Cervical sagittal alignment in patients with adolescent idiopathic scoliosis: is it corrected by surgery?

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OBJECTIVE Cervical sagittal alignment (CSA) is related to function and quality of life, but it has not been frequently studied in patients with adolescent idiopathic scoliosis. This study aimed to reveal the change in CSA following corrective surgery, compare the cervical sagittal parameters according to curve types, and assess related factors for postoperative aggravation of CSA.

METHODS The authors studied 318 consecutive patients with adolescent idiopathic scoliosis who underwent corrective surgery at a single center. Occiput–C2 and C2–7 lordosis, C2–7 sagittal vertical axis (SVA), T-1 slope, thoracic kyphosis, and lumbar sagittal profiles were measured preoperatively and postoperatively. Scoliosis Research Society Outcomes Questionnaire (SRS-22) scores were used as clinical outcomes. Each radiological parameter was compared preoperatively and postoperatively according to curve types (double major, single thoracic, and double thoracic curves). Patients were grouped based on preoperative CSA: the lordotic group (group L) and the kyphotic group (group K). Each radiological parameter was compared between the groups. Related factors for postoperative aggravation of CSA were assessed using multivariate logistic analysis.

RESULTS Of the total number of patients studied, 67.0% (213 of 318) and 54.4% (173 of 318) showed cervical kyphotic alignment preoperatively and postoperatively, respectively. C2–7 lordosis increased (from -5.8° to -1.1° ; $p < 0.001$) and C2–7 SVA decreased (from 24.2 to 20.0 mm; $p < 0.001$) postoperatively regardless of curve types. Although group K showed improvement in C2–7 lordosis (from -12.7° to -4.8° ; $p < 0.001$), group L showed no difference (from 9.0° to 6.9° ; $p = 0.115$) postoperatively. Clinical outcomes were not related to the degree of cervical kyphosis in this cohort. C2–7 lordosis ($p < 0.001$) and pelvic tilt ($p = 0.019$) were related to postoperative aggravation of CSA.

CONCLUSIONS Regardless of the trend of improvement in CSA, many patients (54.4%) still showed cervical kyphotic alignment postoperatively. C2–7 lordosis and C2–7 SVA improved postoperatively in all curve types. However, postoperative changes in C2–7 lordosis showed different results based on preoperative CSA, which could be related to T-1 slope and thoracic kyphosis. However, clinical outcomes showed no difference based on CSA in this study cohort. Greater C2–7 lordosis and proximal thoracic curve preoperatively were risk factors for postoperative aggravation of CSA ($p < 0.001$ and $p = 0.019$, respectively).

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KEY WORDS adolescent idiopathic scoliosis; cervical; sagittal alignment; lordosis; kyphosis; spine

ADOLESCENT idiopathic scoliosis (AIS) is a 3D deformity characterized by scoliosis in the coronal plane, vertebral rotation, and change in the sagittal profile. Hypokyphosis has been frequently found in patients with AIS, indicating that loss of cervical lordo-

sis might be common because of a compensatory mechanism.^{11,16} Recently, sagittal imbalance of the spine has received attention because dysfunction and quality of life have been reported to be correlated with it.^{3,4,12} Reportedly, a positive correlation may exist between C-7 sagittal verti-

ABBREVIATIONS AIS = adolescent idiopathic scoliosis; CSA = cervical sagittal alignment; ICC = intraclass correlation coefficient; LL = lumbar lordosis; MT = midthoracic; Oc = occiput; PT = proximal thoracic; SRS = Scoliosis Research Society; SS = sacral slope; SVA = sagittal vertical axis; TK = thoracic kyphosis; TL/L = thoracolumbar/lumbar; UIV = upper instrumented vertebra.

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cal axis (SVA) and pain or functional disability following surgeries for degenerative lumbar spine disease and deformities.⁴ However, global sagittal imbalance is not a common problem following corrective surgery for AIS.

In addition, cervical kyphosis may be related to neck pain and functional disability.¹⁹ Because cervical sagittal curvature is influenced by thoracic sagittal profiles, it can be an important consideration in corrective surgery for AIS. Most patients with AIS have been reported to show cervical kyphotic curvature.⁹ However, the effect of corrective surgery on cervical sagittal alignment (CSA) is not clearly defined. Cervical lordosis has been reported to decrease following corrective surgery in patients with Lenke type 1 AIS.⁶ In addition, the cervical spine may tend to decompensate independent of the surgical technique.¹⁴ However, there have been varied opinions on postoperative CSA. Reportedly, the effect of corrective surgery on CSA may be determined based on the preoperative thoracic sagittal profile,¹⁸ that is, cervical lordosis improves postoperatively in patients with preoperative hypokyphosis; however, a reverse effect has been observed in patients with preoperative normokyphosis.¹⁸

In these studies, no definite conclusion has been reached regarding CSA in patients with AIS. Furthermore, to our knowledge, no study has compared the postoperative changes in CSA according to curve types in patients with AIS. Thus, this study aimed to reveal the change in CSA following corrective surgery, compare the preoperative and postoperative cervical sagittal parameters according to curve types, and assess related factors for postoperative aggravation of CSA.

Methods

We studied 318 consecutive patients with AIS who underwent corrective surgery between January 2010 and December 2012 at our institution. All patients were followed for at least 2 years. Demographic data, including sex, age, height, and weight, were obtained from electronic medical records. Clinical data were assessed using Scoliosis Research Society (SRS) Outcomes Questionnaire (SRS-22) scores. Radiological data were obtained from whole-spine anteroposterior and lateral radiographs using the picture archiving communication system at our institution. Plain radiographs were obtained with patients in a standing position in both views and with their arms folded forward in lateral views.

All patients underwent corrective surgery using rod derotation with pedicle screw fixation. A hybrid method with hooks was not used. Pedicle screws were inserted at all levels. Direct vertebral rotation or thoracoplasty was not performed. All procedures were performed by a single surgeon. Curve types were determined based on Lenke classification as follows: 1) double major curve, 2) single thoracic curve, 3) double thoracic curve, and 4) other curve types.¹⁵

Patients were divided into 2 groups based on the preoperative status of CSA: the cervical lordosis group (group L) and the kyphosis group (group K). If preoperative C2–7 lordosis was $< 0^\circ$, patients were assigned to group K. Otherwise, patients were assigned to group L. All patients

were regularly followed with serial radiographs obtained 1, 6, and 12 months after surgery and yearly thereafter. This study was approved by the institutional review board of our institution, which waived the requirement for informed consent because of the retrospective nature of the data analysis.

Radiological Assessment

Radiological outcomes included the degree of curves and coronal and sagittal balance. The degree of proximal thoracic (PT), midthoracic (MT), and thoracolumbar/lumbar (TL/L) curves were assessed using the preoperative and postoperative Cobb angle method. The degree of trunk shift was assessed as the distance between the C-7 plumb line and the central sacral vertical line for whole-spine standing anteroposterior radiographs. The T-1 tilt was defined as the angle between the T-1 upper endplate and the horizontal line to the ground in standing radiographs. The sagittal parameters included occiput (Oc)–C2 and C2–7 lordosis, C2–7 SVA, T-1 slope, thoracic kyphosis (TK), lumbar lordosis (LL), sacral slope (SS), and C7–S1 SVA.

Oc–C2 lordosis was measured as the angle between the line from the anterosuperior border of the atlas to the inferior end of the occiput and lower endplates of C-2. C2–7 lordosis was defined as the Cobb angle between the lower endplates of C-2 and C-7. C2–7 SVA was defined as the distance from the posterosuperior corner of C-7 and the vertical line from the center of the C-2 body. T-1 slope was measured as the angle between the upper endplate of T-1 and the horizontal line to the ground in standing radiographs. TK was measured as the Cobb angle between the upper endplate of T-1 and the lower endplate of T-12. LL was defined as the Cobb angle between both upper endplates of L-1 and S-1. SS was defined as the angle between the upper endplates of the sacrum and the horizontal line to the ground in standing radiographs. The C7–S1 SVA was defined as the distance from the posterosuperior corner of S-1 and the vertical line from the center of the C-7 body.

Each radiological parameter was assessed by 2 independent surgeons, and the assessment was repeated after a 1-month interval. The mean values of measurements were used for analysis. The methods of measurement are summarized in Fig. 1.

Statistical Analysis

Demographic data were descriptively analyzed. Radiological parameters were compared between each follow-up period using a paired t-test. Postoperative changes in radiological parameters were compared among curve types using analysis of variance and the chi-square test. Post hoc analysis was performed using Bonferroni correction. Comparisons between groups L and K were performed using an independent t-test. Correlation analysis was performed between preoperative cervical lordosis and postoperative changes in cervical lordosis.

Intra- and interobserver agreements were assessed using the intraclass correlation coefficient (ICC) method. Each domain of SRS-22 scores was compared according

FIG. 1. Measurements of radiological, coronal, and sagittal parameters. RSH = radiological shoulder height.

to CSA using an independent t-test. Risk factor analyses were conducted using univariate analysis, followed by multivariate logistic regression analysis. Statistical analyses were performed using Statistical Package for Social Sciences software (version 21.0; SPSS, Inc.), and p values < 0.05 were considered statistically significant.

Results

Demographic Data and Curve Type

This study included 45 boys and 273 girls with a mean age of 15.5 ± 4.3 years, a mean height of 158.8 ± 8.1 cm, and a mean weight of 49.1 ± 9.3 kg. The mean follow-up was 38.4 ± 13.5 months. The mean fusion level was 11.0 ± 1.6 .

Curve types were determined as follows: 152 double

major (Lenke type 3C and 6C), 82 single thoracic (Lenke type 1), 38 double thoracic (Lenke type 2), and 46 other type curves. The most commonly selected upper instrumented vertebra (UIV) was T-4 (171 of 318, 53.8%), followed by T-3 (77 of 318, 24.2%). The most commonly selected lower instrumented vertebra was L-3 (122 of 318, 38.4%), followed by L-1 (93 of 318, 29.2%). Demographic data according to curve types are summarized in Table 1.

Comparisons of Radiological Parameters According to Curve Type

Serial radiographs showed immediate restoration of C2–7 lordosis, and this restoration was maintained throughout the follow-up. However, improvement in C2–7 SVA occurred mainly between 1 and 2 years postoperatively and was maintained thereafter (Table 2).

TABLE 1. Preoperative demographic data and radiological parameters according to curve type

Variable	Double Major (Lenke types 3C, 6C)	Single Thoracic (Lenke type 1)	Double Thoracic (Lenke type 2)	Total
No. of patients	152	82	38	318
Sex (M/F)	21:131	11:71	8:30	45:273
Age (yrs)*	15.5 ± 4.3	16.0 ± 5.3	14.6 ± 2.1	15.5 ± 4.3
Height (cm)*	159.8 ± 7.9	157.8 ± 9.1	158.7 ± 7.8	158.8 ± 8.1
Weight (kg)*	50.2 ± 9.3	48.2 ± 9.6	48.3 ± 9.7	49.1 ± 9.3
BMI (kg/m ²)*	19.6 ± 2.8	19.3 ± 3.4	19.0 ± 2.8	19.4 ± 2.9
UIV (no.)	T-3 (23), T-4 (100), T-5 (22), others (7)	T-3 (26), T-4 (50), T-5 (4), others (2)	T-2 (4), T-3 (24), T-4 (8), others (2)	T-3 (77), T-4 (171), T-5 (32), others (38)
LIV (no.)	T-12 (8), L-1 (39), L-2 (9), L-3 (69), L-4 (26), others (1)	T-12 (6), L-1 (42), L-2 (25), L-3 (9)	L-1 (11), L-2 (16), L-3 (10), others (1)	T-12 (14), L-1 (93), L-2 (55), L-3 (122), L-4 (32), others (2)
No. of fusion levels*	11.3 ± 1.5	10.7 ± 0.9	11.7 ± 1.3	11.0 ± 1.6
FU (mos)*	36.7 ± 12.8	40.1 ± 13.9	38.1 ± 13.3	38.4 ± 13.5

BMI = body mass index; FU = follow-up; LIV = lower instrumented vertebra.

* Data are reported as the mean ± SD.

A comparison of preoperative and postoperative radiological data according to curve types is presented in Table 3. Oc–C2 lordosis did not change postoperatively in any curve type. However, C2–7 lordosis and C2–7 SVA improved postoperatively regardless of curve types. TK increased postoperatively in double major and double thoracic curves (from 24.1° to 27.5° and from 20.5° to 26.3°, respectively). Regarding lumbar sagittal profiles, postoperative changes showed a slight difference according to curve types. LL increased in double major and double thoracic curves (from 43.5° to 45.3° and from 36.8° to 40.8°, respectively); however, SS decreased only in double major curves (from 37.4° to 36.1°). PT curve increased only in single thoracic curves (from 10.0° to 11.6°). C7–S1 SVA decreased in double major and double thoracic curves.

Degrees of postoperative changes in sagittal parameters revealed no difference among curve types, except for PT curve (Table 4). Post hoc analysis showed that PT curve increased in single thoracic curve but decreased in double thoracic curve ($p = 0.043$).

Postoperative changes in C2–7 lordosis did not differ

according to UIV ($p = 0.200$). These results were also confirmed in subgroup analysis based on each curve type (double major $p = 0.446$, single thoracic $p = 0.806$, and double thoracic $p = 0.165$).

Sagittal Parameters According to Preoperative CSA

Of the total number of patients, 67.0% (213 of 318) and 54.4% (173 of 318) showed preoperative and postoperative cervical kyphotic alignment (Fig. 2). Average C2–7 lordosis was 9.0° in group L and –12.7° (kyphotic) in group K. Although C2–7 lordosis increased in group K (from –12.7° to –4.8°; $p < 0.001$), it did not change postoperatively in group L (from 9.0° to 6.9°; $p = 0.115$) (Fig. 3). In addition, T-1 slope increased postoperatively in group K (from 10.7° to 12.3°; $p = 0.004$); however, it decreased in group L (from 19.1° to 18.4°; $p = 0.400$). TK increased in both groups. Each sagittal parameter according to preoperative CSA is summarized in Table 5. Only the postoperative changes in C2–7 lordosis showed differences between groups L and K in all 3 curve types (Table 6).

Preoperative C2–7 lordosis was negatively correlated with postoperative changes in C2–7 lordosis. Pearson correlation coefficients were –0.488, –0.475, and –0.377 in double major, single thoracic, and double thoracic curves, respectively. Scatter plots are shown in Fig. 4.

Clinical Outcomes According to CSA

No domain of SRS-22 scores showed any difference according to CSA (lordosis vs kyphosis) preoperatively and postoperatively (Table 7).

Risk Factors for Aggravation of CSA

Univariate analyses revealed that C2–7 cervical lordosis ($p < 0.001$), T-1 slope ($p = 0.001$), TK ($p = 0.031$), SS ($p = 0.039$), and PT curve ($p = 0.012$) were related to progression of cervical kyphosis postoperatively. However, multivariate logistic regression analysis revealed that only preoperative C2–7 cervical lordosis and PT curve were risk

TABLE 2. Serial follow-up of cervical sagittal parameters

Exam	C2–7 Lordosis (°)*	p Value†	C2–7 SVA (mm)	p Value†
Preop	–5.8 ± 13.2		24.2 ± 8.9	
Postop 1 mo	–2.9 ± 11.2	0.005	23.5 ± 7.8	0.557
Postop 6 mos	–2.5 ± 11.5	0.583	24.4 ± 10.0	0.878
Postop 1 yr	–2.5 ± 12.0	0.914	23.3 ± 8.5	0.458
Postop 2 yrs	–0.5 ± 12.1	0.111	21.8 ± 7.5	0.019
Postop 3 yrs	0.6 ± 14.7	0.185	19.7 ± 7.8	0.138
Postop 4 yrs	–0.3 ± 13.8	0.424	20.4 ± 9.4	0.768
Final visit	–1.1 ± 13.6	0.166	20.0 ± 9.4	0.828

Data are reported as the mean ± SD.

* Negative value indicates that the curve is kyphotic.

† Comparisons between each consecutive visit.

TABLE 3. Comparisons of pre- and postoperative radiological parameters according to curve type

Radiological Parameter	Double Major (Lenke types 3C & 6C)			Single Thoracic (Lenke type 1)			Double Thoracic (Lenke type 2)		
	Preop	Final Visit	p Value	Preop	Final Visit	p Value	Preop	Final Visit	p Value
PT curve (°)	22.0 ± 8.7	8.4 ± 6.2	<0.001	27.5 ± 7.3	10.2 ± 5.1	<0.001	42.0 ± 12.8	19.9 ± 6.3	<0.001
MT curve (°)	50.8 ± 12.0	12.8 ± 7.0	<0.001	52.0 ± 10.2	9.6 ± 5.0	<0.001	57.3 ± 13.2	11.4 ± 6.1	<0.001
TL/L curve (°)	44.1 ± 12.0	14.1 ± 7.9	<0.001	27.4 ± 7.5	6.3 ± 5.7	<0.001	26.0 ± 9.4	4.3 ± 4.0	<0.001
Trunk shift (mm)*	-6.9 ± 13.2	-6.6 ± 10.6	0.796	6.0 ± 12.6	-3.8 ± 9.9	<0.001	3.5 ± 13.7	-7.1 ± 10.2	<0.001
RSH (mm)†	-14.1 ± 12.4	4.5 ± 10.4	<0.001	-17.2 ± 12.8	5.7 ± 10.7	<0.001	-3.4 ± 10.5	10.0 ± 11.6	<0.001
T-1 tilt (°)‡	-3.0 ± 7.1	2.5 ± 5.7	<0.001	-3.4 ± 6.6	4.8 ± 4.7	<0.001	9.2 ± 7.3	11.2 ± 5.3	0.043
C0-2 CL (°)	27.3 ± 8.7	27.7 ± 8.5	0.456	26.5 ± 8.8	27.7 ± 7.9	0.174	27.9 ± 7.5	30.1 ± 9.2	0.091
C2-7 CL (°)‡	-5.6 ± 12.8	-0.4 ± 13.1	<0.001	-7.6 ± 13.3	-3.2 ± 13.6	0.004	-4.6 ± 16.5	-1.2 ± 16.5	0.097
C2-7 SVA (mm)	24.4 ± 9.3	20.2 ± 8.8	<0.001	24.5 ± 8.7	20.6 ± 9.5	<0.001	23.4 ± 7.9	20.0 ± 10.0	0.013
T-1 slope (°)	13.4 ± 8.3	14.3 ± 8.8	0.223	11.7 ± 8.3	12.6 ± 9.1	0.312	13.4 ± 10.9	15.8 ± 11.9	0.049
TK (°)	24.1 ± 11.6	27.5 ± 10.3	<0.001	23.3 ± 12.7	24.9 ± 11.3	0.191	20.5 ± 13.5	26.3 ± 14.3	<0.001
LL (°)	43.5 ± 10.8	45.3 ± 10.5	0.024	44.8 ± 11.5	44.7 ± 10.3	0.927	36.8 ± 14.9	40.8 ± 13.4	0.044
SS (°)	37.4 ± 9.1	36.1 ± 7.7	0.014	36.8 ± 10.6	36.1 ± 10.0	0.401	35.9 ± 9.6	36.4 ± 9.6	0.679
Pelvic tilt (°)	10.5 ± 7.7	11.4 ± 7.5	0.078	10.0 ± 5.9	11.6 ± 6.9	0.006	12.3 ± 8.9	11.1 ± 6.5	0.251
C7-S1 SVA (mm)	0.4 ± 25.2	-6.5 ± 27.3	0.008	-1.6 ± 28.5	-8.0 ± 29.9	0.129	14.3 ± 30.4	-5.6 ± 27.6	<0.001

CL = cervical lordosis; RSH = radiological shoulder height.

Data are reported as the mean ± SD.

* Negative value indicates that the C-7 plumb line is located on the left side of center of sacrum.

† Negative value indicates that the left side is more depressed than the right side.

‡ Negative value indicates that the curve is kyphotic.

factors for aggravation of CSA ($p < 0.001$ and $p = 0.019$, respectively) (Table 8).

Reliability Assessment of Measurements

Inter- and intraobserver reliability to assess sagittal parameters are summarized in Table 9. Most parameters showed excellent interobserver and intraobserver reliability (ICC > 0.8).

Discussion

CSA and global sagittal balance in patients with AIS have recently received attention. Our study showed that cervical lordosis improved in patients with preoperative

cervical kyphosis; however, it did not change in patients with preoperative cervical lordosis. Several studies have evaluated postoperative changes in CSA. It has been proposed that changes in the cervical sagittal profile vary according to the preoperative sagittal profile of TK.^{5,18} The result was confirmed by our study, which showed larger T-1 slope and TK in group L preoperatively and postoperatively.

Reportedly, TK influences C2-7 lordosis through the T-1 slope,¹³ and T-1 slope can be an important parameter to correlate cervical and thoracic sagittal alignment in AIS.¹⁷ Interestingly, T-1 slope increased in group K ($p = 0.004$), but it did not change in group L ($p = 0.400$), which correlated with no change in cervical lordosis in group

TABLE 4. Comparisons of postoperative changes in sagittal alignment among curve types

Variable	Double Major (Lenke types 3C & 6C)	Single Thoracic (Lenke type 1)	Double Thoracic (Lenke type 2)	p Value
Ch_C0-2 CL (°)	0.4 ± 7.0	1.3 ± 8.1	2.2 ± 7.8	0.388
Ch_C2-7 CL (°)	5.2 ± 13.1	4.4 ± 13.3	3.5 ± 12.5	0.720
Ch_C2-7 SVA (mm)	-4.2 ± 8.1	-3.9 ± 8.9	-3.4 ± 8.0	0.851
Ch_T-1 slope (°)	0.9 ± 8.7	0.9 ± 7.7	2.5 ± 7.4	0.547
Ch_TK (°)	3.5 ± 10.2	1.6 ± 10.7	5.9 ± 7.2	0.088
Ch_LL (°)	1.8 ± 9.5	-0.1 ± 11.1	4.0 ± 11.9	0.119
Ch_SS (°)	-1.4 ± 6.9	-0.8 ± 8.0	0.5 ± 7.4	0.350
Ch_pelvic tilt (°)	0.8 ± 5.8	1.6 ± 4.9	-1.2 ± 6.1	0.049*
Ch_C7-S1 SVA (mm)	-6.9 ± 31.8	-6.4 ± 37.2	-19.8 ± 33.5	0.088

Ch_ = changes of variables between preoperative period and final follow-up.

Data are reported as the mean ± SD.

* Post hoc analysis revealed that there was a difference between Lenke types 1 and 2 ($p = 0.043$).

FIG. 2. Distribution of CSA in the preoperative and postoperative periods. A: Double major curve. B: Single thoracic curve. C: Double thoracic curve. D: Total.

L ($p = 0.115$) in our study. This indicates that a different compensatory mechanism existed between the 2 groups. It has also been suggested that T-1 slope and C2–7 SVA are related to health-related quality of life in patients with AIS.²³ However, we found no difference in C2–7 SVA according to preoperative CSA.

Reportedly, C2–7 lordosis is related to the global thoracic sagittal alignment in Lenke type 5C curves.²⁰ In another study, cervical lordosis decreased slightly in Lenke type 3C and 6C curves.²² However, to our knowledge, no studies have compared CSA by different curve types. Based on the results of our study, C2–7 lordosis increased in 3 types of curves, although it did not reach statisti-

cal significance in double thoracic curves ($p = 0.097$). In double major curves, TK increased without the change in T-1 slope postoperatively. In double thoracic curves, both T-1 slope and TK increased postoperatively, which might be the result of instrumentation to a more upper thoracic level. This could lead to restoration of cervical lordosis.

However, the degree of increasing TK was minimal in the single thoracic curve (from 23.3° to 24.9° ; $p = 0.191$), which led to only slight change in T-1 slope (from 11.7° to 12.6° ; $p = 0.312$). This result was different in a recently published study by Hiyama et al.,⁶ which showed that reduction in cervical lordosis after operation is affected by the loss of TK in Lenke type 1 curves. The hypokyphotic effect of posterior corrective surgery for Lenke type 1 and 2 curves was also suggested.⁷ However, we could not explain the effect of scoliosis types on CSA based on the above findings.

The relationship between cervical kyphotic change and UIV has been controversial. Reportedly, kyphotic changes in C2–7 sagittal alignment were correlated with the level of UIV in Lenke type 1 curves.¹⁴ In contrast, it was suggested that postoperative CSA is independent of UIV in Lenke type 3C and 6C curves.²² Our study also demonstrated that CSA was unrelated to UIV, regardless of curve types. However, our results cannot be compared directly to those of previous studies because patients who underwent correction by hybrid constructs were included in those studies.¹⁴ In contrast, we used only pedicle screws.

Inherent loss of cervical lordosis in patients with AIS has been suggested by several investigators.⁹ Reportedly, cervical hypolordosis improves with use of the postero-

FIG. 3. Postoperative changes in C2–7 lordosis in groups L (preoperative lordotic group) and K (preoperative kyphotic group).

TABLE 5. Pre- and postoperative sagittal parameters according to preoperative CSA

Sagittal Parameter	Group L (n = 105)			Group K (n = 213)		
	Preop	Final Visit	p Value	Preop	Final Visit	p Value
C0–2 CL (°)	24.4 ± 8.7	26.1 ± 8.4	0.015	28.5 ± 8.2	29.0 ± 8.5	0.421
C2–7 CL (°)*	9.0 ± 8.1	6.9 ± 13.4	0.115	–12.7 ± 8.7	–4.8 ± 12.1	<0.001
C2–7 SVA (mm)	23.7 ± 9.0	20.2 ± 8.9	<0.001	24.5 ± 8.9	19.9 ± 9.6	<0.001
T-1 slope (°)	19.1 ± 8.1	18.4 ± 9.6	0.400	10.7 ± 7.5	12.3 ± 8.2	0.004
TK (°)	30.1 ± 11.5	32.8 ± 11.8	0.007	20.9 ± 11.0	24.6 ± 10.0	<0.001
LL (°)	42.5 ± 12.2	44.8 ± 10.6	0.022	43.1 ± 11.7	44.8 ± 11.0	0.021
SS (°)	34.7 ± 11.3	34.6 ± 10.4	0.863	37.6 ± 9.5	36.2 ± 7.9	0.010
Pelvic tilt (°)	11.2 ± 8.6	11.5 ± 7.2	0.635	10.5 ± 6.7	11.1 ± 7.1	0.113
C7–S1 SVA (mm)	5.3 ± 24.1	–7.3 ± 28.4	<0.001	0.0 ± 28.5	–7.7 ± 28.0	0.002

Data are reported as the mean ± SD.

* Negative value indicates that the curve is kyphotic.

medial translation technique, although the proportion of patients who maintain physiological cervical lordosis remains low.⁸ It has been suggested that inherent rigidity of the cervical spine limits changes in CSA.¹ In our study, the incidence of cervical kyphosis in AIS was as high as 67.0%, and the proportion was still high at 54.4% postoperatively.

Regardless of the high incidence of cervical kyphosis, the numbers of patients who complained of neck pain are not likely to be higher than expected. In fact, no correlation was found between SRS-22 scores and CSA in our study cohort. However, a correlation between neck pain and cervical sagittal malalignment has been recently proposed.²¹ In addition, it could be a problem in the future, even if it is not observed currently.

Although cervical sagittal imbalance existed, global sagittal balance, as measured by C7–S1 SVA, was relatively well maintained in all curve types in our study. It has been suggested that the global spine is well balanced with spontaneous adjustment despite cervical sagittal imbalance.²⁴ In contrast, one study proposed that LL may influence cervical lordosis.² It was thought that thoracic

sagittal profiles, T-1 slope, and C2–7 lordosis correlated and varied together. However, the effect of correction on lumbar sagittal profiles has not been clearly defined.

In general, it is known that CSA does not directly relate to lumbar sagittal profiles.¹³ However, LL increased postoperatively in double major and double thoracic curves, which might be related to more distal instrumentation. Interestingly, PT curve also increased in double major and single thoracic curves but not in double thoracic curves. In addition, greater PT curve is related to postoperative aggravation of cervical lordosis. La Maida et al.¹⁰ have proposed that this is a compensatory mechanism. However, further study will be required to reveal the relationship between CSA and PT curve.

This study had a few limitations. First, clinical significance was not considered. Although cervical sagittal malalignment is generally known to be related to pain and dysfunction, it is questionable whether patients with AIS feel neck pain more frequently than normal control subjects. Although SRS-22 score was used for analysis, it was not specified for neck pain or disability. Second, only coronal curve types were considered. It has been proposed

TABLE 6. Comparisons of postoperative changes of radiological parameters according to preoperative CSA in each curve type

Radiological Parameter	Double Major (Lenke types 3C & 6C)			Single Thoracic (Lenke type 1)			Double Thoracic (Lenke type 2)		
	Group L (n = 49)	Group K (n = 103)	p Value	Group L (n = 23)	Group K (n = 59)	p Value	Group L (n = 16)	Group K (n = 22)	p Value
Ch_C0–2 CL (°)	1.9 ± 6.7	–0.3 ± 7.1	0.154	2.9 ± 6.6	0.7 ± 8.6	0.297	0.5 ± 9.0	3.4 ± 6.7	0.259
Ch_C2–7 CL (°)	–1.9 ± 13.1	8.7 ± 11.7	<0.001	–4.2 ± 11.6	7.3 ± 12.7	0.001	–2.6 ± 14.3	7.8 ± 9.0	0.009
Ch_C2–7 SVA (mm)	–3.9 ± 7.9	–4.2 ± 8.8	0.278	–1.7 ± 6.2	–4.7 ± 9.5	0.200	–3.0 ± 6.6	–3.8 ± 9.1	0.771
Ch_T-1 slope (°)	–0.7 ± 8.0	1.7 ± 8.3	0.020	1.3 ± 6.7	0.8 ± 8.1	0.807	0.5 ± 7.6	3.9 ± 7.1	0.169
Ch_TK (°)	2.8 ± 10.0	3.7 ± 10.3	0.440	1.4 ± 10.1	1.7 ± 10.9	0.911	5.8 ± 7.8	6.0 ± 7.0	0.933
Ch_LL (°)	2.4 ± 10.0	1.7 ± 10.9	0.634	–1.0 ± 12.4	0.2 ± 10.7	0.682	5.4 ± 8.7	3.0 ± 13.9	0.558
Ch_SS (°)	–0.1 ± 6.8	–1.4 ± 7.7	0.164	–0.8 ± 7.7	–0.7 ± 8.2	0.965	1.6 ± 6.0	–0.3 ± 8.3	0.431
Ch_pelvic tilt (°)	0.3 ± 6.1	0.6 ± 5.6	0.648	2.3 ± 5.7	1.4 ± 4.7	0.487	–2.1 ± 7.1	–0.5 ± 5.3	0.445
Ch_C7–S1 SVA (mm)	–12.5 ± 30.8	–7.7 ± 35.2	0.245	–3.3 ± 32.6	–7.5 ± 38.9	0.672	–23.1 ± 26.9	–17.5 ± 38.0	0.618

Ch_ = changes of variables between pre- and postoperative period.

Data are reported as the mean ± SD. Negative value indicates that the values measured in the postoperative period are lower than those measured in the preoperative period.

FIG. 4. Scatter plots showing the correlation between postoperative changes in C2–7 lordosis and preoperative C2–7 lordosis. **A:** Double major curve. **B:** Single thoracic curve. **C:** Double thoracic curve.

that the apex of TK is important for the position of cervical sagittal balance.⁹ Third, it was impossible to analyze the effect of the surgical technique because only the posterior derotational maneuver by pedicle screw fixation was used.

Hybrid techniques with hooks or anterior correction could lead to different results.

However, our study is meaningful because, to our knowledge, it is the first study to compare postoperative

TABLE 7. Pre- and postoperative comparisons of SRS-22 scores by CSA

SRS-22 Domain	Preop Score			Final FU Score		
	Cervical Lordosis (n = 105)	Cervical Kyphosis (n = 213)	p Value	Cervical Lordosis (n = 145)	Cervical Kyphosis (n = 173)	p Value
Function	2.78 ± 0.58	2.67 ± 0.49	0.209	2.14 ± 0.45	2.26 ± 0.45	0.186
Pain	3.33 ± 0.36	3.29 ± 0.43	0.612	3.00 ± 0.33	3.00 ± 0.32	0.904
Self-image	2.07 ± 0.47	2.08 ± 0.35	0.911	2.03 ± 0.27	2.12 ± 0.30	0.107
Mental health	2.57 ± 0.42	2.49 ± 0.37	0.209	2.22 ± 0.42	2.18 ± 0.32	0.526
Subtotal	2.69 ± 0.30	2.63 ± 0.23	0.191	2.35 ± 0.24	2.39 ± 0.20	0.329
Satisfaction	2.00 ± 0.78	2.17 ± 0.79	0.578	1.71 ± 0.78	1.76 ± 0.64	0.724
Total	2.66 ± 0.29	2.61 ± 0.23	0.195	2.29 ± 0.25	2.33 ± 0.20	0.349

Data are reported as the mean ± SD.

TABLE 8. Preoperative radiological risk factors for progression of cervical kyphosis

Radiological Parameter	Restoration of CL (n = 205)	Aggravation of CL (n = 106)	p Value (univariate)	p Value (multivariate)
UT curve angle (°)	26.2 ± 10.8	26.0 ± 12.5	0.887	NE
MT curve angle (°)	52.0 ± 12.7	50.9 ± 12.6	0.498	NE
TL/L curve angle (°)	36.2 ± 14.2	35.3 ± 13.8	0.574	NE
Trunk shift (mm)*	-1.3 ± 15.1	-1.7 ± 15.4	0.805	NE
T-1 tilt (°)†	-1.4 ± 7.7	-0.8 ± 9.1	0.553	NE
C0–2 CL (°)	27.2 ± 8.5	27.3 ± 8.9	0.944	NE
C2–7 CL (°)‡	-9.0 ± 12.1	0.7 ± 13.1	<0.001	<0.001
C2–7 SVA (mm)	23.9 ± 8.6	24.8 ± 9.5	0.435	NE
T-1 slope (°)	12.3 ± 8.2	15.7 ± 9.1	0.001	0.696
TK (°)	22.8 ± 11.4	25.9 ± 12.8	0.031	0.544
LL (°)	43.5 ± 11.4	25.9 ± 12.8	0.204	NE
SS (°)	37.6 ± 9.1	34.8 ± 11.8	0.039	0.372
Pelvic tilt (°)	10.0 ± 7.3	12.2 ± 7.4	0.012	0.019
C7–S1 SVA (mm)	1.3 ± 28.0	2.3 ± 25.7	0.780	NE

NE = not entered; UT = upper thoracic.

Data are reported as the mean ± SD.

* Negative value indicates that the C-7 plumb line is located on the left side of center of sacrum.

† Negative value indicates that the left side is more depressed than the right side.

‡ Negative value indicates that the curve is kyphotic.

changes in CSA based on different curve types as well as preoperative cervical sagittal balance. Furthermore, another strength of our study is the relatively large number of patients.

Conclusions

Many patients (54.4%) still showed cervical kyphotic alignment postoperatively regardless of the trend of improvement in CSA. C2–7 lordosis and C2–7 SVA improved postoperatively in all curve types. However, postoperative changes in C2–7 lordosis showed different results according to preoperative CSA, which could be related to T-1 slope and TK. However, clinical outcomes showed no difference according to CSA in this study cohort. Preoperative greater C2–7 lordosis and PT curve were risk factors for postoperative aggravation of CSA ($p < 0.001$ and $p = 0.019$, respectively).

TABLE 9. Interobserver and intraobserver reliability of each radiological parameter

Radiological Parameter	Interobserver	Intraobserver
C0–2 CL	0.840	0.972
C2–7 CL	0.924	0.775
C2–7 SVA	0.973	0.989
T-1 slope	0.927	0.894
TK	0.932	0.940
LL	0.909	0.961
SS	0.902	0.926
Pelvic tilt	0.919	0.922
C7–S1 SVA	0.986	0.975

Data are reported as the ICC.

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Disclosures

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Author Contributions

Conception and design: Cho. Acquisition of data: Choi. Analysis and interpretation of data: Cho, Hwang, Choi, DH Lee. Drafting the article: Cho. Critically revising the article: Hwang, CS Lee. Reviewed submitted version of manuscript: Hwang, Choi, DH Lee, CS Lee. Approved the final version of the manuscript on behalf of all authors: Cho. Statistical analysis: DH Lee. Administrative/technical/material support: Hwang. Study supervision: Hwang, DH Lee, CS Lee.

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