Spine

SPINE Volume 40, Number 1, pp 25-30

DEFORMITY

Posterior Correction and Fusion Surgery Using Pedicle-Screw Constructs for Lenke Type 5C Adolescent Idiopathic Scoliosis

A Preliminary Report

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Study Design. A retrospective case series.

Objective. To assess whether a short fusion strategy is applicable when treating adolescent idiopathic scoliosis with Lenke type 5C curve by posterior correction and fusion surgery using pedicle-screw constructs.

Summary of Background Data. Previous studies have discussed the selection of the lower instrumented vertebra to best preserve motion segments and obtain coronal balance. However, reports evaluating the selection of the upper instrumented vertebra when treating Lenke type 5C curves are not available.

Methods. We evaluated 29 patients who were treated surgically for adolescent idiopathic scoliosis with Lenke type 5C curve (mean age, 16.8 ± 4.7 yr; range, 10–29 yr). The mean follow-up period was 28.0 ± 6.3 months (range, 24–48 mo). We compared radiographical parameters and clinical outcomes between patients with an upper instrumented vertebra at the end vertebra (EV) (n = 10) and those treated by short fusion (S group), with a upper instrumented vertebra 1-level caudal to the EV (n = 19 patients).

Results. In the EV group, a preoperative mean Cobb angle of 50° ± 15° was corrected to 8° ± 7°, which was maintained at the final follow-up (7° ± 1°). In the S group, a mean preoperative Cobb angle of 47° ± 4° was corrected to 8° ± 5°, but this increased significantly to 12° ± 7° at final follow-up (P = 0.033). The mean correction rate at final follow-up was significantly lower in the S group (72%) than in the EV group (86%) (P = 0.027). Coronal and sagittal balance, thoracic kyphosis, lumbar lordosis, L4 tilt, and clinical outcomes evaluated by Scoliosis Research Society patient questionnaire-22 were equivalent between the 2 groups.

Conclusion. Scoliosis Research Society patient questionnaire-22 scores and radiographical parameters other than the correction rate were equivalent between the 2 groups. A short fusion strategy, in which the upper instrumented vertebra is 1-level caudal to the upper EV, is applicable to posterior correction and fusion surgery with pedicle-screw constructs for Lenke type 5C curves.

Key words: adolescent idiopathic scoliosis, thoracolumbar/lumbar curve, short fusion, pedicle-screw fixation, posterior spinal fusion, Lenke classification, 5C, upper instrumented vertebra (UIV), comparison study, fusion area.

Level of Evidence: 4

Spine 2015;40:25–30

Anterior spinal correction and fusion surgery (ASF) has been a standard method for treating thoracolumbar and lumbar major curves with nonstructural thoracic curves, such as Lenke type 5C curves, in patients with adolescent idiopathic scoliosis (AIS) for more than a decade.[1,2] Because the fusion area required for ASF is shorter than that required for posterior correction and fusion surgery (PSF), ASF spares more mobile segments and provides superior corrective ability in the coronal plane.[3,4] Surgical outcomes were recently reported for PSF with pedicle-screw constructs for Lenke type 5C curves.[5–8] Geck *et al*[7] compared ASF and PSF outcomes in patients with Lenke type 5C curves, and concluded that PSF using a pedicle-screw construct provides superior correction and better maintenance of the correction, but requires a longer fusion area. Regarding the selection of the lower instrumented vertebra (LIV) when treating Lenke 5C curves, Wang *et al*[8] reported that LIV levels correlated significantly with the magnitude of the correction and with coronal balance. However, no reports have evaluated the

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Acknowledgment date: June 29, 2014. First revision date: September 24, 2014. Acceptance date: September 26, 2014.

The manuscript submitted does not contain information about medical device(s)/drug(s).

No funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000000652

selection of the upper instrumented vertebra (UIV). For the Lenke type 1 curve, Matsumoto *et al*[9] advocated selecting a UIV 1-level caudal to the upper end vertebra (UEV); this short fusion strategy allows for balanced shoulders after PSF while requiring a shorter fusion area. This study was conducted to determine whether this short fusion strategy is applicable to a Lenke type 5C curve treated by PSF with a pedicle-screw construct.

MATERIALS AND METHODS

We retrospectively reviewed consecutive patients from 2007 through 2011 who underwent surgery at Keio University Hospital to treat AIS with Lenke type 5C curve. Patients were eligible for the study if they (1) were treated for a Lenke type 5C curve using a segmental pedicle-screw construct, (2) were followed for at least 2 years, and (3) were 29 years or younger at the time of surgery, and if (4) full sets of preoperative, postoperative, and follow-up radiographs and (5) Scoliosis Research Society (SRS)-22 patient questionnaires from prior to surgery and the final follow-up were available. There were 29 patients (1 male and 28 females) who met the inclusion criteria. The mean age at the time of surgery was 16.8 ± 4.7 years (range, 10–29 yr). The mean follow-up period was 28.0 ± 6.3 months (range, 24–48 mo).

From January 2007 to July 2008, 10 patients were treated for AIS with Lenke type 5C curve, with a UIV at the UEV (EV group). From August 2008 to April 2011, 19 patients were treated for AIS with Lenke type 5C curve. These patients were treated using a short fusion strategy (Figure 1), in which the UIV was placed 1-level caudal to the UEV (S group). In the EV group, the LIV was at L3 in 8 patients and L4 in 2 patients. In the S group, the LIV was at L3 in all but 1 patient, who had an LIV at L4. The mean age at the time of surgery, preoperative Cobb angle of the main curve, and preoperative flexibility of the main curve were similar between the 2 groups. The mean follow-up period of 34.1 months in the EV group was significantly longer than the 25.1 months of the S group (Table 1).

Surgical Technique

A midline incision was made, and the posterior elements of the spine, including the spinous processes, laminae, and transverse processes, were meticulously exposed. The inferior facet joint processes were removed to increase curve flexibility.

TABLE 1. Demographic Characteristics and Clinical Features of the Subjects

Variables	EV Group	S Group	P
Age at surgery (yr)	17.2 ± 4.3	16.6 ± 4.9	0.762
Follow-up periods (mo)	34.1 ± 6.5	25.1 ± 0.6	0.002*
Preoperative Cobb angle (°)	49.7 ± 14.7	46.5 ± 4.4	0.441
Flexibility (%)	64.2 ± 16.2	68.9 ± 13.8	0.418

*Statistically significant.
EV group indicates end vertebra group; S group, short fusion group.

Pedicle screws were placed bilaterally at every vertebra. Multiaxial reduction screws were used at 2 or 3 vertebrae around the apex on the concave side of the curve. A 5.5-mm–diameter titanium-alloy rod contoured to the physiological lumbar lordosis was placed on the convex side of the curve, and the rod was rotated to simultaneously correct scoliosis and create lumbar lordosis. The rod was bent *in situ* to correct residual lumbar curves. On the concave side, a 5.5-mm–diameter titanium-alloy rod contoured to have less lordosis compare with that of the convex rod placed on the concave side. The rod on the concave side was placed gradually, approximating the apical vertebrae, with reduction screws, whereas a vertebral column manipulator was applied on the convex side to derotate the vertebrae. Finally, the LIV was horizontalized. Local bone and β-tricalcium phosphate grafts were used in all patients.

Radiographical parameters were measured according to Spinal Deformity Group.[10] guidelines. These included the Cobb angles of the main and thoracic curves, L4 tilt angle, correction rate, coronal and sagittal global balances, thoracic kyphosis (T5–T12), and lumbar lordosis (L1–S1). UIV and LIV tilt were defined as the angle between the superior endplate and the horizontal for the UIV, and between the inferior endplate and the horizontal for the LIV. The UIV disc angle was defined as the angle from the superior endplate of the UIV relative to the inferior endplate of the adjacent upper vertebra. The LIV disc angle was defined as the angle between the inferior endplate of the LIV relative to the superior endplate of the adjacent lower vertebra.

The global coronal balance was measured as the distance from the central sacral vertical line to the C7 plumb line, and was considered positive if the C7 plumb line fell to the right of the central sacral vertical line. The global sagittal balance was measured as the distance from the C7 plumb line to the posterior superior corner of the sacrum. It was considered positive if the C7 plumb line fell anterior to the posterior superior corner of the sacrum, and negative if it fell to the posterior. The intraoperative time, estimated blood loss, and results of the SRS-22 questionnaire.[11,12] at follow-up were also evaluated.

Statistical analysis of all data was performed using SPSS Statistics 20 (IBM Corp., Armonk, NY). The distribution of variables determined the mean, standard deviation, and range. Radiographical parameters and clinical data were compared between the 2 groups by using the Student t test. A P value less than 0.05 was considered statistically significant. Radiological parameters and clinical data were collected and analyzed by the first author, who was not involved in the treatment of the patients.

RESULTS

The mean preoperative Cobb angle of the main curve was 49.7° ± 14.7° in the EV group and 46.5° ± 4.4° in the S group, with a postsurgical mean of 7.5° ± 6.8° and 8.1° ± 5.1°, respectively. Although the correction was maintained in the EV group at the final follow-up, a mean correction loss of 5.1° ± 7.8° occurred in the S group. The mean correction rate at the final follow-up was significantly larger in the EV group (85.9% ± 13.2%) than in the S group (72.3% ± 15.3%) (P = 0.027). The mean preoperative coronal balance was −14.7 ± 24.0 mm in the S group and −2.0 ± 19.9 mm in the EV group (not significant). Postoperative coronal balance was maintained at −3.1 ± 27.0 mm in the EV group, but deteriorated to −19.7 ± 14.1 mm in the S group (Table 2); however, coronal balance in the S group subsequently improved, to −8.6 ± 11.6 mm at the final follow-up. Regarding the upper and lower instrumented segments, UIV and LIV tilt were identical in both groups at the final follow-up. The LIV disc angle increased in both groups postoperatively to the final follow-up, but this increase was not statistically significant (Table 3).

The mean preoperative sagittal balance was −13.7 ± 31.9 mm in the EV group and −13.3 ± 19.0 mm in the S group. In both groups, the global sagittal balance tended toward a backward shift from just after surgery to the final follow-up (EV group, −40.6 ± 19.6 mm; S group, −29.0 ± 18.9 mm). The mean values for lumbar lordosis and thoracic kyphosis were similar for both groups at each time point (Table 4).

TABLE 2. Comparison of Radiographical Parameters in Coronal Plane

	EV Group (n = 10)	S Group (n = 19)	*P*
Cobb angle of major curve (°)			
Preoperatively	49.7 ± 14.7	46.5 ± 4.4	0.441
Immediately postoperative	7.5 ± 6.8	8.1 ± 5.1	0.580
Final follow-up	7.2 ± 0.9	12.2 ± 6.7	0.033*
Cobb angle of thoracic curve (°)			
Preoperatively	23.5 ± 10.6	24.7 ± 5.6	0.690
Immediately postoperative	11.3 ± 7.2	13.2 ± 5.7	0.460
Final follow-up	14.8 ± 11.6	15.9 ± 8.3	0.782
Global coronal balance (mm)			
Preoperatively	−2.0 ± 19.9	−14.7 ± 24.0	0.165
Immediately postoperative	−3.1 ± 27.0	−19.7 ± 14.1	0.100
Final follow-up	−5.9 ± 9.8	−8.6 ± 11.6	0.655
Apical vertebral translation (mm)			
Preoperatively	50.0 ± 12.7	49.2 ± 14.4	0.456
Immediately postoperative	9.7 ± 5.8	11.1 ± 4.1	0.293
Final follow-up	9.9 ± 6.9	13.1 ± 6.7	0.188
L4 tilt (°)			
Preoperatively	22.7 ± 12.8	25.9 ± 8.3	0.609
Immediately postoperative	4.9 ± 3.7	10.5 ± 4.7	0.062
Final follow-up	6.3 ± 3.9	8.3 ± 2.5	0.333

**Statistically significant.*
EV indicates end vertebra.

TABLE 3. Radiographical Parameters in Adjacent Segments

	EV Group (n = 10)	S Group (n = 19)	*P*
UIV tilt (°)			
Preoperatively	17.8 ± 8.3	17.3 ± 4.0	0.841
Immediately postoperative	3.4 ± 2.0	3.8 ± 2.0	0.555
Final follow-up	5.6 ± 3.7	5.4 ± 2.8	0.880
LIV tilt (°)			
Preoperatively	28.9 ± 9.6	25.4 ± 4.6	0.690
Immediately postoperative	4.4 ± 3.3	5.5 ± 4.6	0.460
Final follow-up	7.0 ± 6.1	5.2 ± 4.0	0.782
UIV disc angle (°)			
Preoperatively	2.6 ± 1.2	2.9 ± 2.0	0.165
Immediately postoperative	2.4 ± 1.4	2.5 ± 1.9	0.100
Final follow-up	3.8 ± 2.8	2.9 ± 2.0	0.655
LIV disc angle (°)			
Preoperatively	6.4 ± 6.0	4.4 ± 4.4	0.456
Immediately postoperative	5.6 ± 3.2	4.7 ± 2.2	0.293
Final follow-up	6.8 ± 4.7	7.3 ± 3.6	0.188

LIV indicates lower instrumented vertebra; EV, end vertebra; UIV, upper instrumented vertebra.

The mean intraoperative time was 180.3 ± 41.1 minutes in the EV group and 156.1 ± 45.4 minutes in the S group (P = 0.030). The mean intraoperative estimated blood loss was 316.7 ± 113.8 ml in the EV group and 212.3 ± 108.8 ml in the S group (P = 0.049) (Table 5).

In the EV group, 1 patient experienced transient leg pain during the follow-up period. In the S group, 1 patient developed a superficial infection during the follow-up period. No deep-wound infection, pseudarthrosis, additional surgery, or permanent paralysis was recorded in either group.

The differences were not statistically significant between the 2 groups in any domain of SRS-22.

Case Presentations

Case 1

A 12-Year-Old Girl in the EV Group. The preoperative Cobb angle of the main curve was 44° at T10–L3. T10, which was the UEV of the main curve, was selected as the UIV, and the L3 was selected as the LIV. The Cobb angle of the major curve

TABLE 4. Comparison of Radiographical Parameters in Sagittal Plane

	EV Group (n = 10)	S Group (n = 19)	*P*
Global sagittal balance (mm)			
Preoperatively	−13.7 ± 31.9	−13.3 ± 19.0	0.924
Immediately postoperative	5.7 ± 20.7	−14.1 ± 20.8	0.212
Final follow-up	−40.6 ± 19.6	−29.0 ± 18.9	0.132
Thoracic kyphosis (°)			
Preoperatively	17.3 ± 9.3	12.2 ± 7.3	0.115
Immediately postoperative	18.5 ± 8.5	14.5 ± 6.1	0.182
Final follow-up	22.8 ± 5.8	16.6 ± 10.1	0.085
Lumbar lordosis (°)			
Preoperatively	48.8 ± 9.1	41.6 ± 9.6	0.060
Immediately postoperative	41.0 ± 9.8	36.5 ± 10.1	0.258
Final follow-up	45.1 ± 8.8	39.1 ± 10.6	0.139

EV group indicates end vertebra group; S group, short fusion group.

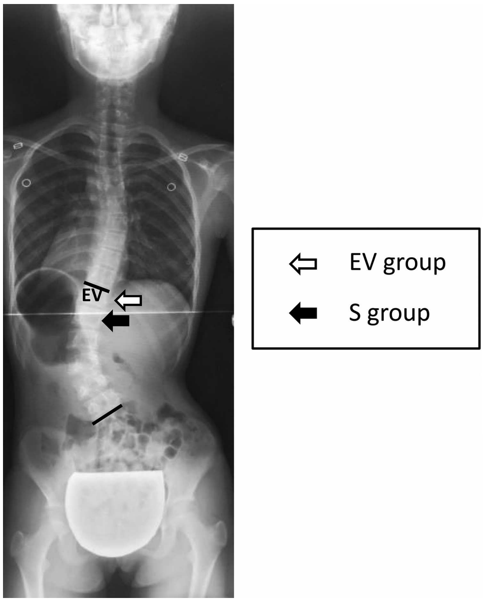

Figure 1. Selection of the UIV: the UIV is at the EV of the main curve in the EV group (white arrow), and 1 level below the EV in the S group (black arrow). UIV indicates upper instrumented vertebra; EV group, end vertebra group; S group, short fusion group.

was 6° after surgery. This correction was maintained at the 2-year follow-up (Figure 2A–C).

Case 2

A 13-Year-Old Adolescent Girl in the S Group. The preoperative Cobb angle of the main curve was 43° at T10–L3. T11, which was 1-level caudal to the UEV, was selected as the UIV, and L3 as the LIV. The Cobb angle of the main curve was 9° immediately after surgery, and 13° at the final follow-up (Figure 3A–C).

DISCUSSION

Lark *et al*[13] compared nonselective fusion (*i.e.*, including the thoracic curve in fusion) and selective lumbar and/or thoracolumbar fusion in patients with Lenke 5C curves, and reported that 27% of Lenke 5C curves treated by experienced scoliosis surgeons were treated by nonselective fusion. The concept of selective fusion in surgery to treat spinal deformity was first described by Moe[14] in 1958. In 2001, Lenke *et al*[15] described a new surgical classification system that suggested the structural curves to be included in arthrodesis. The UIV is often at the UEV of the thoracolumbar/lumbar curve, and the LIV is often at the lower EV or 1 level below.

Recently, the use of pedicle-screw constructs with PSF has provided superior coronal correction with a shorter fusion length than is possible with the segmental hooks of hybrid constructs.[16–18] Shufflebarger *et al*[6] reported favorable outcomes of PSF for the thoracolumbar/lumbar curve in AIS when used with a pedicle-screw construct and a wide facetectomy, and with fusion and instrumentation from the inferior to the UEV. In 2013, Bennett *et al*[19] described 5-year surgical outcomes for patients with AIS who underwent posterior pedicle-screw fixation. with a UIV at the UEV. As with these 2 studies, the UIV has usually been selected at the UEV in PSF for Lenke 5C curves.

In this study, although the correction rate of the main curve was lower in the S group than in the EV group, the other radiographical parameters were equivalent in the 2 groups. The correction of the main curve in the S group had decreased at the final follow-up because the fusion area did not include the UEV. The loss of correction observed at final follow-up may have occurred to compensate the residual nonstructural thoracic curve and rebalance the spine. Indeed, in this study, the S group maintained favorable coronal and sagittal balances. The shorter intraoperative time and reduced blood loss in the S group indicate that a short fusion strategy is less invasive than conventional end-to-end fusion.

Indeed, in this study, the S group maintained favorable coronal and sagittal balances. We think that a well-balanced spine obtained in the S group, although the final correction

TABLE 5. Comparison of 2 Groups

	EV Group	S Group	*P*
Correction (%)	85.9 ± 13.2	72.3 ± 15.3	0.027*
Operation (min)	180.3 ± 41.1	156.1 ± 45.4	0.030*
Estimation of blood loss (ml)	316.7 ± 113.8	212.3 ± 108.8	0.049*

**Statistically significant.*
EV group indicates end vertebra group; S group, short fusion group.

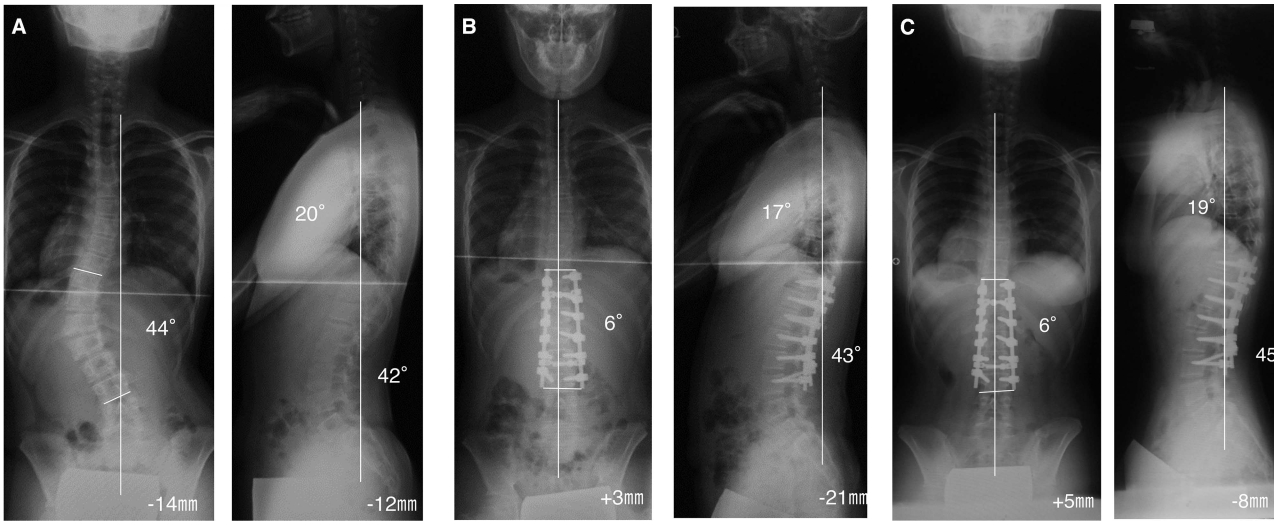

Figure 2. A, A 12-year-old adolescent girl in the EV group. The structural lumbar curve was 44° before surgery. **B**, The Cobb angle of the major curve was corrected to 6°. **C**, The correction of the main curve was maintained at the final follow-up. EV indicates end vertebra.

rate was worse than that in the EV group, should yield good long-term outcomes.

The shorter intraoperative time and reduced blood loss in the S group indicate that a short fusion strategy is less invasive than conventional end-to-end fusion. According to Kamerlink *et al*,[20] the estimated surgical cost of Lenke 5C curves was $32,652 for a surgery and the largest contributors to the overall cost were implants (29%). Thus, the short fusion strategy is not only less invasive, but also can contribute to the reduction of surgical costs.

This study is the first to demonstrate that a short fusion strategy, in which the UIV is 1-level caudal to the UEV, is a reasonable alternative to conventional fusion strategy, in which the UIV is selected at the UEV, when using PSF with pedicle-screw constructs to treat Lenke type 5C curves.

This study had the limitation of relatively short follow-up periods, and a longer follow-up study will be required to observe changes in the residual curve. Suk *et al*[21] reported that the correction loss after selective thoracic fusion using segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis was 3% with minimum 5-year follow-up. Min *et al*[22] assessed the long-term surgical outcomes for AIS using pedicle screw constructs and found that the correction rate was decreased from 63% at 2 years to 55% at 10 years. Thus, we must conduct a follow-up of this cohort for a longer period of time, preferably more than 10 years, to improve the validity of the results of this study. This study was based on retrospectively collected data with a relatively small number of patients, and a multicenter, randomized trial with a larger number of patients is necessary to clarify the value of this short fusion strategy in treating Lenke type 5C curves.

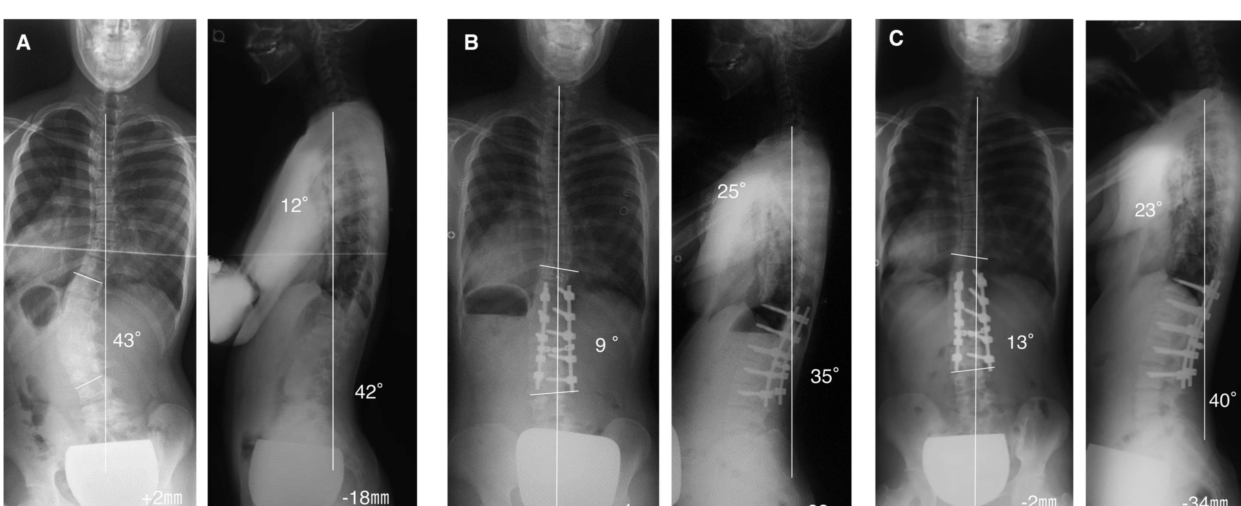

Figure 3. A, 13-year-old adolescent girl in the S group. The structural lumbar curve was 43° before surgery. **B**, The Cobb angle of the major curve was corrected to 9°. **C**, A slight loss of correction was observed at the final follow-up. The Cobb angle of the major curve was 13°. S group indicates short fusion group.

CONCLUSION

Although there was a decrease in the correction rate in the group treated with a shorter fusion length, global balance and follow-up SRS-22 results were equivalent in the 2 groups. Surgical procedures using the short fusion strategy were significantly less invasive than those in the EV group. Thus, the short fusion strategy, which uses a UIV 1-level caudal to the UEV, can be considered as an alternative to the conventional strategy, which includes the UEV in the fusion, when treating Lenke 5C curves with PSF.

➢ Key Points

- We compared conventional and short fusion strategies in 29 patients with Lenke type 5C AIS.
- Radiographical parameters, except for the correction rate, and SRS-22 scores were equivalent in patients treated with conventional end-to-end fusion or a short fusion strategy.
- The short fusion strategy, in which the UIV is 1-level caudal to the UEV, is a reasonable alternative to the conventional fusion area in posterior correction surgery for patients with Lenke type 5C curve.

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