoperative TK was significantly associated with preoperative sagittal imbalance. Late-stage or irreversible ASD may be defined by the existence of the degenerative progression of hyper-TK. Mild or moderate

Table 3: Univariate analysis of factors related to preoperative sagittal imbalance

	Balanced group (15 cases)	Imbalanced group (16 cases)	*P*
PI	51±7	56±5	0.1210
Preoperative LL	38±10	34±8	0.0950
Preoperative TLK	11±11	9±21	0.3343
Preoperative TK	37±13	52±20	0.0147
Preoperative PT	24±9	25±8	0.4452
Preoperative SS	31±6	29±6	0.3838
Preoperative lack of LL	26±10	30±10	0.1329

PI - Pelvic incidence; LL - Lumbar lordosis; TLK - Thoracolumbar kyphosis; TK - Thoracic kyphosis; PT - Pelvic tilt; SS - Sacral slope

Table 4: Univariate analysis of factors related to postoperative sagittal imbalance

	Balanced group (25 cases)	Imbalanced group (6 cases)	*P*
PI	52±9	56±5	0.2060
Postoperative LL	49±8	48±12	0.3372
Postoperative TLK	3±7	6±4	0.1164
Postoperative TK	39±11	50±15	0.3558
Postoperative PT	19±6	27±5	0.2585
Postoperative SS	28±7	28±3	0.4140
Postoperative lack of LL	12±8	21±10	0.0192

PI - Pelvic incidence; LL - Lumbar lordosis; TLK - Thoracolumbar kyphosis; TK - Thoracic kyphosis; PT - Pelvic tilt; SS - Sacral slope

DLS without hyper-TK can be well maintained or improved by surgery. Surgical restoration of an ideal LL is the primary goal of realignment in cases of ASD, as the present analysis suggested that the improvement of STA appeared to correlate well with changes in LL compared with the preoperative value in cases without PSO. The present analysis actually suggested that postoperative lack of LL was significantly associated with postoperative sagittal global imbalance. Our surgical concept is to achieve correction of lumbar or thoracolumbar malalignment to the ideal alignment as much as possible. Jang *et al*. reported a reciprocal relationship between LL and TK in sagittal thoracic compensated ASD and a correlation between surgical restoration of LL and improvement of TK.[24] Patients with ASD without preoperative hyper-TK will show a compensatory normalization of TK, finally becoming stable or improving to the normal STA. Surgical restoration of LL results in satisfactory or acceptable sagittal balance.

Although many surgical spine fusion techniques exist for the treatment of ASD, the most common ones involve posterior instrumented fusion. Pedicle screw instrumentations have become the gold standard technique to maintain stability for posterior fusion procedures. This method is also used as a powerful reduction tool for correction of scoliosis, kyphosis, and spondylolisthesis. Various kinds of screws can be used, such as polyaxial, monoaxial, and monoplanar screws. Polyaxial pedicle screws are favored due to the difficulty of rod insertion with fixed monoaxial screws. Polyaxial screw heads slip on the screw shank at lower dynamic loads compared to monoaxial or monoplanar screws, resulting in angular change between the rod and pedicle screw, which could cause loss of segmental lordosis.[25] A posterior fusion technique using posterior side-loading spinal instrumentation system with monoblock pedicle screws as applied in the present study appeared easier than other pedicle screws to correct frontal imbalance. More recently, anterior or lateral lumbar interbody fusion techniques such as a technique of anterior column realignment have been gaining popularity for the correction of ASD. Anterior or lateral surgical techniques with posterior fusion surgery may offer advantages of better spinal correction rate, perioperative blood loss, or operation time compared to the standard posterior technique. Kotwal *et al*. found that the average Cobb angle improved 11.2° after lateral lumbar interbody fusion in 118 patients (237 levels).[10] Johnson *et al*. found that the average Cobb angle and segmental LL improved 5.9° and 3.3°, respectively, after extreme LIF for lumbar degenerative disease.[11] Baghdadi *et al*. reported that the average Cobb angle and segmental LL improved 24.0° and 6.0°, respectively, after LIF for lumbar degenerative disease.[12] The average Cobb angle and segmental LL in the present study improved 21.7° and 12.2°, respectively, compared to those earlier results of LIF. Surgery-related complications represent problems to be resolved. Serious complications with anterior or lateral fusion techniques, such as major vascular laceration, retrograde ejaculation, postoperative colonic obstruction, or injury to the sympathetic chain, which are not encountered in posterior only surgery, need to be noted.[10-12,15] Posterior instrumented fusion surgery using posterior side-loading spinal instrumentation system used in the present study appeared well suited to the restoration of mild or moderate ASD, despite recent technological improvements in LIF.

Several limitations to the present study must be considered. The first is that the present study was not a prospective, randomized trial, but rather a retrospective case analysis. The second is that a larger number of subjects would be desirable to allow definitive conclusions. The third limitation is the lack of comparative data on postoperative ADL or QOL improvement. STA is defined by angle and reasonable index, which does not require calibration, but there is no article describing relation between changes of STA and functional outcomes. Although these limitations need to be taken seriously, radiographic parameters before and after surgery in the present study suggested that posterior side-loading spinal instrumentation system was useful to achieve better correction of frontal or sagittal imbalance, except in cases of preoperative hyper-TK. Longer follow-up is warranted, and the optimal indications for ASD surgery should be carefully determined.

CONCLUSIONS

The surgical concept of ASD focusing on the correction of LL was demonstrated. Radiological parameters before and after surgery suggested that the posterior side-loading spinal instrumentation system is useful to achieve better correction of frontal or sagittal imbalance, except in cases of preoperative hyper-TK. Although the surgery of ASD is still challenging, posterior instrumented fusion surgery using posterior side-loading system may be well applied for mild or moderate ASD without hyper-TK. The posterior side-loading system is practical and can be one of the surgical choices.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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