Original Article
Clinics in Orthopedic Surgery 2025;17:250-257 • https://doi.org/10.4055/cios23228

Comparison of 3-Dimensional Correction and Clinical Outcomes of Lenke 1A Curves with the Stable Vertebra (SV) or SV-1 Selected as the Lowest Instrumented Vertebra

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Background: Lowest instrumented vertebra (LIV) selection is controversial in Lenke 1A curves. Alignment of the LIV in coronal, sagittal, and transverse planes is important for correction of overall scoliosis, as well as the alignment of uninstrumented lumbar curve. In this study, we aimed to evaluate the 3-dimensional correction and clinical outcomes of Lenke 1A curves, corrected with rod derotation (RD) maneuver, according to the LIV level.

Methods: Prospectively collected data of 46 consecutive idiopathic scoliosis surgery patients with Lenke 1A scoliosis who had been treated with posterior instrumentation and fusion were retrospectively evaluated. Patients were divided into 2 groups according to the LIV level: stable vertebra (SV) group (25 patients) and 1 level proximal to SV (SV-1) group (21 patients). Patients were compared pre- and postoperatively according to radiographic and clinical outcomes. Measured parameters in coronal plane were Cobb angle of thoracic curve, shoulder balance, coronal balance, LIV translation, and LIV tilt; in sagittal plane, thoracic kyphosis, lumbar lordosis, sagittal balance, and distal junctional angle. Transverse plane analysis included rotational measurement of apical vertebra (AV), LIV, and LIV+1 with computerized tomography. Clinical outcomes were evaluated with Scoliosis Research Society (SRS)-22 questionnaire. Surgical times were noted.

Results: There were no statistically significant differences between the 2 groups in terms of preoperative radiographic values. In both groups, Cobb angle of thoracic curve, shoulder balance, LIV translation, and LIV tilt improved significantly after the surgery. Postoperatively, AV rotation decreased in both groups significantly. No significant change was observed in rotations of LIV and LIV+1 after the surgery. Clinical outcomes and surgical times were similar between the groups.

Conclusions: Selection of the LIV as SV or SV-1 in Lenke 1A patients led to similar results in terms of coronal and sagittal plane reconstruction, as well as AV and LIV rotation. With RD maneuver, an acceptable amount of rotation could be achieved at LIV and LIV+1. Radiologic and functional outcomes were satisfactory in both LIV levels. To save 1 more mobile segment, it seems reasonable to select SV-1 as the LIV if possible in order to obtain a well-aligned LIV in all 3 planes.

Keywords: *Scoliosis, Adolescent, Instrumentation*

Received July 24, 2023; Revised July 11, 2024;
Accepted November 3, 2024
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In adolescent idiopathic scoliosis surgery (AIS), correction of transverse plane deformity is as important as coronal and sagittal plane correction. It aids in restoration of coronal and sagittal spinal alignments, decreases thoracic hump, and improves functional outcomes.[1,2] Rod derotation (RD) and direct vertebral rotation (DVR) are traditional maneuvers used to correct axial rotation. Derotation of instrumented segments also affects uninstrumented levels. How the unfused levels' rotation behaves postoperatively is controversial, and different outcomes have been shown in different studies.[3,4] Rotation of the lowest instrumented vertebra (LIV) is thought to be an important factor in the alignment of uninstrumented lumbar curve.[5] If residual LIV rotation is high, postoperative lumbar curve progression and coronal decompensation may occur.[6]

Although some studies evaluated the axial rotation of fused and unfused levels, it has not been studied in the literature how the level of LIV effects the rotational vertebral alignment. Our aim in this study was to evaluate the 3-dimensional correction, especially the changes in the rotation of some strategic vertebrae of Lenke 1A curves corrected with RD maneuver, according to LIV selection.

METHODS

Institutional Ethics Committee approval was obtained (Haydarpasa Numune Education and Research Hospital; IRB No. 2022-KK-210). Informed consent was obtained from all individual participants' parents or guardians.

Patients and Groups

Prospectively collected data of 46 consecutive AIS patients with Lenke 1A scoliosis who had been treated with posterior instrumentation and fusion were retrospectively evaluated. Patients who had diagnosis other than AIS, underwent prior spine surgery, were over 20 years at the time of surgery, and were not available for postoperative computed tomography (CT) were excluded.

The LIV was selected as the stable vertebra (SV) or 1 level proximal to the SV (SV-1). Final decision for the LIV level was made intraoperatively. If the disc below the LIV was leveled with instrumentation to the SV-1 and correction maneuvers, the SV-1 was selected as the LIV. Otherwise, the instrumentation was extended to the SV. Two groups were categorized according to the LIV level: SV group (25 patients) and SV-1 group (21 patients).

Surgical Technique

All operations were performed with the same surgical team. After a standard exposure, polyaxial pedicle screws were inserted bilaterally at every level of the deformity by the freehand technique. After posterior release with wide facetectomies, a first precontoured rod was inserted to the concave side of the thoracic curve and the deformity was corrected using RD maneuver. A second precontoured rod was inserted to the convex side. Compression, distraction, and in situ bending maneuvers were added if necessary. Correction of the deformity was assessed using fluoroscopy. If a disc below the LIV could not be leveled with instrumentation to the SV-1, rods were released, instrumentation was extended to the SV, new rods were prepared, correction maneuvers were repeated, and disc alignment was assessed again. After decortication, allograft was placed for fusion. Neuromonitoring was used in all surgeries. Surgical times were noted.

Radiographic and Clinical Outcome Measurements

Whole spine standing anteroposterior and lateral radiographs (Figs. 1 and 2) as well as CT scans were evaluated preoperatively and at the last follow-up. Two blinded spinal surgeons (SE, MKM) who were not in the operative team performed all of the measurements. The following parameters were evaluated on standing radiographs: Cobb angle of the thoracic curve; shoulder balance as coracoid

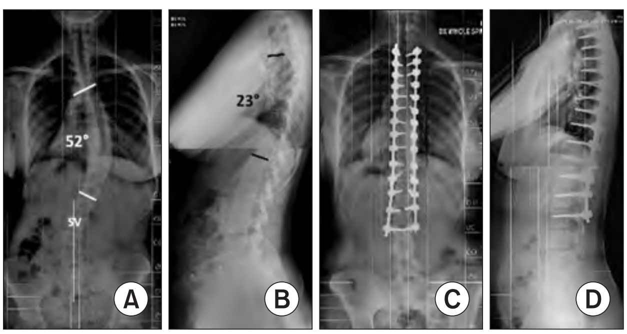

Fig. 1. (A, B) Anteroposterior and lateral radiographs of a 16-year-old girl with Lenke 1A scoliosis, showing 52° of main thoracic curve and 23° of thoracic kyphosis. (C, D) Postoperative radiographs at the last follow-up showing T2-L3 fusion. The patient was fused to the stable vertebra (SV).

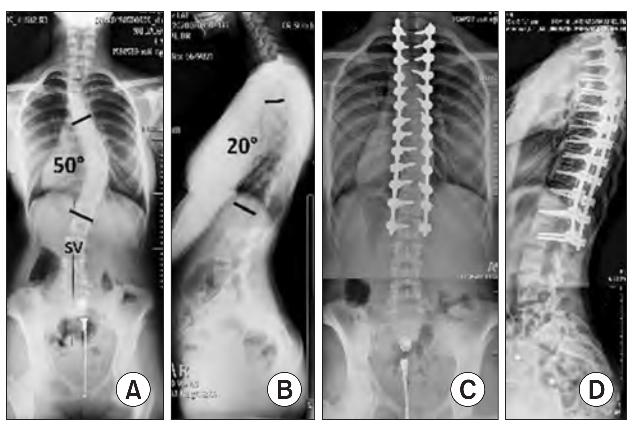

Fig. 2. (A, B) Anteroposterior and lateral radiographs of a 14-year-old girl with Lenke 1A scoliosis, showing 50° of main thoracic curve and 20° of thoracic kyphosis. (C, D) Postoperative radiographs at the last follow-up showing T2-L2 fusion. The patient was fused to the stable vertebra (SV)-1.

height difference based on the distance between the horizontal lines passing through the upper margin of each coracoid process; LIV translation as the distance between the midpoint of the LIV and central sacral vertical line (CSVL); LIV tilt as the inclination of the lower endplate of the LIV in the horizontal plane; coronal balance as the perpendicular distance between the C7 plumb line and central sacral vertical line (C7PL-CSVL); thoracic kyphosis (T5-T12); lumbar lordosis (L1-L5); sagittal balance as C7 plumb line; and distal junctional angle (DJA) between the superior endplate of the LIV and the inferior endplate of the adjacent distal vertebra. DJA > 10° was defined as distal junctional kyphosis. Curve flexibility was measured with bending anteroposterior radiographs. Risser grade was also noted.

Axial plane analysis was performed on CT images. Measurements were performed on true axial images, which were reconstructed according to the tilt of the corresponding vertebra in coronal and sagittal planes. Strategic vertebrae, which were evaluated on the transverse plane were the apical vertebra (AV) of thoracic curve, the LIV, and the vertebra 1 level caudal to the LIV (LIV+1). The angle between the long axis of the vertebra and sagittal plane was defined as vertebral rotation angle and was measured as described previously (Figs. 3 and 4).[7] Clinical outcomes were evaluated with Scoliosis Research Society (SRS)-22 questionnaire preoperatively and at final follow-up by face to face interviews.

Statistical Analyses

IBM SPSS for Windows version 21.0 (IBM Corp.) was used for statistical analysis. All continuous variables were presented as mean ± standard deviation. Demographic and radiographic parameters were compared between the groups by using Mann-Whitney *U*-test. Wilcoxon test was used for pre-and postoperative comparative analysis within the groups. A *p*-value less than 0.05 was considered statistically significant. The interobserver reliability was estimated using intraclass correlation coefficients (ICCs).

RESULTS

Demographic values and curve characteristics are given in Table 1. Surgical times were similar between the groups. Mean follow-up time was 28 months (range, 24–35 months). There were no statistically significant differences between the 2 groups in terms of preoperative radiographic values. In both groups, Cobb angle of thoracic curve, shoulder balance, LIV translation, and LIV tilt improved significantly after the surgery (Table 2). None of the patients developed coronal or sagittal imbalance. Distal junctional kyphosis was not observed.

Preoperative and postoperative rotational angles of AV, LIV, and LIV+1 are given in Table 3. Preoperative and postoperative values were similar between the groups. Postoperatively, AV rotation decreased in both groups significantly. No significant change was observed in rotations of other strategic vertebrae after the surgery. The interobserver reliability was between 0.73 and 0.95 for all

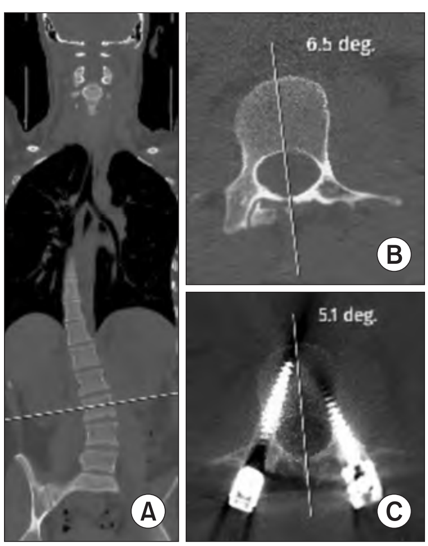

Fig. 3. (A-C) Axial plane rotation assessment of a patient from the stable vertebra group. The lowest intrumented vertebra (L3) rotation angle decreased from 6.5° to 5.1°.

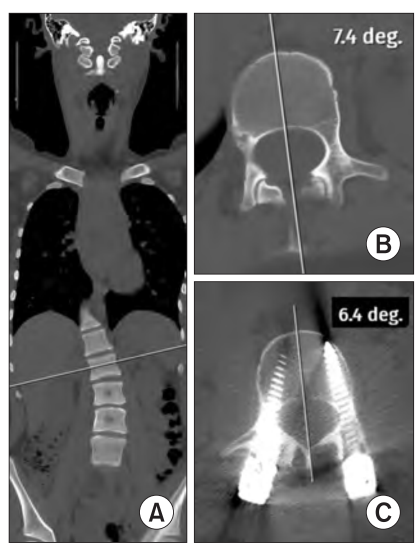

Fig. 4. (A-C) Axial plane rotation assessment of a patient from the stable vertebra-1 group. The lowest intrumented vertebra (L2) rotation angle decreased from 7.4° to 6.4°.

Table 1. Demographic Values, Curve Characteristics, and Surgical Times

Variable	SV group (n = 25)	SV-1 group (n = 21)	*p*-value
Age (yr)	15.2 ± 1.58	15.7 ± 1.65	0.698
Sex (male : female)	6 : 19	5 : 16	0.524
SV level (L1 : L2 : L3)	2 : 14 : 9	0 : 6 : 15	0.038*
Number of fused levels	13.12 ± 1.15	14.42 ± 1.46	0.923
MT curve flexibility (%)	48.52 ± 12.86	51.63 ± 9.75	0.276
Risser grade (range, 0–5)	3.8 ± 0.7	3.6 ± 0.6	0.642
Surgical time (min)	193.7 ± 24.3	181.4 ± 27.6	0.195

Values are presented as mean ± standard deviation. SV group: stable vertebra group, SV-1 group: 1 level proximal to the SV group.
SV: stable vertebra, MT: main thoracic.
*Statistically significant difference, $p < 0.05$.

Table 2. Preoperative and Postoperative Values in Coronal and Sagittal Planes

Variable	SV group	SV-1 group	*p*-value
Preoperative MT Cobb angle (°)	55.36 ± 8.72	52.27 ± 11.32	0.843
Postoperative MT Cobb angle (°)	12.25 ± 5.38	13.75 ± 6.84	0.658
p-value†	< 0.001*	< 0.001*	
Preoperative CHD (mm)	9.2 ± 5.3	8.5 ± 4.7	0.537
Postoperative CHD (mm)	2.7 ± 1.6	2.4 ± 1.3	0.495
p-value†	0.002*	0.003*	
Preoperative LIV translation (mm)	8.8 ± 3.6	9.6 ± 4.8	0.634
Postoperative LIV translation (mm)	4.1 ± 2.2	4.3 ± 3.1	0.593
p-value†	0.005*	0.004*	
Preoperative LIV tilt (°)	20.3 ± 8.2	23.7 ± 7.4	0.768
Postoperative LIV tilt (°)	4.2 ± 2.4	5.5 ± 3.1	0.624
p-value†	< 0.001*	< 0.001*	
Preoperative C7PL-CSVL (mm)	11.2 ± 8.2	10.3 ± 7.4	0.582
Postoperative C7PL-CSVL (mm)	8.7 ± 6.3	9.4 ± 3.9	0.513
p-value†	0.196	0.725	
Preoperative T5-T12 TK (°)	22.3 ± 5.2	24.4 ± 4.9	0.674
Postoperative T5-T12 TK (°)	20.8 ± 4.7	21.2 ± 3.8	0.738
p-value†	0.815	0.726	
Preoperative L1-L5 LL (°)	51.5 ± 12.6	49.7 ± 13.8	0.753
Postoperative L1-L5 LL (°)	47.6 ± 13.5	48.5 ± 14.3	0.845
p-value†	0.615	0.782	

Table 2. Continued

Variable	SV group	SV-1 group	*p*-value
Preoperative C7-PL (mm)	–14.7 ± 19.8	–12.7 ± 20.4	0.564
Postoperative C7-PL (mm)	–11.5 ± 17.6	–10.3 ± 19.5	0.715
p-value†	0.426	0.625	
Preoperative DJA (°)	5.8 ± 3.6	6.2 ± 2.9	0.647
Postoperative DJA (°)	6.4 ± 3.1	7.3 ± 2.6	0.574
p-value†	0.532	0.496	

Values are presented as mean ± standard deviation. SV group: stable vertebra group, SV-1 group: 1 level proximal to the SV group.
SV: stable vertebra, MT: main thoracic, CHD: coracoid height difference, LIV: lowest instrumented vertebra, C7PL-CSVL: C7 plumb line and central sacral vertical line, TK: thoracic kyphosis, LL: lumbar lordosis, DJA: distal junctional angle.
*Statistically significant difference, $p < 0.05$; comparison between groups. †Comparison between preoperative and postoperative values.

Table 3. Preoperative and Postoperative Values in Transverse Plane

Variable	SV group	SV-1 group	*p*-value
Preoperative AV Rot (°)	14.25 ± 5.38	13.53 ± 4.34	0.437
Postoperative AV Rot (°)	11.27 ± 4.62	10.87 ± 3.94	0.376
p-value†	0.019*	0.025*	
Preoperative LIV Rot (°)	6.63 ± 3.45	7.15 ± 4.38	0.527
Postoperative LIV Rot (°)	5.52 ± 2.98	6.73 ± 4.15	0.435
p-value†	0.386	0.582	
Preoperative LIV+1 Rot (°)	5.53 ± 2.85	5.87 ± 3.27	0.735
Postoperative LIV+1 Rot (°)	4.56 ± 3.82	5.14 ± 4.06	0.674
p-value†	0.652	0.716	

Values are presented as mean ± standard deviation. SV group: stable vertebra group, SV-1 group: 1 level proximal to the SV group.
SV: stable vertebra, AV Rot: apical vertebra rotation, LIV Rot: lowest instrumented vertebra rotation.
*Statistically significant difference, $p < 0.05$; comparison between groups.
†Comparison between preoperative and postoperative values.

Table 4. Comparison of Clinical Outcomes

SRS score	SV group	SV-1 group	*p*-value
Preoperative activity	4.1 ± 0.6	4.0 ± 0.4	0.467
Postoperative activity	4.2 ± 0.4	4.3 ± 0.7	0.513
Preoperative pain	4.3 ± 0.5	4.2 ± 0.3	0.542
Postoperative pain	4.1 ± 0.3	4.0 ± 0.6	0.493
Preoperative self image	3.9 ± 0.7	3.8 ± 0.5	0.492
Postoperative self image	4.1 ± 0.4	4.2 ± 0.8	0.585
Preoperative mental health	4.0 ± 0.7	4.1 ± 0.2	0.558
Postoperative mental health	4.2 ± 0.6	4.1 ± 0.7	0.442
Preoperative satisfaction	4.1 ± 0.5	4.0 ± 0.9	0.593
Postoperative satisfaction	4.3 ± 0.7	4.2 ± 0.4	0.653
Preoperative total	4.1 ± 0.6	4.2 ± 0.3	0.586
Postoperative total	4.2 ± 0.8	4.3 ± 0.9	0.635

Values are presented as mean ± standard deviation. SV group: stable vertebra group, SV-1 group: 1 level proximal to the SV group.
SRS: Scoliosis Research Society.

continuous measures, which showed good to excellent ICC. Clinical outcomes were similar between the groups pre- and postoperatively (Table 4). There were no intra- or postoperative complications.

DISCUSSION

Three-planar correction should be obtained in AIS surgery for optimal outcomes. New instrumentation systems and techniques enable this correction better than historical ones. While Harrington instrumentation corrected coronal plane deformity with distractive forces, it caused flattening of sagittal profile and had no effect on axial plane.[8] Axial plane correction was first obtained with Cotrel-Dubousset instrumentation, which used the RD technique.[9] Later DVR technique was introduced, and better rotational correction amounts were reported.[1,10] While apical rotational correction with RD is around 15%,[11,12] DVR enables correction as high as 55%.[13] Our apical rotational correction amount was 20.3%, which was comparable with the literature.

Second and third strategic vertebrae, which we evaluated in terms of axial rotation were LIV and LIV+1 respectively. Pre- and postoperative rotation amounts of the LIV are particularly important because they affect postoperative coronal and axial alignments of unfused segments, as well as functional outcomes.[14-16] He et al.[14] showed that it is a risk factor for distal adding-on, if the fusion is stopped at a level with higher preoperative rotation. Chang et al.[15] showed that higher LIV rotation was observed in Lenke 1 patients with unsatisfactory results after fusion to a neutral vertebra (NV) or NV-1. In the study of Pasha et al.,[16] the LIV was selected as the SV in Lenke 1B and 1C patients. With DVR, the LIV rotation decreased from 8° to 7° and from 9° to 6° in Lenke 1B and 1C patients, respectively, at 2-year follow-up. With fusion to SV or SV-1, we obtained similar LIV rotation correction amounts in Lenke 1A patients with RD maneuver. It seems that fusion to SV leads to comparable LIV rotation amounts in Lenke 1 patients, independent from lumbar modifier and the correction maneuver. It has been shown that rotation of unfused levels may paradoxically increase after the surgery, while instrumented levels' rotations decrease.[3] In our study, although LIV+1 rotation decreased insignificantly postoperatively, we think that fusion to the SV or SV-1 prevents a possible paradoxical increase in unfused levels.

The LIV can be selected as the last substantially touched vertebra (LSTV) or 1 level proximal to it (LSTV-1) in Lenke 1A patients. Qin et al.[17] showed that higher risk of distal adding-on is present with fusion to the LSTV-1. In their study, patients with distal adding-on had higher preoperative LIV rotation. On the other hand, Bai et al.[18] concluded that Lenke 1A patients with lower Risser sign, postoperative hypokyphosis, and > 10 mm preoperative LIV-CSVL distance are prone to develop distal adding-on when fused to LSTV. Patients with the LIV at the SV or SV-1 had lower amount of distal adding-on compared to patients with the LIV selected as the SV-2 or SV-3 in their study. Furthermore, Miyanji et al.[19] suggested to fuse some subtypes of Lenke 1A curves even distal to the SV. We do not perform selective thoracic fusion in Lenke 1A curves and prefer to fuse them to the SV or SV-1 according to intraoperative alignment. In this manner, we aim to decrease possible risks of distal adding-on and distal junctional kyphosis. In our study, fusion to the SV or SV-1 enabled optimal correction of LIV translation and LIV tilt and also preserved DJA. Beside optimal coronal and sagittal parameters, also an acceptable axial rotation of the LIV can be obtained with fusion to the SV or SV-1, which prevents these complications. Extension of fusion to more distal levels decreases the number of mobile segments, which may lead to loss of function. It has been shown in several studies that lumbar mobility is decreased when the LIV moves distally.[20,21]

On the other hand, quality of life was shown to be unaffected from decreased lumbar motion.[20,22] In order to establish a balance between preserving lumbar motion and preventing future decompensation, we aimed to stop the fusion within the stable zone in our patients. Therefore, we tried to stop at the SV-1 if possible to preserve 1 more mobile segment. Clinical outcomes were similar with fusion to the SV or SV-1.

There are several methods to measure axial rotation of vertebrae from direct roentgenograms. Visual estimation, ruler-based, analytical, and 3-dimensional reconstruction techniques for axial rotation measurement have variable accuracy. Among them, SterEOS has the highest accuracy, but it still has a measurement error around 2°.[23] CT is a reference point for all other measurement techniques and is considered to be a gold standard for rotation measurement.[24] One disadvantage of CT is the radiation exposure, which can be minimized by using low-dose scan. Change of rotation in supine position is another disadvantage, but this effect can be underestimated.[25] We use preoperative CT scans routinely to evaluate dimensions and configurations of the pedicles. In order to standardize the measurements, we performed postoperative low-dose CT in available patients.

To the best of our knowledge, this is the first study in the literature to evaluate the axial plane correction in Lenke 1A patients according to LIV selection. Strong point of this study is the uniformity of the patient group. All patients had similar curve characteristics and were operated by a single spinal surgeon at the same institution. One of the limitations is the retrospective nature of the study. The number of the patients was relatively small due to the limited number of patients with postoperative CT images.

In conclusion, selection of the LIV as the SV or SV-1 in Lenke 1A patients led to similar results in terms of coronal and sagittal plane reconstruction, as well as AV and LIV rotation. With RD maneuver, an acceptable amount of rotation could be achieved at the LIV and LIV+1. Radiologic and functional outcomes were satisfactory in both LIV levels. To save 1 more mobile segment, it seems reasonable to select the SV-1 as the LIV if possible in order to obtain a well-aligned LIV in all 3 planes.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGEMENTS

Sevki Erdem and Mert Kahraman Marasli from Haydarpasa Numune Education and Research Hospital performed the radiographic measurements.

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