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Selecting the C7-LIV Line Vertebra as the Upper Instrumented Vertebra for Adolescent Idiopathic Scoliosis Lenke Type 1A Curves: Multicenter and a Minimum 2-year Follow-up Study

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Abstract

Study Design: Retrospective multicenter cohort study

Objective: We evaluated a new upper instrumented vertebra (UIV) selection method that used the modified Shinshu line (MSL) to establish the selected UIV as the MSL vertebra (MSLV).

Summary of Background Data: No reports have addressed optimal UIV selection according to the lower instrumented vertebra (LIV) for good trunk balance in Lenke 1A curves.

Methods: Forty-five consecutive patients (44 female, 14.4 ±2.4 years) receiving posterior spinal fusion (PSF) for a Lenke 1A adolescent idiopathic scoliosis (AIS) curve were analyzed. We defined the novel MSL as the line between the center of the spinous process of C7 and that of the spinous process of the LIV. The vertebral body with which the MSL first contacted proximally was defined as the MSLV. The groups in which the UIV was at, proximal to, or distal to the MSLV were defined as the matched group (M-group; 15 cases [15 female], 14.7±2.1 years), proximal group (P-group; 20 cases, [19 female], 15.0 ± 2.2 years), and distal group (D-group; 10 case [10 female], 14.8 ± 2.5 years), respectively. We measured Cobb angle, main thoracic (MT) curve correction rate and C7 plumb line absolute value (C7PL) at pre- and 2 years postoperatively for comparisons using Dunnett's test, with the M-group as the control.

Results: In the M-group, P-group, and D-group, the Cobb angle correction rate between pre- and postoperative time points were 65.3±1.3%, 62.4±1.6%, and 52.8±6.8%, respectively, and comparable apart from a smaller correction tendency in the D-group versus the M-group (P=0.08). At 2 years postoperatively, C7PL was 0.5±0.4 cm, 1.0±0.6 cm, and 1.3±0.9 cm, respectively, and significantly smaller for the M-group (both P<0.05).

Conclusions: Better trunk balance were obtained without reducing correction rate by setting the novel MSLV as the UIV in PSF for Lenke type 1A curves.

Key Words: adolescent idiopathic scoliosis, Lenke type 1A curve, upper instrumented vertebra, lowest instrumented vertebra, surgical outcome, correction rate, multicenter study, central sacral vertical line, trunk balance, shoulder balance, modified Shinshu line, C7

Level of Evidence: 3

Key points

- We have devised a new upper instrumented vertebra (UIV) selection method using the C7-lowest instrumented vertebra (LIV) line (modified Shinshu line; MSL) that establishes the UIV as the MSL vertebra (MSLV).

- The MSL is the line between the center of the spinous process of C7 and that of the spinous process of the LIV.

- The vertebral body with which MSL first contacts proximally is defined as the MSLV.

- In the posterior spinal fusion for Lenke type 1A curves, better trunk and shoulder balance were obtained without a reduction in correction rate by setting the MSLV as the UIV.

Introduction

Segmental pedicle screw (PS) fixation for scoliosis was introduced by Suk et al. in 1995[1]. In patients with adolescent idiopathic scoliosis (AIS), PS constructs have been shown to improve radiographic outcomes over traditional hook and hybrid constructs[2,3,4,5,6]. Lenke 1A AIS is regarded as the most common curve type. The deformity is defined as a structural main thoracic (MT) curve with nonstructural proximal thoracic (PT) and thoracolumbar/lumbar (TL/L) curves and lumbar modifier A, namely, a central sacral vertical line (CSVL) between the bilateral pedicles of the lumbar apex vertebra[7,8]. Regarding the fusion area determination method for AIS Lenke 1A curves, the last touching vertebra (LTV)[9] and the last substantially touching vertebra[10] to the CSVL have been described for determination of the lowest instrumented vertebra (LIV). On the other hand, several selection techniques have been reported for the upper instrumented vertebra (UIV) based on preoperative shoulder balance[11,12,13].

A shortcoming of the above studies is that they consider the UIV and LIV in isolation, whereas the required UIV may change depending on the LIV position, such as for Lenke 5C curves[14]. However, there have been no reports on the selection of optimal UIV according to the LIV for Lenke 1A curves to obtain optimal correction rate and trunk and shoulder balance. Oba et al.[14] have recently devised the Shinshu line (S-line) as a preoperative UIV and LIV selection method for AIS Lenke type 5C deformities that does not exacerbate the MT vertebral curve after surgery. When the S-line was extended upwards, it passed through the C7 spinous process in almost cases (Fig. 1a).

In the present study, we devised a novel UIV determination method for Lenke 1A AIS curves using the C7-LIV line (modified S-line; MSL) and established the selected UIV as the MSL vertebra (MSLV). The MSL was defined as the line between the center of the spinous process of C7 and that of the spinous process of the LIV, with the vertebral body first contacting the MSL proximally as the MSLV (Fig. 1b). The purpose of this investigation was to determine if coronal and sagittal balance and correction were optimal when the UIV was at, proximal to, or distal to the MSLV. A total of 45 AIS Lenke type 1A patients who underwent PSF for MT curves and followed for a minimum of 2 years were analyzed in this retrospective cohort study.

Materials and Methods

Patients

This study was approved by the ethics committee of our institution (approval number: 4496). We retrospectively reviewed the medical records of 45 consecutive patients (44 female and 1 male; mean±standard deviation [SD] age: 14.4±2.4 years, range: 12–21 years) with Lenke 1A AIS who underwent PSF using an all-PS construct at among 4 university hospitals between September 2006 and November 2015. The inclusion criteria were as follows: (1) diagnosis of AIS with a type 1A curve according to the Lenke classification system[15], (2) receiving one-stage PSF using the rod rotation and direct vertebral rotation technique with an all-PS construct, and (3) a minimum follow-up period of 2 years. Patients with other types of scoliosis, such as congenital, neuromuscular, or syndrome-related, were excluded. In all cases, the LTV to the CSVL was selected as the LIV. All patients completed the 2-year observation period.

Radiological assessment

Standing long-cassette postero-anterior (PA) radiographs were evaluated by 3 surgeons (R.M., T.H., and H.O.) before surgery and at 2 years post-surgery. The investigators were not the operating surgeons and reviewed the radiographs while blinded to outcomes. Radiographs from the affiliated facilities were sent by digital media and measured by the surgeons as described above. We defined the novel MSL as the line between the center of the spinous process of C7 and that of the spinous process of the LIV (Fig. 1b). The vertebral body with which the MSL first contacted proximally was defined as the MSLV. The MSLV was determined using preoperative standing PA whole-spine radiographs immediately before surgery. The group in which the UIV was at the MSLV was defined as the matched group (M-group). The group in which the UIV was proximal to the MSLV was defined as the proximal group (P-group). The group in which the UIV was distal to the MSLV was classified as the distal group (D-group).

We evaluated the Cobb angle of the PT and MT curves, correction rate, absolute deviation of the length between the C7 plumb line and CSVL (C7PL), absolute clavicular rib intersection angle (CRIA)[16], sagittal balance (sagittal vertical axis [SVA] and T5-12, T10-L2, and T12-S1 angle), and proximal junction kyphosis (PJK; diagnosed as proximal junction sagittal Cobb angles between the lower endplate of the uppermost instrumented vertebra and the upper endplates of the 2 supradjacent vertebrae being (1) more than 10°, and (2) at least 10° greater than preoperative measurements at 2 years postoperative[17], and Scoliosis Research Society (SRS)-22r questionnaire results preoperatively and 2 years postoperatively.

Statistical analysis

Radiographic parameters and SRS-22r findings were compared for the M-group, P-group, and D-group. Paired *t*-tests were employed to analyze overall data before and at 2 years after surgery. Dunnett's multiple comparisons were performed using the M-group as the control. Considering the effect of multiple surgeons on the results, additional multivariate analyses using mixed effect models were carried out. Outcome of interest parameters (e.g., C7PL) were used as response variables, groups based on the MSLV were adopted as fixed effects in explanatory variables, and the variation of contributed surgeons was employed as a random effect. Logistic regression analysis was performed to identify the risk factors of coronal imbalance after surgery within each group. All analyses were performed using the Statistical Package for Social Sciences for Windows version 21.0 (IBM, Chicago, IL, USA) and the statistical package R version 3.6.1 (available at http://www.r-project.org).

Results

Radiographic outcomes of correction surgery

The Cobb angle of the MT curve in the cohort was significantly decreased after surgery ($P<0.05$). The mean± SD correction rate was 61.2±15.3% between pre- and 2 years post-surgery. Apical vertebral translation (AVT) was also significantly decreased after surgery ($P<0.05$), with a percent change of 67.5±13.3%. Regarding coronal balance, C7PL and CRIA did not change remarkably between pre- and 2 years postoperatively. In terms of sagittal balance, T5-12 kyphotic angle and T12-S1 lordosis angle were significantly increased after surgery, with gains of 8.4±9.1° and 6.2±14.6°, respectively (both $P<0.05$). On the other hand, SVA and T10-L2 kyphotic angle values remained comparable with baseline levels (Table 1). The distributions of the UIV and LIV are summarized in Table 1.

SRS-22r outcomes

Pre-operative overall SRS-22r scores were 4.2±0.9 for function, 4.1±0.7 for pain, 2.6±0.5 for self-image, 3.8±0.6 for mental health, and 3.7±0.5 for subtotal. At 2 years after surgery, these values were all improved at 4.7±0.2, 4.5±0.6, 4.1±0.6, 4.2±0.6, and 4.4±0.4, respectively. Two-year satisfaction was 4.1±0.8 and total score was 4.4±0.4.

Characteristics of sorted patients

Among the 45 consecutively treated patients, the M-group contained 15 cases (all female; mean± SD age: 14.7±2.1 years), the P-group contained 20 cases (19 female and 1 male; mean± SD age: 15.0±2.2 years), and 10 cases were classified into the D-group (all female; mean± SD age: 14.8±2.5 years). Eight surgeons performed the procedures, with no remarkable grouping imbalances according to the operator (Fisher's exact test, P=0.39). The mean follow-up period was 3.6 years (range: 2–8 years). A mean of 9.7 vertebrae (range: 6–14 segments) were instrumented.

Comparisons of radiographic measurements among the test groups

We observed no significant differences for the P-group or D-group versus the M-group for Cobb angle or correction rate between before and 2 years after surgery (Table 2, 3), although the D-group tended to exhibit less correction (P=0.08). There was a significant difference in correction rate between the M-group and the D-group in additional multivariate analysis using a mixed-effects model, with the variation of the contributing surgeons employed as a random effect (P<0.01), with none between the M-group and the P-group. Regarding C7PL, preoperative values were comparable among the groups. However, trunk deviation was significantly smaller in the M-group than in the P-group (0.5 cm difference; 95% confidence interval [CI] 0.1 to 0.9 cm, P=0.04) and in the D-group (0.7 cm difference; 95% CI 0.2 to 1.2 cm, P=0.01) at 2 years after surgery. Those results were confirmed by additional multivariate analysis using a mixed-effects model with the variation of the contributing surgeons adopted as a random effect (P=0.02 for the M-group vs. the P-group and P<0.01 for the M-group vs. the D-group). Concerning CRIA, although pre-surgical values were similar among the groups, the M-group had a significantly smaller CRIA as compared with the P-group (1.8° difference; 95% CI 0.8 to 2.8°, P<0.01) and the D-group (1.6° difference; 95% CI 0.4 to 2.8°, P=0.01), which were consistent with additional multivariate analysis findings with a mixed-effects model using the variation of the contributing surgeons as a random effect (P<0.01 and P=0.02, respectively). AVT and the measurement parameters for sagittal balance (SVA and T5-12, T10-L2, and T12-S1 angle) were all comparable between the M- and other groups before and 2 years after surgery. No remarkable differences in PJK incidence were observed among the groups (Fisher's exact test, P=0.78). The SRS-22r self-image score at 2 years postoperatively was significantly lower in the P-group than in the M-group (-0.50 difference; 95% CI -0.9 to 0.1, P=0.02). The other SRS-22r item scores were all similar between the M-group and other groups pre- and post-surgically (Table 4).

Predictors of postoperative coronal imbalance

Logistic regression analysis to assess for predictors of postoperative coronal imbalance revealed significant differences for C7PL>1 cm and for CRIA>3° (26 cases in total). Both the P-group (odds ratio [OR] 16.0, 95% CI 3.0 to 85.3, P=0.001) and the D-group (OR 9.3, 95% CI 1.46 to 59.5, P=0.01) were significantly more likely to exhibit coronal imbalance as compared with the M-group.

Discussion

The present study made 3 important clinical observations about the newly proposed MSL: (1) the M-group exhibited no significant differences in Cobb angle correction rate of the MT curve as compared with the other groups, with the D-group tending to have diminished correction, (2) regarding postoperative C7PL, values in the M-group were significantly lower than in the other groups, indicating better coronal balance, and (3) postoperative CRIA in the M-group was also significantly less than in the other groups, thus demonstrating superior shoulder balance. Based on these findings, setting the MSLV as the UIV may provide optimal trunk and shoulder balance without affecting correction.

For AIS Lenke 1A curves, if the LIV is selected as the LTV from the CSVL and the UIV is set as the proximally last vertebral body touched by the MSL, the 2-year postoperative coronal and shoulder balance in this study was significantly better. We believe that all vertebral bodies should situate on the CSVL as an ideal state of coronal balance after PSF for AIS. A shorter fusion area is also desirable if comparable results can be obtained. Furthermore, since the non-structural curve is expected to correct spontaneously, PSF should be limited to the structural curve when possible. However, there are currently no clear criteria for determining fusion area. In our study, the LIV was the LTV to the CSVL to avoid postoperative adding-on based on reports by Matsumoto et al.[9] In this determination method, the non-structural TL/L curve with less deformation below the LTV was expected to self-correct after surgery. Thus, the LIV point is ideally at the center of the postoperative LIV spinous process that coincides with the CSVL.

The above concept was also applied to the upper and middle thoracic spine in the reverse direction from the upper vertebral body to the lower part; it was desirable for the vertebral bodies from C7 to the LIV to be in a straight line, whereby the line connecting the center of the C7 spinous process to that of the LIV vertebral spinous process was defined as the MSL. This line assumes a postoperative CSVL from C7 to the LIV to become the postoperative C7PL. Thus, the UIV is selected as the LTV for the MSL in the same way as the method for determining the original LIV. The result is a non-structural curve above the UIV, just as the one below the LIV, for which spontaneous curve correction can be expected.

The M-group showed no significant difference in the correction rate of MT curve Cobb angle as compared with the P-group, although multivariate analysis revealed that the D-group produced significantly smaller correction. Matsumoto et al.[18] reported no remarkable differences in the MT curve correction rate for Lenke type 1 curves regardless of whether the UIV was the end vertebra (EV) or 1 below the EV. Our results of comparable correction rates of the MT curve between the MSLV and 1 level above the MSLV were similar. However, the correction rate of MT curve Cobb angle in the D-group was significantly less. Selecting the

MSLV therefore appears advantageous over a more caudal vertebral body. In 19 cases (42.2%) in our cohort, the EV and the MSLV matched. There were 11 cases where the EV and UIV were unmatched, 30 cases where the UIV was above the EV, and 4 cases where the UIV was below the EV. Comparisons of C7PL and CRIA between the EV-UIV matching group and the group with the UIV located above the EV showed no significant differences (P=0.87 and P=0.70, respectively). The caudal group included only 4 cases and was therefore not subjected to statistical comparisons. Thus, the positional relationship between the UIV and the EV appeared to not affect coronal balance.

Regarding postoperative C7PL, that in the M-group was significantly smaller than in the other groups and indicated good coronal balance. Eardley-Harris et al.[19] described junctional kyphosis, coronal imbalance, adding-on, and revision surgery as complications of selective spinal fusion, whereas this study focused on coronal imbalance. Sudo et al.[20] reported that for short fusion (UIV=EV-1) in patients with a flexible Lenke 5C TL/L curve, global coronal balance at the time of final follow-up was comparable to conventional EV-EV fixation. Our results corroborated this finding. It was possible that residual flexibility had a greater effect on coronal balance in the M-group than in the P-group by shortening the fixation of the non-structural PT curve.

In terms of postoperative CRIA, the M-group had significantly smaller values than did the other groups; thus, shoulder balance at the study endpoint was significantly better. The following reasons are considered for this observation. First, if fixed to the cranial side, the fusion area in the non-structural curve becomes longer, and the spontaneous correction of postoperative shoulder balance as reported by Tang et al.12 is lost. Second, if the fusion area is shortened more than necessary, there is a possibility that correct shoulder balance may not be obtained due to insufficient correction.

Lastly, the P-group had significantly worse postoperative SRS-22r self-image item scores than did the M-group. The reason for this may be that the surgical wound reaches the base of the neck due to the fusion area extending to the cranial side, with cases in which trunk and shoulder balance nonetheless deteriorate.

This study had several limitations. First, it was a retrospective cohort investigation that will need prospective observational research to validate the utility of the MSL. Second, the mean postoperative follow-up period was 2 years; longer trials are needed to fully assess our results. Third, the number of contributing surgeons may have influenced the results for MT Cobb angle correction rate. The possibility of determining the appropriate fusion area for curves other than Lenke type 1A by the MSL also merits further research.

Conclusions

In PSF for Lenke type 1A curves, better trunk and shoulder balance may be obtained without reducing correction rate by setting the novel MSLV as the UIV.

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Fig. 1a. When the S-line is extended upwards, it passes through the C7 spinous process.

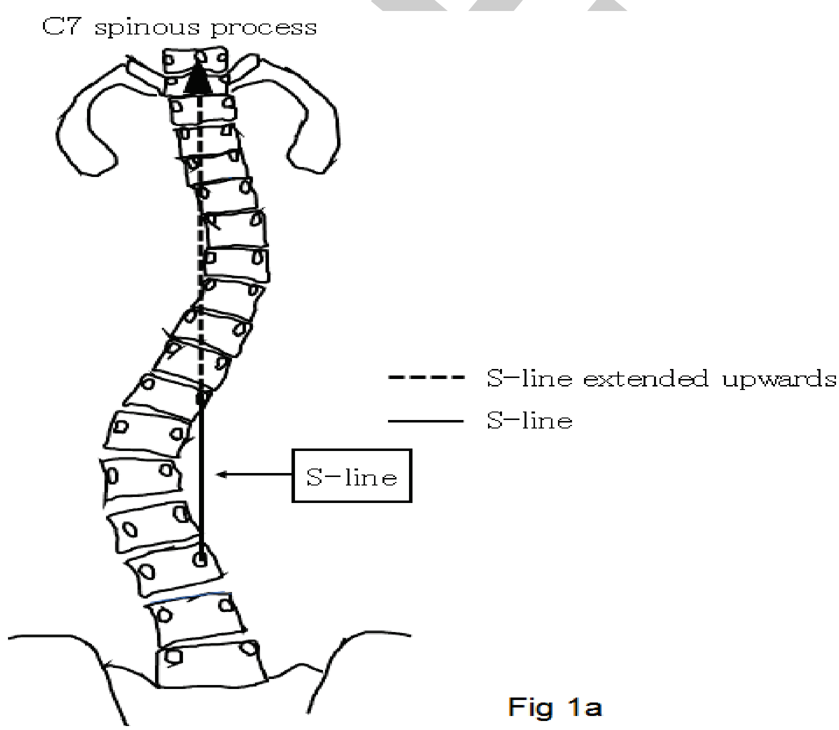

Fig 1a

Fig. 1b. The MSL is a line connecting the center of the C7 spinous process and the center of the spinous process of the LIV. The vertebral body with which MSL first contacts proximally is defined as the MSLV.

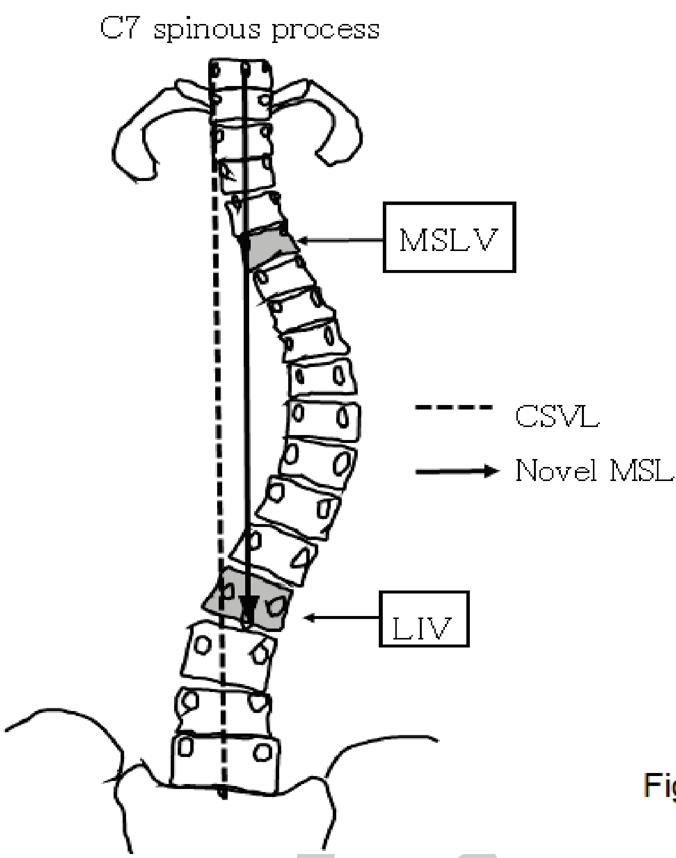

Fig 1b

Table 1. Radiographic outcomes of correction surgery

Variable	Preoperative	Postoperative	P-value
PT Cobb angle (°)	24.9±5.7	13.5±7.2	<0.01
MT Cobb angle (°)	50.7±6.1	19.3±7.1	<0.01
C7PL (cm)	1.2±0.9	0.9±0.7	0.07
CRIA (°)	2.5±1.9	0.9±0.7	0.41
AVT (mm)	53.5±15.0	16.6±6.5	<0.01
T5-12 thoracic kyphosis (°)	11.5±7.0	19.4±9.3	<0.01
T10-L2 kyphosis (°)	1.5±7.4	1.9±7.8	0.87
T12-S1 lumbar lordosis (°)	-44.8±8.9	-49.0±11.1	0.02
SVA (mm)	22.3±22.5	19.6±20.2	0.54
Number of fused vertebrae		9.7±1.4	
UIV T2:T3:T4:T5:T6:T7 (cases)		3:5:10:21:5:1	
LIV T11:T12:L1:L2:L3 (cases)		1:9:21:11:3	

Note: Interval and ratio values represent the mean ± standard deviation.

Abbreviations: PT, proximal thoracic; MT, main thoracic; C7PL, Absolute C7 plumb line; CRIA, Absolute clavicle rib intersection angle; AVT, apical vertebral translation; SVA, sagittal vertical axis; UIV, upper instrumented vertebra; LIV, lowest instrumented vertebra

Table 2. Comparisons of preoperative radiographic measurements among the test groups

Variable	M-group (n=15)	P-group (n=20)	D-group (n=10)	P-value[1]	P-value[2]
Coronal parameters					
PT Cobb angle (°)	23.5±1.1	27.1±1.3	22.4±2.1	0.11	0.83
MT Cobb angle (°)	49.1±1.5	51.7±1.5	51.2±2.1	0.39	0.64
C7PL (cm)	1.1±0.2	1.0±0.1	1.5±0.1	0.99	0.38
CRIA (°)	2.1±0.4	2.4±0.4	3.4±0.7	0.90	0.19
AVT (mm)	52.8±2.5	53.3±3.7	53.7±6.3	0.99	0.99
Sagittal parameters					
T5-12 thoracic kyphosis (°)	10.9±2.0	11.5±1.5	12.5±2.5	0.96	0.83
T10-L2 kyphosis (°)	0.1±2.0	1.5±1.5	3.7±2.6	0.83	0.44
T12-S1 lumbar lordosis (°)	-45.4±2.0	-43.1±2.2	-47.4±3.0	0.69	0.82
SVA (mm)	23.4±7.3	19.2±5.0	22.4±3.3	0.82	0.99
Fused area					
Number of fused vertebrae					
UIV T2:T3:T4:T5:T6:T7 (cases)	0:1:4:9:1:0	3:4:6:5:2:0	0:0:0:7:2:1		
UEV T2:T3:T4:T5:T6:T7 (cases)	0:0:0:8:7:0	0:0:1:9:7:3	0:0:2:6:1:1		
UIV-UEV	-4: 0, -3: 0, -2: 3, -1: 6, 0: 6, 1: 0, 2: 0	-4: 1, -3: 4, -2: 3, -1: 11, 0: 1, 1: 0, 2: 0	-4: 0, -3: 0, -2: 0, -1 : 2, 0: 4, 1: 3, 2: 2		
LIV T11:T12:L1:L2:L3 (cases)	0:4:7:4:0	0:5:10:2:3	1:0:4:5: 0		

Note: Interval and ratio values represent the mean ± standard error. [1]M-group vs. P-group. [2]M-group vs. D-group.

Abbreviations: PT, proximal thoracic; MT, main thoracic; C7PL, Absolute C7 plumb line; CRIA, Absolute clavicle rib intersection angle; AVT, apical vertebral translation; SVA, sagittal vertical axis; UIV, upper instrumented vertebra; LIV: lowest instrumented vertebra

Table 3. Comparisons of 2-year postoperative radiographic measurements among the test groups

Variable	M-group (n=15)	P-group (n=20)	D-group (n=10)	P-value[1]	P-value[2]
Coronal parameters					
PT Cobb angle (°)	10.0±0.8	17.2±1.6	11.3±2.7	<0.01	0.86
MT Cobb angle (°)	16.9±1.3	19.3±1.6	23.1±2.8	0.52	0.06
Correction rate (%)	65.3±1.3	62.4±1.6	52.8±6.8	0.79	0.08
C7PL (cm)	0.5±0.1	1.0±0.1	1.3±0.3	0.04	0.01
CRIA (°)	1.6±0.3	3.4±0.4	3.3±0.4	<0.01	0.01
AVT (mm)	15.7±1.1	16.1±1.7	19.2±2.5	0.97	0.33
Sagittal parameters					
T5-12 thoracic kyphosis (°)	21.6±2.2	15.8±1.5	23.2±4.1	0.11	0.86
T10-L2 kyphosis (°)	0.6±1.9	3.1±1.8	1.6±2.7	0.58	0.93
T12-S1 lumbar lordosis (°)	-51.3±3.3	-47.6±2.2	-48.5±3.9	0.54	0.77
SVA (mm)	12.4±5.6	25.3±3.4	18.8±8.4	0.11	0.67
PJK	1 case (2.2%)	2 cases (4.4%)	none		

Notes: Interval and ratio values represent the mean ± standard error. [1]M-group vs. P-group. [2]M-group vs. D-group.

Abbreviations: PT, proximal thoracic; MT, main thoracic; C7PL, C7 plumb line; CRIA, clavicle rib intersection angle; AVT, apical vertebral translation; SVA, sagittal vertical axis; UIV, upper instrumented vertebra; LIV, lowest instrumented vertebra; PJK, proximal junctional kyphosis

Table 4. Comparisons of SRS-22r scores among the test groups

Variable	M-group (n=15)	P-group (n=20)	D-group (n=10)	P-value[1]	P-value[2]
Preoperative					
Function	4.3±0.2	4.2±0.2	3.9±0.4	0.97	0.67
Pain	4.2±0.1	4.1±0.2	4.1±0.4	0.87	0.89
Self-image	2.7±0.1	2.4±0.1	2.8±0.1	0.08	0.90
Mental health	3.9±0.09	3.8±0.2	3.8±0.2	0.63	0.93
Subtotal	3.8±0.07	3.6±0.1	3.7±0.2	0.53	0.93
Postoperative					
Function	4.7±0.08	4.8±0.04	4.7±0.06	0.79	1.00
Pain	4.5±0.1	4.5±0.2	4.4±0.2	0.99	0.95
Self-image	4.3±0.08	3.8±0.1	4.3±0.09	0.02	1.00
Mental health	4.3±0.2	4.2±0.1	4.2±0.09	0.87	0.84
Subtotal	4.6±0.1	4.3±0.1	4.3±0.09	0.25	0.50
Satisfaction	4.4±0.2	3.9±0.2	4.2±0.2	0.24	0.89
Total	4.5±0.08	4.3±0.09	4.4±0.06	0.35	0.91

Notes: Values represent the mean ± standard error. [1]M-group vs. P-group. [2]M-group vs. D-group.

Abbreviation: SRS-22r, Scoliosis Research Society 22r questionnaire