Impact of Growing Rod Surgery for Early-Onset Scoliosis on Cervical Sagittal Alignment

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Abstract:

Study Design: Single-institution retrospective study.

Objective: To assess the impact of growing rods (GRs) on postoperative cervical sagittal alignment in patients with early-onset scoliosis (EOS).

Summary of Background Data: Cervical sagittal malalignment is associated with neck and cervical spine dysfunction. The impact of surgery for adolescent idiopathic scoliosis on postoperative changes in cervical spine alignment has been reported by studies. Nevertheless, research on sagittal and spinopelvic parameters in patients with EOS is limited.

Methods: In this study, 28 patients who underwent GR and were followed up until final fusion or bone maturity were included. Standing whole-spine radiographs obtained before GR, after the initial GR surgery, and at the final follow-up were utilized to measure the radiographic parameters. Patients with one or more of the previously reported poor prognostic factors were included in the cervical malalignment (CM) group (n=13), and those with none of the factors were included in the non-CM group (n=15) at the final follow-up, which was followed by correlation analysis and multivariate logistic regression analysis.

Results: No significant change in sagittal alignment between preoperative and final follow-up measurements was found. Pearson correlation analysis revealed a significant positive correlation between the change in the C2-7 angle and T1 slope (T1S) or thoracic kyphosis and a negative correlation between the change in the C2-7 angle and T1S minus C2-7 angle (T1S−CL). The percentage of patients in the CM group increased from 25% preoperatively to 46% at the final follow-up but without significant change. The CM group had significantly smaller preoperative C2-7 angles and lumbar lordosis (LL) and larger T1S−CL and pelvic incidence minus LL (PI−LL) values than the non-CM group.

Conclusion: Smaller preoperative C2-7 angles and larger T1S−CL values were identified as risk factors for CM. Postoperative CM is more likely to occur in patients with reduced compensatory function to maintain preoperative cervical kyphosis.

Keywords:

early-onset scoliosis, growing rod, cervical sagittal alignment, T1 slope, T1S minus C2-7 angle, C2-7 angle, cervical malalignment

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Introduction

In the treatment of early-onset scoliosis (EOS), progression of spinal deformity must be controlled, and normal lung growth until skeletal maturity should be promoted[1,2]. Dual growing rods (GRs) are a commonly utilized surgical method for severe EOS and typically culminate in final fusion (FF)[3,4].

Existing studies on GR surgery have mainly addressed correcting coronal plane deformities, preserving lung space, and managing complications associated with frequent extension surgeries. Nevertheless, research on the sagittal profiles of spinal alignment, including the cervical spine is lacking[1,4,5], despite recent reports on the sagittal plane and

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spinopelvic parameters in patients with EOS[6,7].

Cervical sagittal malalignment is associated with neck pain and function limitations in the cervical spine[8], therefore, changes in cervical sagittal alignment during surgical interventions must be considered. Postoperative changes in the thoracic spine alignment can affect cervical spine alignment. In adolescent idiopathic scoliosis (AIS), cervical kyphosis in postoperative patients with thoracic hypokyphosis has been reported, which indicates a correlation between postoperative thoracic kyphosis (TK) and cervical sagittal alignment. Nonetheless, Yagi et al and Luo et al reported a strong correlation between postoperative cervical lordosis (CL) angle and T2 tilt rather than TK, which showed a strong correlation with global alignment[9,10]. Although there is controversy in the literature, several reports on AIS have focused on postoperative changes in cervical spine alignment. However, reports on EOS are lacking. Therefore, this study aimed to investigate the changes in postoperative cervical sagittal alignment in patients with EOS who underwent FF surgery following GR surgery.

Materials and Methods

In this study, patients with EOS who underwent traditional GR surgery with multiple rod extensions and FF surgery or reached bone maturity without FF surgery at a single institution between 2004 and 2017 were examined. The bone maturity was defined as Risser grade 4 or 5. Inclusion criteria are as follows: had initiation of dual GR surgery before triradiate cartilage closure, underwent ≥1 lengthening procedure, underwent FF surgery or reached skeletal maturity without FF surgery, and had a follow-up of ≥2 years after the last surgery. Patients who underwent cervical spine fusion were excluded. Moreover, owing to concerns about their ability to follow instructions during standing whole-spine radiographs, patients with mental retardation were excluded.

Radiographic analysis

Evaluation was carried out using standing whole-spine radiographs taken before GR surgery, after the initial GR surgery, and at the final follow-up. The standing whole-spine radiographs were conducted as described previously[9]. The researchers asked the patients to stand looking straight ahead (not with the chin down) with their knees locked, their feet at shoulder width, and their arms straight at the side. The patients were then asked to flex their shoulders forward approximately at 30° with their elbows bent and their knuckles in the supraclavicular fossa bilaterally and to look at their knees. The radiographic coronal parameters included Cobb angles for the proximal thoracic, main thoracic, and thoracolumbar/lumbar curves. Radiographic cervical sagittal parameters included the C2-7 angle (CL), T1 slope (T1S), T1S minus the C2-7 angle (T1S−CL), and C2-7 sagittal vertical axis (C2-7 SVA). Other sagittal parameters included TK (T2−T12), pelvic incidence (PI), lumbar lordosis (LL), PI minus LL (PI−LL), pelvic tilt, sacral slope, and global SVA. Each parameter was measured as previously reported[11,12]. As an indicator of bone maturity, the Risser grade was measured using anteroposterior standing whole-spine radiographs. Each parameter was compared between the groups preoperatively, postoperatively, and at the final follow-up. To examine the impact of preoperative and postoperative changes in each parameter on the C2-7 angle, a correlation analysis of the amount of change (Δ) was carried out.

A cervical sagittal malignment was defined based on the following criteria: C2-7 angle <−10°, T1S−CL >20°, and C2-7 SVA >40 mm (13). Patients with ≥1 of these factors were included in the cervical malalignment (CM) group, whereas those with none of these factors were included in the non-CM group. Within-group comparisons were carried out for each parameter preoperatively and at the final follow-up. To investigate factors that contribute to worsened cervical sagittal alignment postoperatively, patients without CM before surgery were further analyzed. Patients who were included in the non-CM group preoperatively were divided into two groups according to whether they remained non-CM (non-CM → non-CM) or developed CM (non-CM → CM) at the final follow-up visit.

Statistical analysis

All data are presented as mean±standard deviation. Unpaired two-tailed Student's *t*-test was employed for single comparisons between the non-CM and CM groups. To compare preoperative, postoperative, and final follow-up values, repeated-measures analysis of variance was utilized. To evaluate the relationship between each parameter in the preoperative and postoperative coronal and sagittal alignments and changes in sagittal alignment, Pearson correlation analysis was employed. All the statistical analyses were carried out using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $P<.05$.

Results

Patient demographics

In the present study, a total of 28 patients with EOS were included, with 19 (67.9%) females and 9 (32.1%) males. The mean age at the first surgery was 8.4±3.0 (range, 4−13) years, and the mean age at the final follow-up was 17.8±3.0 (range, 14−24) years. On average, patients underwent 4.5±3.5 (range, 1−15 times) rod lengthening, and the mean follow-up period was 113.6±50.0 (range, 19−190) months.

Diagnoses were idiopathic scoliosis in 10 patients; syndromic scoliosis in 16 patients (SOTOS syndrome, *n*=2; Arnold-Chiari malformation, *n*=1; Noonan syndrome, *n*=1; Klippel-Feil syndrome, *n*=1; congenital spondyloepiphyseal dysplasia, *n*=3; tetralogy of Fallot, *n*=3; Marfan syndrome, *n*=1; craniosynostosis, *n*=1; and unknown, *n*=3); and congenital scoliosis in two patients.

Table 1. Mean Values of Coronal and Sagittal Cervical Alignment Parameters.

Parameter	Preoperative	Postoperative	Final follow-up	*P* value	*P** value
Cobb angle					
Proximal thoracic, °	38.1±17.0	28.3±13.2	25.0±12.3	**<0.001*****	**<0.001*****
Main thoracic, °	74.5±14.2	38.9±16.2	29.1±14.2	**<0.001*****	**<0.001*****
Thoracolumbar/lumbar, °	38.7±16.5	16.7±14.1	15.0±13.3	**<0.001*****	**<0.001*****
Sagittal alignment					
C2-7 angle, °	6.0±15.9	7.9±18.0	−3.4±14.2	0.676	**0.023***
T1 slope, °	16.2±13.3	13.9±7.9	9.0±10.5	0.428	**0.028***
T1S − CL, °	10.2±12.2	5.9±13.6	12.4±11.1	0.225	0.482
TK, °	29.9±21.4	21.4±12.9	24.7±11.7	0.007	0.257
PI, °	46.8±9.6	46.4±11.3	46.4±11.7	0.773	0.920
LL, °	8.9±15.2	12.8±12.1	0.5±14.2	0.155	**0.015***
PI − LL, °	9.2±15.8	12.0±12.9	1.6±14.3	0.307	**0.039***
PT, °	11.7±11.4	12.4±11.6	9.7±12.6	0.828	0.555
SS, °	35.5±11.5	34.6±8.6	39.0±12.3	0.766	0.281
C2-7SVA, mm	14.3±8.9	11.4±7.4	12.7±19.3	0.192	0.698
SVA, mm	0.2±32.1	6.4±36.3	−8.0±31.8	0.531	0.303

Mean±*SD* (standard deviation)

P value, comparison between preoperative and postoperative values; *P** value, comparison between preoperative and final follow-up values

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

T1S − CL indicates T1 slope minus C2-7 angle; TK, thoracic kyphosis; PI, pelvic incidence; LL, lumbar lordosis; PI − LL, PI minus LL; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis

Table 2. Correlation Analysis of ΔC2-7 Angle.

Correlation*	Correlation coefficient (*r*)	*P* value
ΔC2-7 angle-ΔT1S	0.541	0.003**
ΔC2-7 angle-ΔT1S − CL	−0.470	0.012*
ΔC2-7 angle-ΔTK	0.576	0.002**
ΔC2-7 angle-ΔC2-7 SVA	0.038	0.848
ΔC2-7 angle-ΔSVA	0.181	0.355

*Pearson correlation

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

Δ=parameter change preoperative to final follow-up

T1S − CL indicates T1 slope minus C2-7 angle;

TK, thoracic kyphosis; SVA, sagittal vertical axis

Radiographic outcomes

The mean Cobb angle of the main thoracic curve significantly improved from 74.5°±14.2° to 38.9°±16.2° after GR surgeries, with the correction being maintained until the final follow-up (29.0°±14.2°; correction rate, 60.7%) (Table 1). Likewise, the mean Cobb angles of the proximal thoracic and thoracolumbar curves revealed significant improvement after the GR placement surgery and remained stable until the final follow-up.

Regarding sagittal alignment, the mean TK decreased significantly from 29.9°±21.4° to 21.4°±12.9° after GR placement (P=0.002). This decrease was maintained at the final follow-up, although it was not statistically significant (25.1°±11.4°, P=0.116). At the final follow-up, the mean C2-7 angle and T1 slope revealed a significant decrease with significant differences (C2-7 angle 6.0°±16.3° to −4.5°±14.5°, P=.008; T1 slope 17.1°±13.1° to 9.0°±10.3°, P=.008). No significant changes were observed in any other parameters (Table 1).

Correlation analysis of postoperative reciprocal changes in cervical sagittal alignment

To assess the presence of reciprocal changes in patients with EOS who underwent GR surgery, we investigated the correlation between the ΔC2-7 angle (Δ=change between preoperative and final follow-up values) and changes in other sagittal parameters before GR surgery and at the final follow-up. Pearson correlation analysis revealed a significant positive correlation between ΔC2-7 angle and ΔT1S as well as ΔTK (ΔT1S, r=0.541, P=.003; TK, r=0.576, P=.002). Furthermore, a significant negative correlation between ΔC2-7 angle and ΔT1S−CL (r=−0.470, P=.012) was found (Table 2).

Comparison of postoperative cervical sagittal alignment between the CM and non-CM groups

Of the 28 patients, 15 and 13 were included in the non-CM and CM groups, respectively. The mean age at the initial surgery and the final follow-up, number of extensions, follow-up period, the grade of Risser sign, and presence of underlying diseases were similar between the two groups (Table 3). Coronal radiographic parameters revealed no significant differences. In terms of the sagittal parameters, significant differences were observed in the C2-7 angle, T1S, and T1S−CL at the final follow-up (non-CM vs. CM: C2-7 angle, 7.5°±8.1° vs −15.8°±8.0°; T1S, 13.4°±5.3° vs 3.9°±

Table 3. Demographics in Postoperative Non-CM and CM Groups.

	Non-CM (*n*=15, 53.6%)	CM (*n*=13, 46.4%)	*P* value
Sex (male/female)	6 (40.0%)/9 (60.0%)	3 (23.1%)/10 (76.9%)	0.581
Mean age at first operation (years)	8.2±3.0	8.7±3.1	0.671
Mean age at final follow-up (years)	17.9±2.8	17.7±3.3	0.835
Mean number of lengthening (times)	4.9±3.9	4.2±3.2	0.604
Follow-up period (months)	117.5±51.0	109.2±50.6	0.672
Risser sign			
Grade 4	3 (20.0%)	4 (30.8%)	0.826
Grade 5	12 (80.0%)	9 (69.2%)	
Diagnoses			
Idiopathic scoliosis	2 (13.3%)	8 (61.5%)	
Syndromic scoliosis	11 (73.3%)	5 (38.5%)	0.526
Congenital scoliosis	2 (13.3%)	0 (0.0%)	

Mean±*SD* (standard deviation)
* *P*<0.05, ** *P*<0.01, *** *P*<0.001

12.8°; T1S−CL, 6.0°±7.3° vs 19.8°±10.4°). In terms of the cervical spine, the preoperative C2-7 angle was significantly smaller, and T1S−CL was significantly larger in the CM group than that in the non-CM group (non-CM vs CM: C2-7 angle 13.5°±13.8° vs −2.6°±14.0°, *P*=.005; T1S−CL 6.7°±13.8° vs 14.1°±8.8°, *P*=.018) (Table 4).

Comparison of postoperative cervical sagittal alignment between the non-CM → non-CM and non-CM → CM groups

To investigate the factors contributing to CM at the final follow-up, we examined patients without CM before surgery. We divided them into two groups according to the cervical alignment at the final follow-up: those who remained non-CM before surgery and during the final follow-up (non-CM → non-CM group) and those who were non-CM before surgery but became CM at the final follow-up (non-CM → CM group) (Table 5). Preoperatively, the C2-7 angle in the non-CM → CM group was significantly smaller (4.9°±8.6° vs 16.4°±12.0°), and T1S−CL in the non-CM → CM group was significantly larger (10.1°±4.8° vs 2.4°±8.7°) than those in the non-CM → non-CM group (Fig. 1). The preoperative C2-7 angle and T1S−CL may have influenced the development of postoperative cervical alignment. Conversely, focusing on sagittal alignments other than the cervical spine, preoperative TK was significantly smaller (22.1°±13.9° vs 37.6°±16.5°), and PI−LL was significantly larger (17.1°±14.1° vs 0.1°±13.8°) in the non-CM → CM group than those in the non-CM → non-CM group. Thus, other noncervical alignments have been suggested to also play a role in postoperative cervical sagittal alignment.

Discussion

Postoperative reciprocal changes in cervical sagittal alignment

In 1995, Hilibrand et al[13] first reported the relationship between postoperative cervical and thoracic sagittal alignments, and recent studies have reported similar correlations in patients with AIS[12,14-17]. Strong correlations between cervical sagittal alignment and health-related quality of life have been reported[11]. These correlations highlight the importance of considering postoperative changes in cervical sagittal alignment during corrective surgery for spinal deformities.

In our study, the C2-7 angle showed no change for initial GR surgery from 6.0°±15.9° preoperatively to 7.9°±18.0°, although it significantly decreased to −3.4°±14.2° at the final follow-up with a significant decrease in T1 slope. These preoperative parameters were comparable with the Asian mean of 4.8°±12° in asymptomatic children, as reported by Lee et al[18] in their study of 181 Korean children. There were no significant changes in T1S−CL or C2-7 SVA post-FF. Several studies have suggested that the C2-7 angle develops with age, which results in a limited range of motion in the cervical spine[19]. The effect of distraction by GR surgery, possibly causing cervical kyphosis, has been suggested to suppress cervical lordotic changes due to natural processes. In the present study, the surgery resulted in significant changes in cervical sagittal alignment but did not lead to poor cervical alignment.

Because cervical alignment changes are considered important for postoperative quality of life in both patients with EOS and AIS, we conducted a correlation analysis of the ΔC2-7 angle and changes in other sagittal alignment parameters before GR surgery and the final follow-up. The analysis revealed a positive correlation between the ΔC2-7 angle and ΔT1S or ΔTK and a negative correlation between the ΔC2-7 angle and T1S−CL. Pepke et al[12] reported that patients with AIS with cervical kyphosis after surgery revealed a decrease in the TK and T1 slope, consistent with previous reports showing that the T1 slope impacts cervical sagittal alignment[17,20-23]. Specifically, when TK is reduced by surgical correction of scoliosis, the T1 slope is reduced, resulting in compensatory kyphosis of the cervical spine. Our results indicated that reciprocal changes in the postoperative

Table 4. Radiographic Parameters in Postoperative Non-CM and CM Groups.

Parameter		Non-CM (*n*=15)	CM (*n*=13)	*P* value
Proximal Cobb angle, °	Preoperative	36.1±17.7	40.3±16.5	0.525
	Final follow-up	23.9±12.4	26.1±12.6	0.646
Main Cobb angle, °	Preoperative	74.3±12.6	74.8±16.4	0.928
	Final follow-up	30.4±13.3	27.5±15.6	0.594
Distal Cobb angle, °	Preoperative	44.7±19.3	34.8±8.7	0.091
	Final follow-up	19.9±15.4	14.3±7.5	0.153
C2-7 angle, °	Preoperative	13.5±13.8	−2.6±14.0	**0.005****
	Final follow-up	7.5±8.1	−15.8±8.0	**<0.001*****
C2-7 SVA, mm	Preoperative	14.1±8.2	14.5±10.1	0.911
	Final follow-up	13.1±25.6	12.2±8.3	0.911
T1 slope, °	Preoperative	20.2±15.3	11.6±8.8	0.084
	Final follow-up	13.4±5.3	3.9±12.8	**0.014***
T1S − CL, °	Preoperative	6.7±13.8	14.1±8.8	**0.018***
	Final follow-up	6.0±7.3	19.8±10.4	**<0.001*****
SVA, mm	Preoperative	3.6±38.7	−4.0±23.3	0.540
	Final follow-up	−7.8±38.2	−9.7±22.0	0.875
TK, °	Preoperative	39.2±21.8	19.3±15.6	**0.011***
	Final follow-up	28.1±12.5	20.8±9.8	0.102
LL, °	Preoperative	42.5±12.8	32.0±9.5	**0.022***
	Final follow-up	47.1±15.2	44.9±10.4	0.655
PT, °	Preoperative	11.9±11.5	11.4±11.8	0.919
	Final follow-up	8.7±15	11.0±9.2	0.644
SS, °	Preoperative	33.7±14.1	37.9±6.6	0.375
	Final follow-up	39.3±14.8	38.7±9.0	0.893
PI, °	Preoperative	45.4±10.6	48.6±8.3	0.399
	Final follow-up	46.8±13.4	45.8±9.7	0.827
PI − LL, °	Preoperative	2.8±14.8	16.6±12.3	**0.016***
	Final follow-up	−0.3±17.5	1.5±9.2	0.744

Mean±*SD* (standard deviation).* $P<0.05$, ** $P<0.01$, *** $P<0.001$

SVA indicates sagittal vertical axis; T1S − CL, T1 slope minus C2-7 angle; TK, thoracic kyphosis; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; PI − LL, PI minus LL

cervical spine occurred in patients with EOS as much as in patients with AIS.

In this study, 46% of patients had poor cervical sagittal alignment, and we compared the groups with good and poor cervical sagittal alignment. The CM group primarily comprised patients with poor C2-7 angle or T1S−CL, whereas only one patient had a poor C2-7 SVA. Comparisons between the two groups showed a significant difference in the postoperative C2-7 angle and T1S−CL but not in the C2-7 SVA. Thus, the C2-7 SVA did not appear to be a major factor for CM in this study. This may be attributed to the limited ability of children in the target group to adjust their posture. C2-7 angle and T1S−CL showed a significant preoperative difference, and logistic regression analysis revealed that both C2-7 angle and T1S−CL were a significant clinical indicator (C2-7 angle odds ratio=1.086, *P*=.02; T1S−CL 0.946, *P*=.038, data not shown). Nevertheless, the odds ratio was close to 1.0, which indicates that these preoperative indicators had a relatively weak impact as a preoperative predictor. Moreover, 43% of patients with initially good cervical alignment changed to malalignment postoperatively, whereas patients with malalignment preoperatively also changed to good cervical alignment, resulting in 46% of patients with poor cervical alignment postoperatively, a slight increase from preoperatively but not significant. Le Huec et al[16] reported 34% asymptomatic cervical kyphosis cases in volunteer adult patients with AIS, which is similar to our preoperative population, requiring long-term follow-up for the postoperative period.

Relationship between T1S−CL and poor postoperative sagittal alignment in cervical spine

T1S−CL serves as an analog to the PI−LL parameter used in the thoracolumbar spine, combining the thoracic and cervical spines. Rao et al[24] reported postoperative cervical kyphosis in patients with a T1S−CL mismatch who underwent laminoplasty for cervical spondylotic myelopathy. When the T1S−CL increased, the posterior neck and suboccipital muscle groups were mostly in a state of decompensation. The patients with a higher T1S−CL required more cervical muscle energy expenditure to maintain their head weight. Consequently, the patients in the mismatched group were more likely to have greater kyphotic alignment changes. Hence, a large T1S−CL mismatch is likely to result

Table 5. Radiographic Parameters in Two Groups: Non-CM → Non-CM and Non-CM → CM.

Parameter		Non-CM → non-CM (n=12)	Non-CM → CM (n=9)	*P* Value
Proximal Cobb angle, °	Preoperative	37.5±18.8	37.6±18.4	0.994
	Final follow-up	25.2±12.4	26.7±14.4	0.794
Main Cobb angle, °	Preoperative	72.0±12.8	74.3±14.3	0.695
	Final follow-up	31.2±13.2	25.1±12.2	0.297
Distal Cobb angle, °	Preoperative	41.7±19.0	31.4±9.5	0.154
	Final follow-up	15.9±8.4	9.9±7.6	0.112
C2-7 angle, °	Preoperative	16.4±12.0	4.9±8.6	**0.024***
	Final follow-up	7.2±7.2	−17.0±8.4	**<0.001*****
C2-7 SVA, mm	Preoperative	13.6±5.4	13.5±10.7	0.986
	Final follow-up	9.1±19.1	11.6±9.6	0.726
T1 slope, °	Preoperative	18.8±7.0	15.0±5.4	0.187
	Final follow-up	14.2±4.5	1.1±13.1	**0.004****
T1S − CL, °	Preoperative	2.4±8.7	10.1±4.8	**0.028***
	Final follow-up	7.0±7.5	18.1±11.9	**0.016***
SVA, mm	Preoperative	−6.1±36.3	6.5±18.1	0.356
	Final follow-up	−5.7±32.1	−5.7±17.7	0.999
TK, °	Preoperative	37.6±16.5	22.1±13.9	**0.035***
	Final follow-up	27.2±11.5	19.0±10.8	0.114
LL, °	Preoperative	43.5±13.7	32.5±10.5	0.060
	Final follow-up	47.0±15.9	45.2±9.0	0.764
PT, °	Preoperative	10.0±10.9	14.8±13.2	0.402
	Final follow-up	4.6±12.6	10.6±10.3	0.285
SS, °	Preoperative	34.7±14.5	37.9±7.9	0.599
	Final follow-up	40.6±15.9	40.1±10.5	0.939
PI, °	Preoperative	43.6±10.5	49.7±8.9	0.195
	Final follow-up	43.1±10.2	45.9±12.0	0.581
PI − LL, °	Preoperative	0.1±13.8	17.1±14.1	**0.015***
	Final follow-up	−3.9±13.4	1.6±8.8	0.322

Mean±*SD* (standard deviation) * $P<0.05$, ** $P<0.01$, *** $P<0.001$

SVA indicates sagittal vertical axis; T1S − CL, T1 slope minus C2-7 angle; TK, thoracic kyphosis; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; PI − LL, PI minus LL

in poor cervical alignment because of the reduced compensatory function for maintaining postoperative kyphosis. Similar to previous reports, our data demonstrated that a large preoperative T1S−CL mismatch increased the risk of poor postoperative cervical sagittal alignment. Nevertheless, in contrast to older adults, children are still in the process of musculoskeletal development, and long-term follow-up is necessary.

Postoperative reciprocal changes in the cervical alignment in the non-CM → CM group

In the non-CM → CM group, the postoperative C2-7 angle was significantly decreased or kyphotic, and the postoperative T1S and TK were significantly decreased. GR surgery reduces kyphosis of the thoracic spine through distraction force, and a reciprocal change is considered to reduce T 1S, which results in cervical kyphosis.

Shah et al[6] reported a decrease in the mean TK from 59° preoperatively to 36° after the initial surgery, which increased to 51° at the final follow-up; these changes were statistically significant. In particular, they reported a significant decrease in postoperative TK and normalization of thoracic alignment in patients with hyperkyphosis. In this study, the non-CM → CM group had significantly lower preoperative TK, which suggests that for patients with greater TK, this led to the normalization of thoracic alignment; however, for patients with lower TK, the smaller thoracic spine affected cervical kyphosis.

Regarding the lumbar spine, Shah et al[6] reported a significant increase in LL at the final follow-up, suggesting that the decrease in TK may have been compensated for by a decrease in lumbar lordosis to maintain global alignment; meanwhile, our study revealed no significant changes in the lumbar spine. The present study also demonstrated significant differences in preoperative PI−LL between the two groups, which indicates that lumbar alignment may have been affected.

Limitations

This study has several limitations. First, the sample size was small for a single-center study, requiring larger studies to carry out comparisons between groups and multivariate

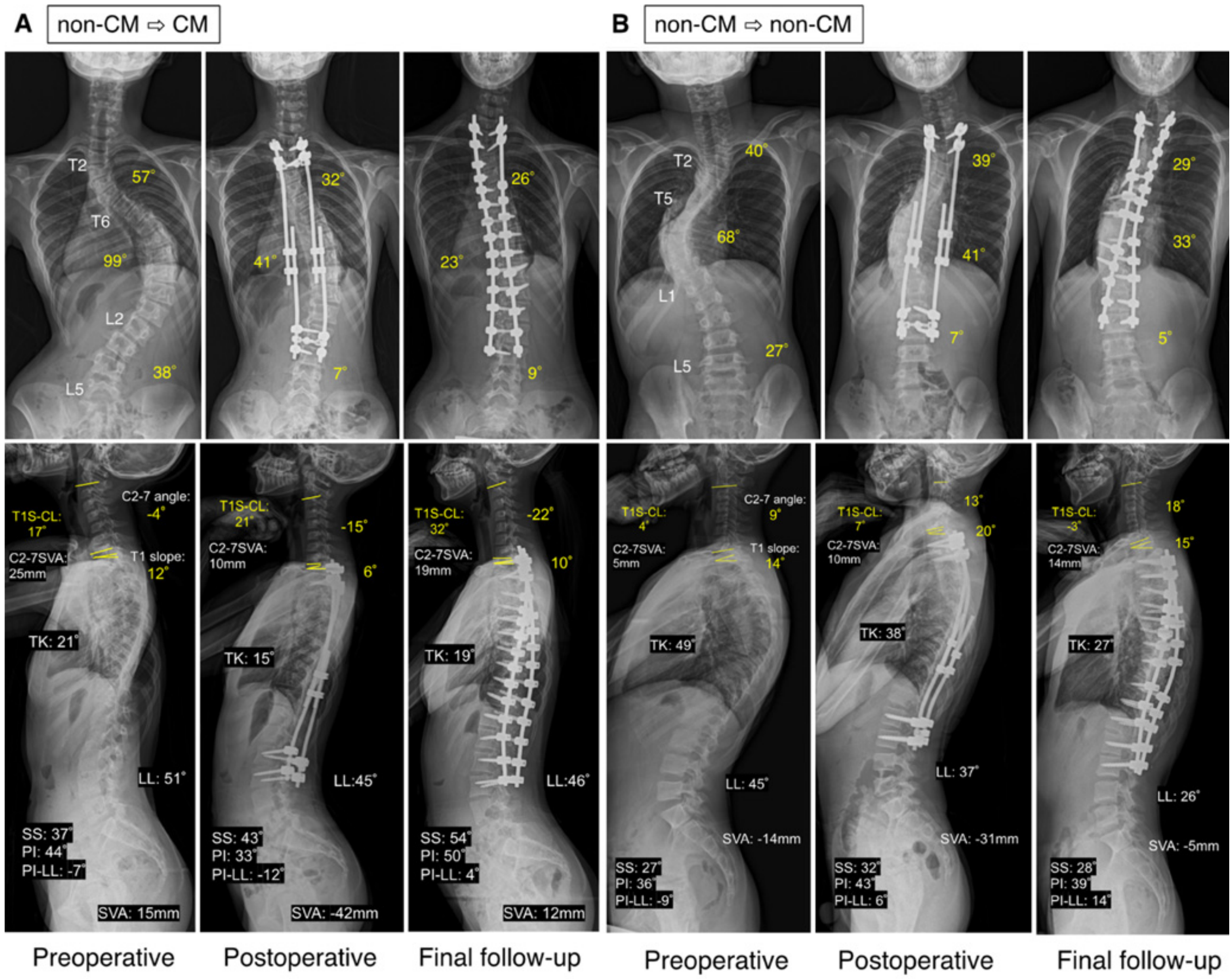

Figure 1.

A, Representative radiograph of non-CM → CM group. A 14-year-old female underwent GR surgery. Preoperative main Cobb angle, 99°; C2-7 angle, −4°; T1 slope, 12°; T1S – CL, 17°; C2-7 SVA, 25 mm; TK, 21°. Postoperative main Cobb angle, 41°; C2-7 angle, −15°; T1 slope, 6°; T1S – CL, 21°; C2-7 SVA, 10 mm. Final follow-up main Cobb angle, 23°; C2-7 angle, −22°; T1 slope, 10°; T1S – CL, 32°; C2-7 SVA, 19 mm. B, Representative radiograph of non-CM → non-CM group. A 14-year-old male underwent GR surgery. Preoperative main Cobb angle, 68°; C2-7 angle, 9°; T1 slope, 14°; T1S – CL, 4°; C2-7 SVA, 5 mm. Postoperative main Cobb angle, 41°; C2-7 angle, 13°; T1 slope, 20°; T1S – CL, 7°; C2-7 SVA, 10 mm. Final follow-up main Cobb angle, 33°; C2-7 angle, 18°; T1 slope, 15°; T1S – CL, −3°; C2-7 SVA, 14 mm.

analyses of CM. Second, postoperative alignment was evaluated after achieving bone maturity with Risser grade 4 or 5; however, the postoperative observation period was relatively short for assessing long-term changes in cervical alignment during adulthood, necessitating further long-term follow-up. Finally, because of the difficulties in administering questionnaires to children, the study did not include assessments of the quality of life or visual analog scale scores. Future studies with longer-term follow-up and comprehensive evaluation of quality of life will provide a more detailed understanding of the impact of GR surgery on EOS patients.

In symptomatic scoliosis with congenital spondyloepiphyseal dysplasia (SED), severe skeletal abnormalities may affect the evaluation of spinal alignment. This study included three patients with SED, and we compared various parameters preoperatively and at the final follow-up between the SED and non-SED patient groups. Since no significant differences were observed, we determined that the patients with SED included in this study did not have severe skeletal abnormalities and included them in the analysis (Supplementary Table 1). We carried out a comparative analysis between the non-CM → non-CM (*n*=9) and the non-CM → CM (*n*=9) in 25 cases, excluding the three SED patients, and the results were consistent with those from the analysis of all 28 patients (Supplementary Table 2).

Since the GR method corrects scoliosis using distraction force, the cervical kyphosis associated with the reduction of TK cannot be avoided. This may be a limitation of this treatment method. Although the postoperative worsening of cervical alignment was not significant in this study, the clinical significance of worsening cervical alignment must be evaluated with long-term follow-up and impact on QOL. As a potential solution, the Shilla growth guidance technique may be considered for surgical treatment of EOS, which was developed to allow growth during treatment of a child's spinal deformity without requiring repeated surgery for lengthening procedures[25]. However, Andras LM, et al[26] reported that the Shilla method, which employs translation force, has a lower correction rate and T1−S1 length and a higher rate of unplanned revision surgery compared with the growing rod surgery, thus requiring an in-depth comparative evaluation of long-term treatment outcomes.

Conclusion

This study is the first to evaluate cervical sagittal alignment in patients with EOS after GR surgery. Analysis of the non-CM → CM group suggested that in patients with thoracic hypokyphosis, a flatter thoracic spine would result in cervical spine kyphosis. Postoperative cervical lordosis significantly decreased, and the percentage of patients with malalignment increased from 25% preoperatively to 46% postoperatively in this study. Nevertheless, this increase was within the range of acceptable cervical sagittal alignment; thus, the effect of distraction by GR surgery on cervical kyphosis was not as great as expected.

GR surgery is considered a beneficial treatment option because it can significantly enhance coronal alignment without worsening the cervical spine alignment. A lower preoperative C2-7 angle or higher T1S−CL was observed in patients with poor postoperative cervical sagittal alignment, which is a significant clinical indicator. In patients with postoperative kyphotic change in the C2-7 angle, the T1 slope and TK were significantly decreased, and cervical and thoracic sagittal alignment changes were correlated in patients with EOS.

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Ethical Approval: The Committee on Ethics and Institutional Review Board approved this study (approval number: 20090042)

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