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Original Article

Comparison of SV and LSTV as the lowest instrumented vertebra in Lenke 1A adolescent idiopathic scoliosis: SV decreasing the distal adding-on phenomenon

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Abstract: To assess the effects of stable vertebra (SV) and last substantially touched vertebra (LSTV) selected as the lowest instrumented vertebra (LIV) in Lenke 1A adolescent idiopathic scoliosis (AIS). We retrospectively reviewed 55 consecutive Lenke 1A AIS patients who underwent posterior spinal fusion with two years follow-up. Patients with SV or LSTV selected as LIV were divided in two groups with radiographic and Scoliosis Research Society (SRS)-22 outcomes. Independent sample t test and Chi-square test were used between the two groups. Comparing the baseline characteristics of the two groups demonstrated no significant differences except the age ($p=0.038$). The deviation between the LIV and central sacral vertical line (CSVL) was significantly different ($p<0.001$) between the two groups at postoperation. Major curve Cobb ($p=0.032$) and intervertebral disc angle ($p=0.001$) were found significant differences at 2-year postoperation. Compared with LSTV group, there was a significantly decreased incidence of distal adding-on in SV group ($p=0.037$). No significant differences in SRS-22 scores were observed. In Lenke 1A AIS patients, LIV choosing both SV and LSTV can acquire satisfied correction of scoliosis. However, SV selected as LIV can decrease the distal adding-on phenomenon.

Keywords: Stable vertebra, last substantially touched vertebra, adolescent idiopathic scoliosis, distal adding-on phenomenon

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity, afflicting the physical and mental health of puberty, and its incidence is 1-3% during the age of 10-16 years [1]. Lenke 1A AIS is regarded as the most common curve type, which is defined as a structural main thoracic curve with nonstructural proximal thoracic and thoracolumbar/lumbar curves and lumbar modifier A namely central sacral vertical line (CSVL) between the bilateral pedicles of lumbar apex [1, 2].

Posterior pedicle screw constructs have become the primary surgical strategy for correction of AIS whose curve Cobb angle exceeds 45 degree [3]. While, the selection of lowest instrumented vertebra (LIV) is crucial to determine the distal end of the fusion. Wang et al [4] claimed that LIV levels correlated significantly with the magnitude of the correction and with coronal balance. Inappropriate LIV selection can lead to curve decompensation, deprivation of lumbar motion segments and distal adding-on phenomenon [5]. However, substantial research have significant controversy regarding the option of the distal fused vertebra [6-8].

The purpose of this study was to investigate the effect that SV and LSTV were selected as the LIV in deformity correction by radiographic and Scoliosis Research Society (SRS)-22 outcomes in Lenke 1A AIS patients. In addition, whether SV selected as LIV is appropriate to reduce the occurrence of Adding-on phenomenon.

Materials and methods

It was a retrospective study which was approved by the Institutional Review Board in our local institution. The baseline characteristics

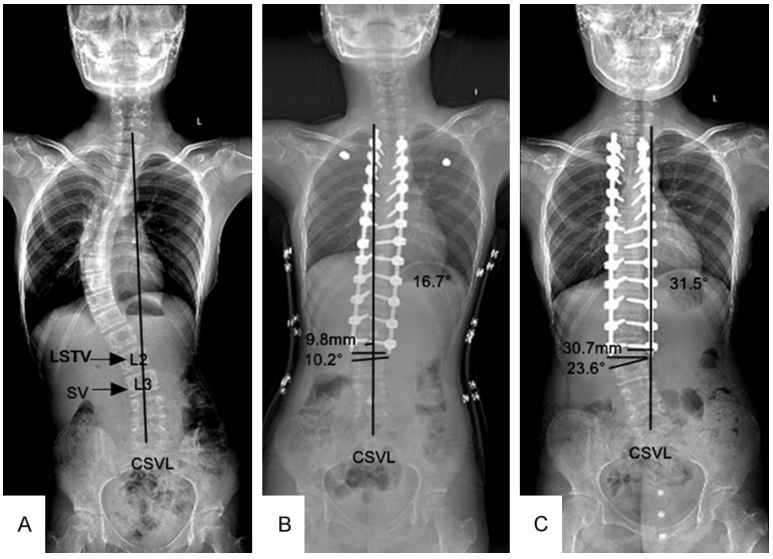

Figure 1. A 14-year-old female with adding-on. A. Preoperative standing anteroposterior radiograph: L2 was last substantially touched vertebra (LSTV). L3 was stable vertebra (SV). B. Two-week postoperation standing anteroposterior radiograph. Main curve (MC) Cobb angle was 16.7°. Intervertebral disc angle (IDA) was 10.2°. The deviation between the LIV and CSVL (LIV-CSVL) was 9.8 mm. C. Two-year postoperation standing anteroposterior radiograph. MC Cobb angle was 31.5°. IDA was 23.6°. The deviation of LIV-CSVL was 30.7 mm.

Table 1. The baseline characteristics of the two groups

Variable	LSTV	SV	p
Gender (F/M)	20/6	24/5	-
Age (y)	13.6±2.02	14.8±2.08	0.038
Riser's sign	2.5±1.63	2.8±1.52	0.439
TSP (-1/N/+1)	1/20/5	2/24/3	-
MT Cobb (°)	54.5±12.21	54.0±10.69	0.882
convex-Bending Cobb (°)	31.3±11.10	31.0±9.65	0.913
Flexibility (%)	43.4±11.55	42.2±14.95	0.738
VR (Nash-Moe)	1.7±0.60	1.8±0.71	0.591
AVT (mm)	40.6±16.05	37.1±18.69	0.461
TTS (mm)	20.5±14.84	18.6±14.12	0.639
TK (T5-T12, °)	26.8±15.04	28.9±14.60	0.604
LL (T12-S1, °)	-52.5±9.10	-56.2±10.98	0.178
PJA (°)	5.4±3.61	6.1±3.04	0.43

LSTV, substantially touched vertebra; SV, stable vertebra; F, female; M, male; TSP, thoracic sagittal profile; -1, hypokyphosis; N, normal; +1, hyperkyphosis; MT, main thoracic; VR, vertebral rotation; AVT, apical vertebra translation; TTS, thoracic trunk shift; TK, thoracic kyphosis; LL, lumbar lordosis; PJA, proximal junctional angle.

and radiographic outcomes were collected in our center from January 2009 to February 2014. Inclusion criteria were Lenke 1A AIS patients, with no thoracoplasty and treated with posterior pedicle screw spinal fusion. The exclusion criteria were patients diagnosed as early-onset scoliosis or neuromuscular scoliosis, accepting previous spine surgery, using hybrid instrumentation or performing SPO, PSO, VCR, VCD surgical techniques. Finally, a total of 55 patients met the above criteria and were followed up for two years.

Patients were divided into two groups according to the position of LIV (SV or LSTV). SV was defined as the LIV where CSVL divided the first vertical blow the main thoracic scoliosis. LSTV was defined as the LIV where CSVL was between the pedicles or touching the pedicle blow the main thoracic scoliosis.

The baseline data, radiographic outcomes and SRS-22 scores of the two groups were collected and analyzed in terms of preoperation and postoperation. Distal adding-on phenomenon was defined as main curve Cobb angle adding more than 5° with the distal end vertebra of main thoracic curve progressing toward distal vertebra, or an increase of more than 10 mm in deviation of the lowest instrumented vertebra from center sacral vertical line or an increase of more than 5° in the angulation of the first disc below the instrumentation at the final follow-up [9-12] (**Figure 1**).

Surgical technique

All surgeries were performed by one senior surgeon at a single institution. After anatomical exposure of the spine, pedicle screws were placed by a free hand technique and then confirmed the location security by C-arm fluoroscopy and awake-test. The correction manoeuvres were the same for both groups. First, on the concave side, distraction was per-

Table 2. The radiographic outcomes of the two groups

Variable	LSTV	SV	p
Two weeks postoperation			
MT Cobb (°)	18.1±10.25	15.9±7.30	0.373
Change of MT Cobb (°)	36.8±7.42	38.1±10.56	0.587
Correction rate (%)	69.1±15.29	70.4±13.43	0.742
AVT (mm)	17.9±11.92	16.5±9.89	0.628
TTS (mm)	11.2±6.96	11.9±9.22	0.729
TK (T5-T12, °)	19.7±12.67	22.9±9.25	0.286
LL (T12-S1, °)	-45.0±9.93	-47.1±10.91	0.453
PJA (°)	7.5±5.73	7.8±5.95	0.731
MC Cobb (°)	20.5±7.61	16.9±7.16	0.077
IDA (°)	2.4±2.91	2.0±2.46	0.590
LIV-CSVL (mm)	9.5±4.37	5.1±3.48	<0.001
Two years postoperation			
MT Cobb (°)	19.2±10.18	17.1±8.17	0.403
Change of MT Cobb (°)	35.3±7.89	36.9±11.35	0.536
Correction rate (%)	66.1±14.71	67.6±15.60	0.712
AVT (mm)	14.5±9.46	13.9±8.72	0.805
TTS (mm)	12.7±10.19	10.6±9.44	0.429
TKCobb (T5-T12, °)	20.7±11.57	25.2±11.69	0.163
LL Cobb (T12-S1, °)	-53.3±8.93	-53.3±9.92	0.999
PJA (°)	10.2±6.71	12.4±7.74	0.186
MC Cobb (°)	22.1±7.71	17.3±8.29	0.032
IDA (°)	5.9±4.99	2.1±2.70	0.001
LIV-CSVL (mm)	14.8±7.53	5.6±3.80	<0.001
Change of MC Cobb (°)	1.4±6.66	-1.2±4.18	0.099
Change of IDA (°)	3.5±3.72	0.1±2.12	0.016
Change of LIV-CSVL (mm)	5.3±5.25	0.3±2.31	0.003
Adding-on	7	1	0.037

LSTV, substantially touched vertebra; SV, stable vertebra; MT, main thoracic; AVT, apical vertebra translation; TTS, thoracic trunk shift; TK, thoracic kyphosis; LL, lumbar lordosis; PJA, proximal junctional angle; MC, major curve; IDA, intervertebral discangle; LIV-CSVL, deviation of the lowest instrumented vertebra from center sacral vertical line.

formed after single rod rotation. Second, on the convex side, compression was performed after inserting the implant rod. The two-step locking caps were finally tightened. Allograft bone material and the disposed laminae and transverse processes were used for fusion.

The baseline data, radiographic and SRS-22 measurements

The following baseline data were recorded for each patient: gender, age, and Risser's sign [13]. Radiographic assessment of the two groups included the use of preoperative supine left and right side-Bending radiographs and preoperative, two weeks postoperative and two years postoperative upright posteroanterior and lateral radiographs.

Radiographic outcomes included thoracic sagittal profile, main thoracic (MT) Cobb angle, convex-Bending Cobb angle, curve flexibility, vertebral rotation index (Nash-Moe method), apical vertebral translation (AVT), thoracic trunk shift (TTS), thoracic kyphosis (TK, T5-T12), lumbar lordosis (LL, L1-L5), proximal junctional angle (PJA). In addition, the change of MT Cobb angle, correction rate of the MT curve, main curve (MC) Cobb angle, intervertebral disc angle (IDA) of LIV and the deviation between the LIV and CSVL (LIV-CSVL) were measured in the postoperative periods. The number of distal adding-on phenomenon of the two groups was recorded and analyzed at two years follow-up. SRS-22 scores (Scoliosis Research Society questionnaire) were also evaluated in regard to patients' function/activity, pain, self-image, mental health, satisfaction.

Statistical analysis

Statistical analysis was performed by IBM SPSS Statistics v.21.0 (IBM Corp., Armonk, N.Y., USA). Data were listed as the mean ± standard deviation. Independent sample *t* test was used to compare two groups' baseline characteristics, radiographic outcomes, and the SRSS-22 scores when collected data were distributed as the normality and equality of variances. Chi-square test was used to compare the differences of qualitative data (Adding-on). If not, Wilcoxon rank sum test was used. A multiple logistic regression was used to analysis the risk factors of adding-on. Significance level was defined as $p<0.05$.

Results

A total of 55 consecutive Lenke 1A AIS patients were finally included in the study (SV: n= 29; LSTV: n=26). Baseline characteristics of

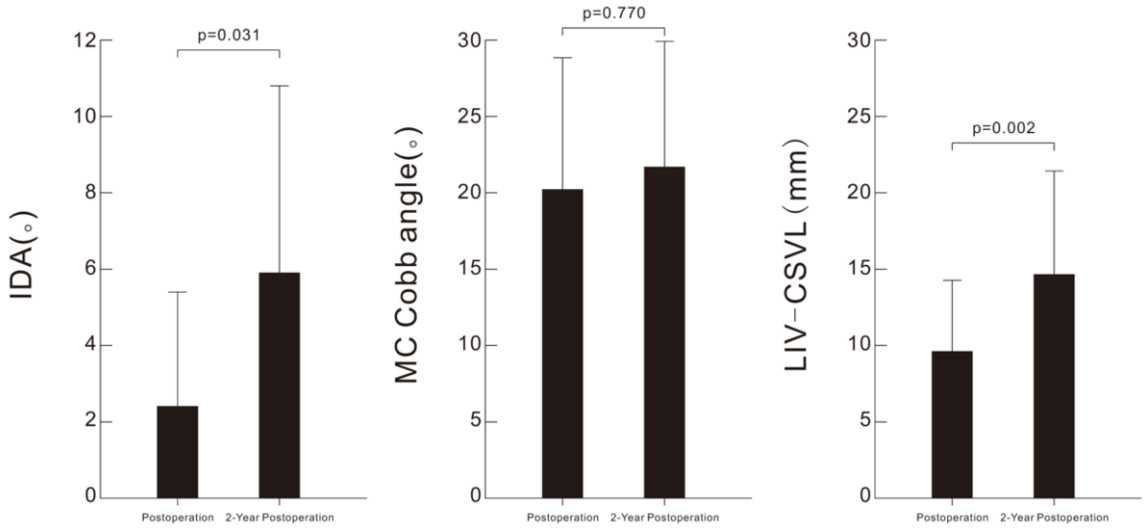

Figure 2. Comparison of intervertebral disc angle (IDA), main curve (MC) Cobb angle, and the deviation between the LIV and CSVL (LIV-CSVL) at postoperation and at 2-year postoperation in LSTV group.

the two groups were given in **Table 1**. In the SV group, there were 24 females and 5 males, and thoracic sagittal profile was 2 hypokyphosis, 24 normal, and 3 hyperkyphosis. In the LSTV group, there were 20 females and 6 males, and thoracic sagittal profile was 1 hypokyphosis, 20 normal, and 5 hyperkyphosis. Compared with the SV group, the younger age was found in the LSTV group (13.6 vs. 14.8 years, p=0.038). There were no significant differences between the two groups in Riser's sign, MT Cobb angle, convex-Bending Cobb angle, curve flexibility, vertebral rotation, apical vertebra translation, thoracic trunk shift, thoracic kyphosis, lumbar lordosis and proximal junctional angle at preoperation.

The radiographic outcomes of the two groups regarding the coronal and sagittal curve correction were shown in **Table 2**. At two weeks postoperative, MT Cobb angle was 18.1°± 10.25° translating into a correction rate of 36.8%±7.42% for the LSTV group and 15.9°± 7.30° translating into a correction rate of 38.1%±10.56% for the SV group. In the coronal plane, several radiographic parameters were found in LSTV group in regard to AVT of 17.9±11.92 mm, TTS of 11.2±6.96 mm and SV group in regard to AVT of 16.5±9.89 mm, TTS of 11.9±9.22 mm. In sagittal segments, several radiographic parameters were observed in LSTV group concerning TK of 19.7°±12.67°, LL of -45.0°±9.93° and PJA of 7.5°±5.73°. Related to the adding-on, MC Cobb angle was 20.5°±7.61° for the LSTV group and 16.9°± 7.16° for the SV group. IDA of LIV was 2.4°± 2.91° for the LSTV group and 2.0°±2.46° for the SV group. LIV-CSVL was 9.5±4.37 mm for the LSTV group and 5.1±3.48 mm for the SV group. Comparing the two groups, there were no statistically significant differences except LIV-CSVL (9.5 vs. 5.1 mm, p<0.001) at two weeks postoperation.

At two-year postoperation, there was not too much change between the two groups in MT Cobb angle, change of MT Cobb angle, correction rate, AVT, TTS, TK and LL based on a comparison of two weeks postoperative. However, compared with the SV group, increased MC Cobb angle (22.1° vs. 17.3°, p=0.032), IDA (5.9° vs. 2.1°, p=0.001) and LIV-CSVL (14.8 vs. 5.6 mm, p<0.001) were found in the LSTV group (22.1° vs. 17.3°, p=0.032). In addition, the distal adding-on phenomenon was higher in the LSTV group (p=0.037).

Comparison of intervertebral disc angle, main curve Cobb angle, and the deviation between the LIV and CSVL at postoperation and at 2-year postoperation, there were significant differences in terms of IDA (p=0.031) and the deviation of the LIV-CSVL (p=0.002) except the MC Cobb angle (p=0.770) in LSTV group (**Figure 2**). However, there were no significant differences in SV group (p>0.05) (**Figure 3**).

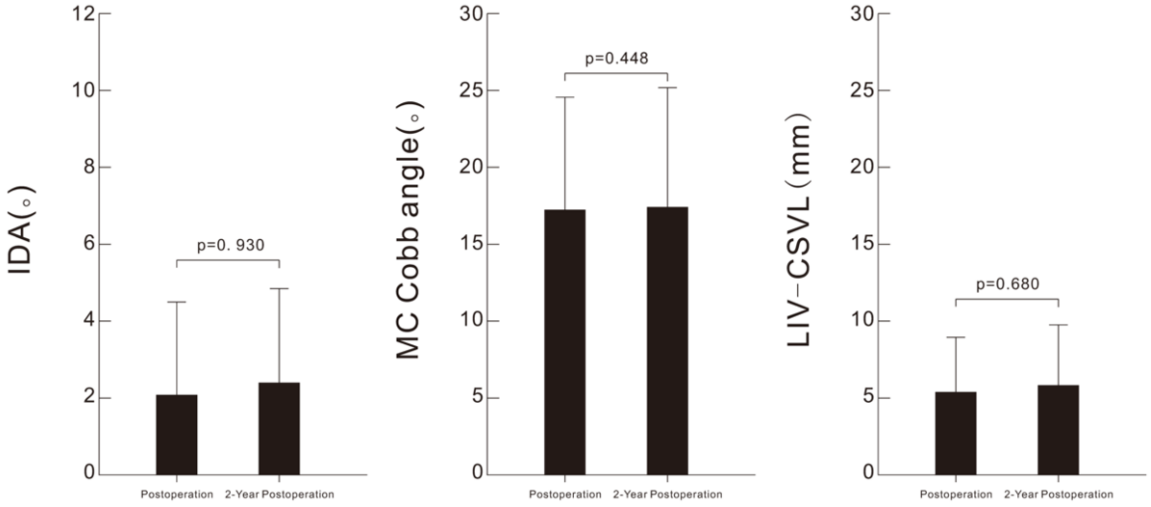

Figure 3. Comparison of intervertebral disc angle (IDA), main curve (MC) Cobb angle, and the deviation between the LIV and CSVL (LIV-CSVL) at postoperation and at 2-year postoperation in SV group.

Table 3. Multiple Logistic Regression Model of Adding-on

Predictive Factors	Odds ratio (95% CI)	p
Age (y)	0.9 (0.6-1.3)	0.476
Flexibility (%)	0.9 (0.8-1.0)	0.147
LSTV & SV as LIV	0.1 (0-0.9)	0.041※

LSTV, substantially touched vertebra; SV, stable vertebra; ※, $p<0.05$.

Table 4. The SRS-22 questionnaire of the two groups

Variable	LSTV	SV	p
Pre-operation			
Function/activity	3.8±0.4	3.7±0.3	0.271
Pain	4.3±0.4	4.3±0.5	0.612
Self-image	3.2±0.4	3.2±0.5	0.774
Mental health	3.9±0.4	3.8±0.4	0.697
Satisfaction	-	-	-
Two years postoperation			
Function/activity	3.8±0.2	3.9±0.2	0.245
Pain	4.2±0.3	4.3±0.3	0.743
Self-image	3.5±0.3	3.7±0.3	0.093
Mental health	4.0±0.3	4.0±0.6	0.637
Satisfaction	4.0±0.6	4.1±0.5	0.693

The risk factors of adding-on which were age, flexibility of the spine, and LSTV and SV selected as LIV were used to establish a multiple logistic regression model (**Table 3**). The results indicated that LSTV and SV selected as LIV was an independent predictive factor.

Table 4 described the assessment of the quality of life of the two groups using the SRS-22 questionnaire at pre-operation and at two-year postoperation. The function/activity, pain, self-image, mental health and satisfaction demonstrated no significant differences in the comparison of the two groups.

Discussion

The purposes of deformity surgery are to achieve a well-balanced spine and to prevent further progression of the deformity [14]. Determination of the LIV plays an important role in the fusion of AIS with Lenke 1A curves. The common selection of LIV includes the end vertebra, the neutral vertebra, the last substantially touch vertebra, and the stable vertebra. Regarding the selection of the LIV, Clément et al [15] reported that LIV levels correlated significantly with the magnitude of the correction and with coronal balance. King et al [16] recommended the stable vertebra for LIV in King Type III and IV curve types, rather than the neutral vertebra resulting in higher adding-on phenomenon in 62% of patients. Qin et al [17] claimed that selecting the LSTV or non-LSTV as the LIV could yield a promising outcome for Lenke 1A scoliosis patients undergoing selective posterior thoracic fusion. Sun et al [18] reviewed 37 AIS patients and found that the distal fusion level was more appropriate to one level below lower-end vertebra (LEV+1) than LEV to lessen LIV translation. Thus, the selection of LIV was still controversial.

In this study, the radiographic and SRS-22 outcomes were compared in Lenke 1A AIS patients using SV versus LSTV as LIV. It was demonstrated that there were no significant differences between the two groups in terms of the coronal correction of MT Cobb angle (p=0.403), correction rate (p=0.712), AVT (p=0.805), and TTS (p=0.429); sagittal correction of TK Cobb angle (p=0.163), LL Cobb angle (p=0.999) and PJA (p=0.186), and SRS-22 outcomes (p>0.05) at two years postoperation. There were few studies evaluating the effects of SV versus LSTV selected as LIV in the treatment of Lenke 1A AIS patients. However, we also found that SV group significantly decreased the distal adding-on phenomenon than LSTV group (p=0.037) at two years postoperation. Although the LSTV reserved lumbar motion segments, the occurrence rate of adding-on was high (8/55, 14.5%). Although long-term results remained unknown, it was widely believed that adding-on phenomenon should be avoided as much as possible, as it might lead to revision surgery. In our study, we found that SV not only acquired satisfied correction of scoliosis, but also decreased the incidence of distal adding-on phenomenon. We believe this conclusion would be significant beneficial to both spinal surgeons and Lenke 1A AIS patients.

According to previous literatures, distal adding-on phenomenon was a common complication in AIS patients after orthopedic surgery [19-22]. Wang et al and Murphy et al reported that the selection of LIV was highly correlated with the presence of adding-on in Lenke 1A type scoliosis [11, 23]. Lakhal et al [24] analyzed 50 Lenke type 1 patients who were treated with spinal fusion instrumentation, demonstrating that the choice of the LIV affected the deterioration of the lumbar curve and the development of distal adding-on. Our findings were relevant to upper reports, which found that the indexes of the distal adding-on phenomenon were significant differences between the two groups. The reason might be that LSTV group's patients with a farther deviation of LIV-CSVL (9.5 vs. 5.1 mm, p<0.001) after surgery had a higher risk of developing postoperative regional coronal imbalance. With the loss of spontaneous lumbar curve correction, further analysis identified eight patients who were subjected to distal adding-on phenomenon, whose MC Cobb angle adding more than 5°, or an increase of more than 10 mm in deviation of the LIV-CSVL, or an increase of more than 5° in IDA at two years postoperation. In our study, there were significant differences in change of the IDA (3.5° vs. 0.1°, p=0.016), and the deviation of LIV-CSVL (5.3 vs. 0.3 mm, p=0.003) between the two groups. Hence, selecting the LSTV as the LIV was more liable to occur the complication of distal adding-on phenomenon. To verify the hypothesis, further radiographic measurements and biomechanical studies need to be performed.

Meanwhile, some limitations should not be ignored. First, it was a retrospective study not a RCT, so that patients were not randomized to select SV or LSTV as LIV according to the surgical procedure. The selection of LIV could be attributed to the evolution of the surgical technique during the study. Second, the relatively small sample size was underpowered for identifying significant differences, and a longer follow-up study would be performed to assess the maintenance of deformity correction and incidence of distal adding-on.

Conclusions

Both SV and LSTV selected as LIV could achieve satisfactory deformity correction in management of Lenke 1A AIS patients. However, comparing the SV selected as the LIV, the LSTV significantly increases the indexes of distal adding-on and are more likely to occur distal adding-on phenomenon.

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All the authors were directly involved in the whole process; therefore, it is disclosed that all the authors contributed equally towards the research.

Disclosure of conflict of interest

None.

Abbreviations

AIS, adolescent idiopathic scoliosis; SV, stable vertebra; LSTV, last substantially touched vertebra; LIV, lowest instrumented vertebra; SRS, Scoliosis Research Society; CSVL, central sacral vertical line; MT, main thoracic; MC, main curve; AVT, apical vertebral translation; TTS,

thoracic trunk shift; TK, thoracic kyphosis; LL, lumbar lordosis; PJA, proximal junctional angle; IDA, intervertebral disc angle.

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