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Reciprocal Changes in Sagittal Alignment in Adolescent Idiopathic Scoliosis Patients Following Strategic Pedicle Screw Fixation

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Study Design: Retrospective observational study.

Purpose: To analyze the effect of low-density (LD) strategic pedicle screw fixation on the correction of coronal and sagittal parameters in adolescent idiopathic scoliosis (AIS) patients.

Overview of Literature: LD screw fixation achieves favorable coronal correction, but its effect on sagittal parameters is not well established. AIS is often associated with decreased thoracic kyphosis (TK), and the use of multi-level pedicle screws may result in further flattening of the sagittal profile.

Methods: A retrospective analysis was performed on 92 patients with AIS to compare coronal and sagittal parameters preoperatively and at 2-year follow-up. All patients underwent posterior correction via LD strategic pedicle screw fixation. Radiographs were analyzed for primary Cobb angle (PCA), coronal imbalance, cervical sagittal angle (CSA), TK, lumbar lordosis (LL), pelvic incidence, pelvic tilt (PT), sacral slope (SS), C7 plumb line, spino–sacral angle, curve flexibility, and screw density.

Results: PCA changed significantly from 57.6°±13.9° to 19°±8.4° (p<0.0001) with 67% correction, where the mean curve flexibility was 41% and screw density was 68%. Regional sagittal parameters did not change significantly, including CSA (from 10.76° to 10.56°, p=0.893), TK (from 24.4° to 22.8°, p=0.145), and LL (from 50.3° to 51.1°, p=0.415). However, subgroup analysis of the hypokyphosis group (<10º) and the hyperkyphosis group (>40º) showed significant correction of TK (p<0.0001 in both). Sacro–pelvic parameters showed a significant decrease of PT and increase of SS, suggesting a reduction in pelvic retroversion SS (from 37° to 40°, p=0.0001) and PT (from 15° to 14°, p=0.025).

Conclusions: LD strategic pedicle screw fixation provides favorable coronal correction and improves overall sagittal sacro–pelvic parameters. This technique does not cause significant flattening of TK and results in a favorable restoration of TK in patients with hypokyphosis or hyperkyphosis.

Keywords: Scoliosis; Spinal fusion; Pedicle screws; Low density; Radiological outcome

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Introduction

The primary goals of surgical treatment of adolescent idiopathic scoliosis (AIS) are preventing further curve progression; attaining a balanced spine; and correcting deformities in coronal, sagittal, and transverse planes [1]. Use of segmental pedicle screws for deformity correction was first demonstrated by Suk et al. [2] and several studies have since reported safety and efficacy of pedicle screws in scoliosis deformity correction [3]. However, because of its stiffness, controversy exists over the ability of all-screw instrumentation to restore thoracic kyphosis (TK) [4,5]. Low-density (LD) pedicle screw constructs utilize fewer pedicle screws that are strategically positioned, thereby reducing neurological risk, surgical time, blood loss, and surgical costs [6]. Studies on the use of different screw density constructs in AIS by Davis and Dunn [7], Kemppainen et al. [8], and Larson et al. [9] have demonstrated satisfactory results with LD screw constructs in comparison with high-density (HD) screw constructs. Though LD screw constructs achieve favorable results, their effect on sagittal parameters is not well established. Therefore, we aimed to study the effect of LD screw fixation in AIS by quantifying changes in sagittal spinal parameters in addition to those in coronal parameters.

Materials and Methods

1. Study design and inclusion criteria

Ninety two patients treated with surgical correction for AIS during the period from January 2012 to December 2014 were included in this retrospective, single center study. The study was approved by the institutional review board and was conducted in accordance with the ethical standards of the declaration of Helsinki.

Inclusion criteria were as follows: AIS with Lenke curve type I–VI, surgical treatment with posterior instrumented fusion with pedicle screws and rod construct, absence of neurological deficit, a normal preoperative magnetic resonance imaging (MRI) of the spinal axis, a and minimum of 2 years of follow-up. Exclusion criteria were as follows: neuromuscular or congenital scoliosis, presence of abnormal MRI, and patients who had undergone anterior surgery.

2. Data collection and radiographic analysis

Demographic data included age, sex, curve patterns, Rissers stage, type of surgery performed, number of fusion segments, and screw density.

Radiographic data were analyzed on anteroposterior and lateral radiographic views of the entire spine in the upright position. Curve flexibility was assessed on supine side-bending films. Preoperative and postoperative data were analyzed with a minimum 2-year follow-up. We analyzed the following parameters: primary Cobb angle (PCA), coronal imbalance (CI), cervical sagittal angle (CSA), TK, lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), C7 plumb line (C7PL), spino–sacral angle (SSA), and screw density. All radiological parameters were assessed as per standard norms described in the literature (Fig. 1A–C). If the plumb line fell to the left of the central sacral vertical line (CSVL), CI was considered negative and if the plumb line fell to the right, CI was considered positive. If the plumb line fell behind the posterosuperior corner of the first sacral vertebra, C7PL was considered negative and if the plumb line fell ahead, C7PL was considered positive. Screw density was calculated using the following formula: screw density=number of pedicle screws placed/number of pedicles in fusion segments×100.

3. Surgical technique

All surgeries were performed under general anesthesia with the patient in prone position and under neuromonitoring surveillance. Pedicle screws were inserted by means of a “free-hand” technique. Strategic pedicle screw fixation (SPSF) was performed in the following manner. The cranial and caudal foundation typically consisted of four screws. Pedicle screws were then strategically placed at the intervening levels, typically including more screws in the concavity of the deformity (Fig. 1D). To improve curve flexibility, facetectomies and Ponte osteotomies were included in individual cases. Next, manually pre-contoured 5.5-mm titanium rods were inserted, and reduction of the deformity was accomplished through a combination of rod derotation, translational reduction, and *in situ* correction, if required. Posterior element decortication and bone grafting were then performed via autograft and allograft.

4. Statistics

Radiographic data was stored and analyzed using picture archiving and communication system. Data analysis was done using the software IBM SPSS ver. 22.0 (IBM Corp., Armonk, NY, USA) in pre- and postoperative cohorts of all patients. Based on the extent of TK, subgroup analysis was performed in the hypokyphosis (<10°), normokyphosis (10°–40°), and hyperkyphosis (>40°) groups. Student *t*-test was used for assessing statistical significance of differences between variables. In all comparisons performed, the statistical significance level was set at $p<0.05$.

Results

1. Demographic results

The study included 92 AIS patients (82 females and 10

Table 1. Radiographic results of the entire cohort (n=92)

Parameter	Range	Mean±standard deviation	*p*-value
Primary Cobb angle (°)			<0.0001
Preop	35 to 97	57.7±13.9	
Postop[a]	2 to 50	19.02±8.4	
Coronal imbalance (mm)			0.157
Preop	–56 to 48	–7.2±24.05	
Postop	–41 to 25	–3.4±14.9	
C2–C6 angle (cervical sagittal angle) (°)			0.893
Preop	–18 to 48	10.76±15.4	
Postop	–9 to 41	10.56±11.9	
Thoracic kyphosis (°)			0.145
Preop	3 to 56	24.46±11.7	
Postop	7 to 48	22.79±8.4	
Lumbar lordosis (°)			0.419
Preop	31 to 78	50.3±10.6	
Postop	29 to 80	51.1±10.3	
Pelvic incidence (°)			0.012
Preop	33 to 71	52±10.1	
Postop	22 to 71	54±10.2	
Sacral slope (°)			<0.001
Preop	17 to 65	37±8.2	
Postop	19 to 61	40±8.1	
Pelvic tilt (°)			0.025
Preop	1 to 47	15±8.1	
Postop	–10 to 41	14±8.3	
Sagittal vertical axis (C7 plumb line) (mm)			<0.0001
Preop	–92 to 76	–8.2±36.8	
Postop	–62 to 104	10.6±30.3	
Spino–sacral angle (°)			0.418
Preop	109 to 150	127.5±8.5	
Postop	107.4 to 146.7	126.8±7.0	

Preop, preoperative; Postop, postoperative.
[a]All postoperative values mentioned are values measured at final follow-up (all patients had a minimum of a 2-year follow-up).

males), with an average age of 15.7 years. All the patients had a fused triradiate cartilage, and, based on the Lenke classification, there were 40 type I, 3 type II, 13 type III, 1 type IV, 25 type V, and 10 type VI patients.

2. Radiographic results

Preoperative analysis of the cohort demonstrated an average PCA of 57.7°±13.9° (range, 35° to 97°), which decreased to 19.0°±8.4° (range, 2° to 50°) at final follow-up, with a significant difference (p<0.0001) (Table 1). Mean primary curve flexibility was 41%, screw density was 68%, and the correction achieved in PCA was 67%. Preoperative CI of −7.2±24.05 mm (range, −56 to 48 mm) improved to −3.4±14.9 mm (range, −41 to 25 mm) postoperatively; however, the change was not statistically significant (p=0.157). With respect to regional sagittal parameters, no significant difference was found in CSA, TK, or LL. Mean preoperative and postoperative CSA were 10.76°±15.4° and 10.56°±11.9°, respectively. Mean preoperative and postoperative TK were 24.46°±11.7° and 22.79°±8.4°, respectively. Mean preoperative and postoperative LL were 50.3°±10.6° and 51.1°±10.3°, respectively. Sacro–pelvic parameters (PI, SS, and PT) showed statistically significant changes in postoperative radiographs. Preoperatively, PI, SS, and PT were 52°±10.1°, 37°±8.2°, and 15°±8.1°, respectively, changing to 54°±10.2°, 40°±8.1°, and 14°±8.3°, respectively, at final follow-up. The global sagittal parameter C7PL showed an 18.8 mm anterior shift with a preoperative value of −8.2±36.8 mm and a postoperative value of 10.6±30.3 mm with a significant difference (p<0.0001). SSA showed a decrease of 0.7° without a significant difference (p=0.418).

3. Analysis based on thoracic kyphosis

Based on the thoracic sagittal modifier, 11 patients showed preoperative thoracic hypokyphosis, 73 showed normokyphosis, and eight showed hyperkyphosis. In all the subgroups, coronal parameters were significantly corrected. In the hypokyphosis and hyperkyphosis groups, TK values were 7.0° and 48.7°, respectively. These changed postoperatively to 16.7° and 25.7°, respectively, and the changes were statistically significant (p<0.0001) in both the subgroups. In the normokyphosis subgroup, there was a decrease in TK from 24.4° to 23.3°; however, this change was not statistically significant (Table 2).

Table 2. Subgroup analysis of Lenke I, Lenke V, hypokyphosis, normokyphosis, and hyperkyphosis groups based on thoracic kyphosis values

Parameter	Lenke I (n=40)			Lenke V (n=25)			Hypokyphosis (n=11) (T5–T12, <10)			Normokyphosis (n=73) (T5–T12, 10–40)			Hyperkyphosis (n=8) (T5–T12, >40)		
	Preop	Postop	p-value	Preop	Postop	p-value	Preop	Postop	p-value	Preop	Postop	p-value	Preop	Postop	p-value
Primary Cobb angle (°)	53.0	16.8	<0.0001	55.0	18.9	<0.0001	55.5	21.3	<0.0001	55.9	17.7	<0.0001	77.1	27.8	<0.0001
Coronal imbalance (mm)	0.06	−4.2	0.206	−22.9	−2.7	<0.001	−10.3	−4.7	0.583	−9.5	−4.03	0.061	16.9	3.4	0.125
C2–C6 angle (cervical sagittal angle) (°)	9.8	10.6	0.708	12.36	11.8	0.885	2.5	9.6	0.112	10.4	10.3	0.951	24.6	13.5	0.27
Thoracic kyphosis (°) (T5–T12)	22.8	21.8	0.488	24.3	26.4	0.290	7.0	16.7	<0.0001	24.4	23.3	0.291	48.7	25.7	<0.0001
Lumbar lordosis (°) (L1–S1)	51.1	50.1	0.602	47.8	51.2	0.037	43.8	46.7	0.36	50.85	51.9	0.360	54.4	50.3	0.196
Pelvic incidence (°)	53	54	0.188	52	54	0.117	53	53	0.629	52	54	0.012	48	51	0.275
Sacral slope (°)	38	40	0.228	36.0	40	0.003	38	40	0.328	37	40	0.001	34	37	0.307
Pelvic tilt (°)	15	16	0.508	16	14	0.049	15	13	0.114	15	14	0.05	14	14	1.00
C7 plumb line (mm)	−14.4	8.5	0.001	−1.68	21.9	0.10	−11.2	11.2	0.110	−9.8	11.79	<0.0001	11.2	0.25	0.606
Spino–sacral angle (°)	128.8	126.4	0.038	125.7	125.4	0.872	131.1	128.1	0.250	127.6	126.7	0.317	121.5	126.2	0.062

All the parameters mentioned are in degrees except coronal imbalance and C7 plumb line, which are mentioned in millimeters. All postoperative parameters were values measured at final follow-up.
Preop, preoperative; Postop, postoperative.

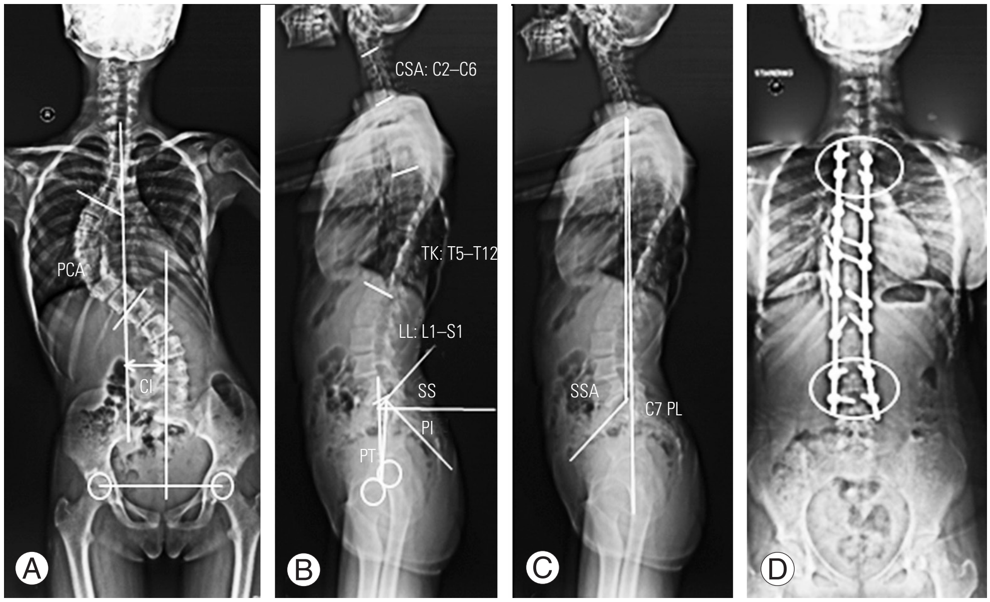

Fig. 1. Measurement of various radiographic parameters including both coronal **(A)** and sagittal parameters **(B, C)**. Postoperative radiograph showing strategic pedicle screw fixation for the cranial and caudal foundation along with intermittent strategic placement of screws **(D)**. PCA, primary Cobb angle; CI, coronal imbalance; CSA, cervical sagittal angle; TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PI, pelvic incidence; PT, pelvic tilt; SSA, spino–sacral angle; C7PL, C7 plumb line.

4. Analysis in the Lenke I and Lenke V subgroups

Statistical significant differences in PCA correction were observed in all the Lenke subgroups (p<0.0001). In the Lenke I group, global spinal parameters (C7PL and SSA) were significantly altered compared with pre and postoperative data, and the remaining parameters did not show any significant differences. In the Lenke V subgroup, CI, LL, SS, and PT showed statistically significant differences between pre and postoperative cohorts (Table 2).

Discussion

The purpose of this study was to demonstrate the effect of LD SPSF on sagittal parameters in AIS. AIS has been associated with decrease in TK [10]. Restoration of TK in AIS is important to prevent increased risk of adjacent-segment disease, disc degeneration, positive sagittal balance, and back pain [11]. Studies on LD screw constructs by Davis and Dunn [7], Bharucha et al. [12], and Shen et al. [13] have noted decreases in TK, and, on the contrary, Wang et al. [14] noted an increase in TK. Therefore, restoration of TK due to LD screw construct has been variable in reported studies, and these studies were restricted mainly to TK and LL. Further, they did not consider reciprocal changes occurring in other sagittal spinal parameters. In the present study, we analyzed not only corrections in coronal parameters but also those in sagittal parameters and compared the parameters with those in the normal adolescent population.

Low implant density is poorly defined in the literature and different techniques, such as the interval pedicle screw strategy, skipped pedicle screw strategy, and key vertebral pedicle screw strategy, have been described [14]. We use strategic pedicle screw placement in which the cranial and caudal foundation typically comprised four screws, and intervening pedicle screws were placed strategically, typically including more screws in the concavity of the deformity (Fig. 2).

1. Coronal parameters

Davis and Dunn [7] reported that strategic screw placement achieved 65.1% improvement in the Cobb angle compared with 69.5%–79.6% in studies with higher screw density constructs [7,15]. They attributed lower coronal plane correction to lesser curve flexibility and to lesser metal density of 52.2%. Li et al. [16] obtained an average of 74% correction with a mean preoperative Cobb angle of 61.87 in Lenke I curves with LD screw constructs. Bha-

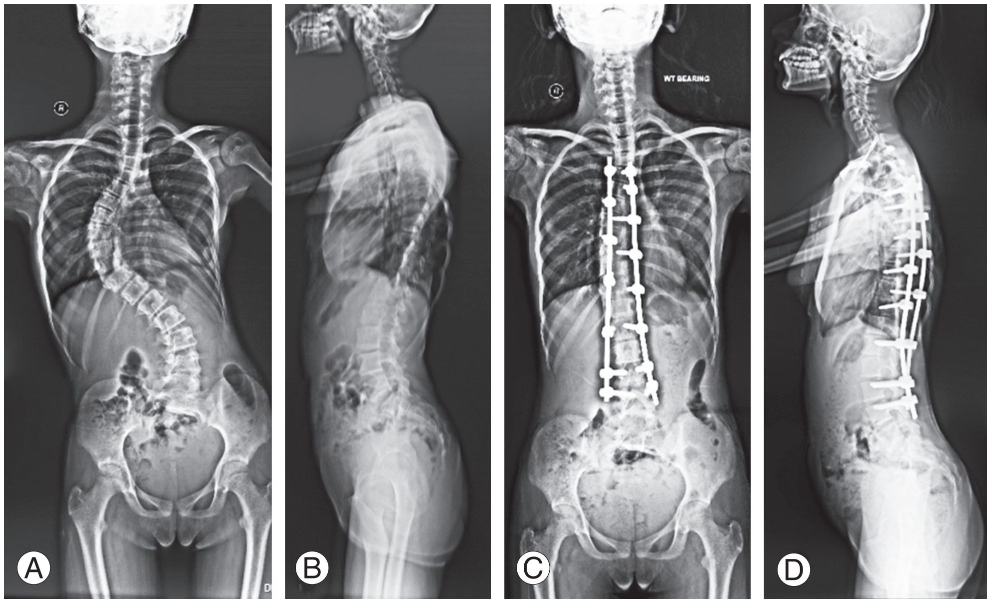

Fig. 2. Preoperative anteroposterior (A) and lateral (B) radiographs showing initial deformation in coronal and sagittal planes. Final follow-up anteroposterior (C) and lateral (D) radiographs showing final correction achieved in coronal and sagittal planes.

rucha et al. [12], in a comparative study on low and HD constructs reported a 66% correction with LD constructs and found no difference in curve correction between the two groups. In the present study, we achieved 67% correction in coronal plane with a primary curve flexibility of 41% and an implant density of 68%. Our results are comparable to studies conducted by Morr et al. [17] and Tannous et al. [18], in which they reported 66.6% and 66.9% improvements in the primary curve, respectively. In comparison to Davis and Dunn [7], we achieved better coronal correction attributable to increased implant density in the present study. With regard to CI, a shift of the plumb line toward CSVL (−7.2 to −3.4 mm) was observed. This indicates an improvement in coronal alignment of the entire spine over the pelvis.

2. Sagittal parameters

Restoration of sagittal alignment is essential to achieve a balanced posture where the spine and pelvis are aligned to minimize energy expenditure. Sagittal alignment of the spine can be evaluated via regional (cervical, thoracic, and lumbar), sacro–pelvic, and global sagittal parameters. In normal adolescent populations, Mac-Thiong [19] and Vedantam et al. [20] reported values of 43.0°±10.4° and 38°±10° for TK and 48.4°±12.4° and 64°±10° for LL, respectively. A study on sacro–pelvic parameters by Mac-Thiong et al. [19] found mean PI values of 49°±11° and 8°±8° for PT and 41°±8° for SS in normal adolescents.

3. Regional parameters

Hilibrand et al. [21] reported straight (lordosis <5°) or kyphotic cervical alignment in 34/39 patients (89%) and increase in cervical kyphosis postoperatively. In a study conducted by Canavese et al. [22] (32 patients), average preoperative CSA was 4.0°±12.3° (range, −30° to 40°) and postoperative average CSA was 1.7°±11.4° (range, −24° to 30°) lordosis, suggesting decrease in cervical lordosis after surgery. Ilharrehorde et al. [23] reported preoperative cervical kyphosis of 11.2, which improved to cervical lordosis of 7.5 postoperatively. We noted minimal alteration in cervical lordosis after surgery (10.76° to 10.56°), which was not significant.

TK values (24.46°) were lower than average compared with those in the normal adolescent group, suggesting hypokyphosis in AIS [10]. Davis and Dunn [7] reported a decrease in TK (5.3°) with LD screw constructs, but this loss in kyphosis was lower than that with HD screw constructs. A comparative study on LD and HD screw constructs by Bharucha et al. [12] and Shen et al. [13] showed a decrease in TK by 2.4° and 2.6°, with LD screw constructs, and 5.0° and 7.4°, with HD screw constructs, respectively. This suggests a greater reduction in TK with HD screw constructs. On the contrary, Wang et al. [14] noted an increase in the average TK with LD screw constructs. We noted a decrease in TK by 1.7° (6%), which is similar to those in studies by Bharucha et al. [12] and Shen et al. [13]. However, in subgroup analysis, the hypokyphosis group showed a 138% increase (7.0° to 16.7°) and the hyperkyphosis group showed a 47.2% decrease (48.7° to 25.7°) in TK. In the normokyphosis group, there was only a 4% reduction (24.4° to 23.3°) suggestive of a slight decrease in TK.

Further, LL was 50.3°, which was lower than that in normal adolescents. This suggests that adolescents affected by scoliosis exhibit hypolordosis in addition to hypokyphosis [10]. Surgery slightly increased the mean value to 51.1°, similar to that reported in a study by Shen et al. [13]. Analysis of the Lenke V subgroup where LL was most severe showed a significant increase in LL of 3.4° (47.8° to 51.2°).

4. Sacro–pelvic parameters

Farshad et al. [24] reported a mean PI of 44°±8°, a PT of 34°±7°, and an SS of 10°±7° in AIS patients, while Roussouly et al. [25] reported preoperative values of PI, PT, and SS of 52.9°±12.4°, 10.8°±7.7°, and 42.2°±8.8°, respectively, and postoperative values of 53.4°±12.7°, 12.5°±7.9°, and 40.9°±8.9°, respectively, in AIS patients. We noted mean preoperative PI values of 52°±10°, SS values of 37°±8°, and PT values of 15°±8°. Higher values of PI and PT were noted in our study group, indicating increased retroversion of the pelvis [23,25]. Postoperatively, there was an increase in SS of 3° with a reciprocal decrease in PT of 1°, in contrary to the findings of studies by Roussouly et al. [25] and La Maida et al. [26]. Considering changes in sacro–pelvic alignment, AIS corrective surgery using SPSF can help create slight pelvic anteversion, as manifested by a decrease in PT, coupled to a slight increase in SS.

5. Global sagittal parameters

A mean negative sagittal imbalance in C7PL (SVA posterior to C7PL) of 8.2 mm was found in the preoperative cohort, shifting anteriorly to 10.6 mm, which is within the normal physiological range (within 20 mm). This result was in contradiction to a study by La Maida et al. [26], which showed a posterior shift of the C7PL, but was in agreement with the observation by Wang et al. [14], showing an anterior shift in C7PL. The SSA showed a decrease of 0.7° (from 127.5° to 126.8°), with restoration of sagittal balance to normal values. Our results are consistent with those of Mac-Thiong et al. [27] evaluating 709 asymptomatic individuals with a mean SSA of 130.4°±8.1° as well as with those of other studies done in AIS patients by Roussouly et al. [25] (129.4° decreased to 129.3° postoperatively) and La Maida et al. [26] (131.1° decreased to 129.5° postoperatively). We observed that although there was an anterior shift in C7PL, global sagittal alignment assessed by SSA suggested that SPSF maintained global spinal balance.

To the best of our knowledge, the present study is the first attempt to analyze the effects of LD screw constructs on overall sagittal parameters in AIS corrective surgery. We found significant correction of the primary curve and improvement in coronal balance. There was restoration of TK in the hypokyphosis and hyperkyphosis groups, while it was maintained in the normokyphosis group. There were specific limitations in this study. First, the retrospective nature of the study design and inclusion of radiographic parameters alone in the analysis were limiting factors. Further, the surgery used 5.5-mm titanium rods, which are elastic and may be inadequate to maintain the anticipated correction when used for column derotation. The effect of LD screw constructs would be influenced by the nature of the rods used and the reduction maneuvers used for deformity correction.

Conclusions

Favorable coronal correction with improvement in sacro–pelvic parameters and global spinal balance was provided by SPSF. In the hypokyphosis and hyperkyphosis groups, TK was significantly corrected with minimal effect in the normokyphosis group. Therefore, SPSF is a viable option to avoid flatback in AIS corrective surgery while still providing good coronal correction.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

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