Journal of Orthopaedic Surgery and Research

RESEARCH ARTICLE | Open Access

Comparison between the lowest instrumented vertebrae L3 with the use of direct vertebrae rotation (DVR) and the lowest instrumented vertebrae L4 for non-DVR in adolescents with idiopathic scoliosis Lenke 5C/6C: when LEV is L4

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Abstract

Objective As there are no substantial selection criteria for determining the lowest instrumented vertebra (LIV) in adolescent idiopathic scoliosis (AIS) Lenke 5C/6C, thus, many surgeons base their selection on experience. The study aims to compare the selection of the lowest instrumented vertebrae (LIV) lumbar vertebra three (L3) with the use of direct vertebrae rotation (DVR) to the lowest instrumented vertebrae (LIV) lumbar vertebra four (L4) with the use of non-DVR for the correction of adolescent idiopathic scoliosis (AIS) Lenke 5C/6C when the lower end vertebrae (LEV) is at lumbar vertebrae four (L4).

Methods This prospective study involved 101 patients who were divided into two groups based on different techniques. The patients were prospectively followed up for at least four years. All patients included in the study had a lower end vertebra (LEV) at L4, while patients older than 18 years and patients with prior surgical procedures were excluded. The DVR group consisted of 49 patients, and the non-DVR group included 51 patients.

Results The preoperative mean LIV disc angle was 3.1 ± 3 and 3.1 ± 1, $P = 0.097$, which corrected to 1.2 ± 0 and 1.1 ± 0 in both groups at 4-year follow-up without statistical significance. The LIVDA and LIVT were statistically insignificant at the preoperative, and there were no significant differences at the follow-up visitation. The DVR group achieved a satisfactory coronal and Cobb's angle correction compared to the NDVR group; however, there were no statistical differences at the follow-up visitations. Both groups achieve a satisfactory correction rate without substantial significance in clinical and radiological outcomes. Furthermore, no post-surgical complications were recorded in either group.

Conclusions DVR is suitable for selecting L3 as the LIV in AIS Lenke 5C/6C compared to L4 in non-DVR. DVR preserved more segments without substantial complications during the follow-up visitations. Nevertheless, both groups will continue to be followed up to prevent adding-on post-surgical complications.

Keywords DVR, Non-DVR, AIS, LIV, Lenke 5C/6C

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Introduction

Selecting the lowest vertebra for fusion level in adolescent idiopathic scoliosis (AIS) is essential to surgical planning. In cases of major thoracolumbar/lumbar (TL/L) curves, the lowest instrumented vertebra (LIV) is usually selected as the lower end vertebrae (LEV). However, fusion can be performed one level caudal to the LEV based on specific criteria. While there are no strict guidelines restricting the selection of the fusion level in AIS patients, several classifications and algorithms exist to aid in the decision-making process [1].

The selection of the ideal caudal fusion level for thoracolumbar/lumbar (TL/L) curves is a complex issue. There is an ongoing debate over fusing the TL/L curves at L3 or L4. Despite several studies conducted on fusion level selection, no definitive conclusions have been reached [2–4]. When choosing the fusion level for major TL/L curves, the primary consideration is whether caudal fusion can terminate at L3 [2].

Stopping the caudal fusion at L3 may preserve flexible lumbar spinal segments but also increase the risk of decompensation, particularly in cases with significant lumbar curvature. On the other hand, extending the caudal fusion below L3 potentially improves coronal correction but increases the incidence of low back discomfort and disc degeneration [5–7].

However, spine surgeons can halt fusion at more proximal levels with advanced segmental instrumentation techniques. Ideally, the lumbar spine's mobility would be preserved by leaving at least three levels unfused. By utilising screw-based posterior segmental instrumentation, this approach spans the three columns of the spine, providing multiple anchorage points at each end of the construct and at least one additional interposed bone attachment [8].

Direct vertebral rotation (DVR) was developed to address issues related to scoliosis surgery by correcting vertebral rotation through derotation of the apex vertebrae and the correction of the axial spinal deformity [9, 10]. The procedure is typically performed following fundamental corrective actions such as in situ bending, rod derotation, or translation. However, recent studies suggest that DVR may not significantly improve clinical and radiological outcomes in patients undergoing surgical treatment for idiopathic scoliosis compared to alternative corrective procedures, such as differential rod contouring (DRC) [11].

This study aims to compare the clinical efficacy of DVR with LIV at L3 to non-DVR with LIV at L4 when the LEV is at L4 in AIS Lenke5C/6C. Despite being a common procedure, this comparison is essential for evaluating the clinical effectiveness and safety of DVR in AIS correction. Given the current controversy and the need for additional research to establish its usefulness [10]. Therefore, it is crucial for surgeons to carefully evaluate the available information and weigh the potential benefits and drawbacks of using DVR in selecting the lowest instrumentation level for the thoracolumbar/lumbar curve correction.

Methods and materials

This is a case–control study of One hundred and one consecutive adolescents (aged 18 years or younger at the time of surgery) who underwent surgery for major thoracolumbar/lumbar idiopathic scoliosis (Lenke 5C and 6C) with posterior approach at our hospital and were prospectively followed for four years or more.

The inclusion criteria were: 1. AIS Lenke 5C and 6C. 2. LIV and L3 and L4. 3. The lower end vertebra (LEV) was at L4 in all patients. 4. DVR and non-DVR techniques. Exclusion criteria were as follows: (1) Patients above 18-year-old. (2) Patients with anterior or other types of approach. (3) Patients with revision surgery.

Thirty patients had AIS Lenke 6C, and seventy-one had AIS Lenke 5C. The initial 52 patients without DVR comprised the control group (N-DVR), while the subsequent 49 consecutive patients using DVR formed the DVR group, all under the same surgeon's directive between 2010 and 2017.

Patients were categorised into two groups based on the lowest instrumented vertebra (LIV) level. In Group DVR, the lowest instrumented vertebra (LIV) was defined as the Lower End Vertebra-1 (LEV-1), while in Group N-DVR, the lowest instrumented vertebrae (LIV) were considered to be the lowest end vertebrae (LEV). To minimise selection bias, all patients in both groups had their lowest end vertebra at the fourth lumbar vertebra.

The institutional review board approved this study, and consent was obtained from patients before this study was conducted.

Study design

In this study, patients were divided into two groups based on the surgical technique employed for the correction of AIS Lenke 5C and 6C curves. The design was structured so that the non-DVR group (n = 52) was treated first, establishing a baseline for comparative prospective data collection, followed by the DVR group (n = 49).

Clinical medical records, radiography films of the spine, and health-related quality of life assessments of the patients (SRS-22) were prospectively recorded, and none of the patients were lost during the minimum 4-year follow-up. Two experienced spine surgeons performed follow-up examinations before surgery, the day of patient discharge from the hospital, 6 months, and four years after surgery. Standing posteroanterior, side bending films and sagittal radiography films of the whole spine were obtained preoperatively and 6 and 48 months postoperatively. Furthermore, two experienced spine surgeons measured all radiography films using the Surgimap software application.

Surgical techniques

The patients underwent surgery in the prone position, during which the posterior elements of the spine were carefully exposed using electrocautery. Those with DVR underwent the Ponte procedure. Pedicle screws were inserted using the freehand technique based on posterior bony elements. All patients were fitted with 5.5 mm. The concave rod was slightly over-contoured into kyphosis to accommodate possible rod flattening during rod rotation. Rod insertion began from the top to the bottom in both groups. The correction of spinal deformity in the N-DVR group was achieved by concave rod derotation. Final correction in both groups involved using coronal in situ bending, with the handles of the coronal in situ benders held as low as possible to produce both scoliosis and hypokyphosis correction. The convex rod was inserted in situ without compressing the main thoracic curve to prevent flattening of the thoracic kyphosis. Compression of screw heads was performed as necessary in cases of structural upper thoracic and/or thoracolumbar/lumbar curves (concave rod). The DVR procedure in the DVR group involved using the SmartLink device (Medtronic). The SmartLink instrument was inserted into three axial pedicle screw pairs in the main lumbar curve, typically bilaterally into L3, L2, and L1 vertebral bodies. The device was used to derotate the lumbar spine by lifting up the low-lying apical major lumbar concave area, providing both DVR and hyperlordosis correction. Spinal fusion was performed using the patient's bone material from facetectomies, osteotomies, tricalcium phosphate, and hydroxyapatite graft extenders.

Spinal cord monitoring during surgery with the use of somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), and electromyography (EMG) involves various neurophysiological techniques to assess the functional integrity of susceptible neural elements, including the spinal cord and nerve roots.

Clinical and radiological data evaluation

A thorough physical examination was performed on the patients prior to surgery, at the time of discharge, and during follow-up appointments. This comprised a neurological examination of the lower limbs and a coronal and sagittal balance assessment.

Before and after the procedure, the patient's spinal alignment and curvature were assessed using upright posteroanterior (PA) and lateral radiographs. Preoperative supine side-bending (SB) coronal concave and convex radiographs were also analysed. The measurements included coronal balance, sagittal balance, thoracic kyphosis (TK), lumbar lordosis (LL), L3 translation on PA film and concave SB film, L3 rotation and L4 tilt on convex SB film, L3/4 disc opening or closing on convex SB film, curve flexibility, Distal junctional angle (DJA), L3-S1 Lumbar Lordosis, Radiography shoulder height (RSH), Pelvic Obliquity, Adding-on phenomenon, Proximal Junctional angle (PJA) and apical vertebral translation (AVT) of the thoracic and lumbar curves.

The distance between the central sacral vertical line (CSVL) and the midpoint of the apical vertebral body defines apical vertebral translation (AVT). L3 translation is measured by the distance between the CSVL and the midpoint of the L3 vertebra on PA film and concave SB film. L3 rotation is defined by Moe–Nash's method [12, 13]. Thoracic kyphosis (TK) is measured by the angle between the upper endplate of T1 and the lower endplate of T12, while the upper endplate of L1 and S1 measures lumbar lordosis (LL). Coronal balance is determined by the coronal C7 plumb line (C7PL) deviation from the CSVL, with a value > 20mm defined as an imbalance. Sagittal balance is measured by the deviation of the sagittal C7PL from the posterior edge of the sacrum, with a value > 50mm defined as imbalance. Flexibility is calculated using the formula: (preoperative Cobb angle − preoperative SB Cobb angle)/preoperative Cobb angle × 100 (%), and curve correction is calculated as follows: (preoperative Cobb angle − post-operative Cobb angle)/ preoperative Cobb angle × 100 (%). The coronal balance and sagittal balance are averaged using absolute values. Furthermore, LIV tilt (the angle between the inferior endplate of LIV in a horizontal plane), LIV translation is the horizontal offset from the centre of LIV to the CSVL (L3-CSVL and L4-CSVL), and LIV disc angle is assessed as the disc angle immediately adjacent to LIV. Distal junctional angle (DJA) was defined as the angle between the LIV's upper end-plate and the vertebra's lower endplate below. DJA ≥ 10° was defined as distal junctional kyphosis (DJK). L3-S1 Lumbar Lordosis (refers to the angle of curvature in the lumbar spine measured between the superior endplate of the L3 vertebra and the superior end plate of the S1 vertebra.

We evaluated adding-on (AO) and proximal junctional kyphosis (PJK). PJK was assessed using the proximal junctional angle (PJA) from the lateral whole spine upright radiographs taken before surgery and during follow-up. PJK is defined as an increase of at least 10^0 in the proximal junction sagittal Cobb angle, with the post-operative angle being 10^0 greater than the preoperative measurement. This is taken between the upper endplate of the upper instrumented vertebra (UIV) plus two and the lower endplate of the UIV. Adding-on is characterised by an increase in the number of vertebrae involved in the distal curve, measured from the upright radiograph to the most recent one. This condition is identified by two criteria: (1) an increase of more than 5mm in the deviation of the first vertebra from the central sacral vertical line (CSVL) below the instrumentation, and (2) an increase of more than 5 degrees in the angulation of the first disc below the instrumentation level.

Furthermore, we assessed the radiographic shoulder height (RSH) evaluates shoulder balance and is defined as the difference in the soft tissue shadow observed on a standing anteroposterior radiograph located directly above the acromioclavicular joint.

All measurements were performed using Surgimap software, and the last vertebra touching the CSVL (last touching vertebra, LTV) was determined for each patient.

SRS-22 evaluation of quality of life

All patients had to complete the Scoliosis Research Society questionnaires (SRS-22) before surgery and during follow-up visits. These questionnaires measure clinical outcomes in five domains: function/activity, pain, self-perceived image, satisfaction with treatment, and mental health.

Statistics analyses

The values are ranges, means, and standard deviations (SD). The degree of significance for continuous variables (unpaired for between and paired for within-group comparison) was determined using a 2-tailed independent t-test. The χ^2 test was applied to categorical variables. *P* values were deemed statistically significant if they were less than 0.05.

Results

The demography data of 101 patients enrolled in this study is shown in Table 1. The mean age at the time of surgery was 14.6 ± 1years for group DVR and 14.3 ± 1years for group NDVR. The mean follow-up for both group DVR and NDVR was 52.7 ± 21 months and 52.9 ± 25 months, respectively. All pedicle screw instrumentation was used in both groups, which comprised 30 Lenke 6C patients and 71 Lenke 5C patients. There were no significant differences in demography data in either group. The average surgical time in both groups was not statistically significant, with group DVR averaging 263 ± 40 min and group NDVR averaging 261 ± 41 min. The estimated blood loss of 455 ± 72ml for group DVR and 458 ± 88ml for group NDVR was statistically insignificant. Table 1 shows the patient demography table.

Table 1 Patient's characteristics and surgical demography

	DVR	NDVR	*P* value
Age (yrs)	14.6 ± 1	14.3 ± 1	0.489
Sex (M/F)	14/35	20/32	
Risser	3.1 ± 0	3.1 ± 0	
Follow-up (months)	52.7 ± 21	52.9 ± 25	0.978
Blood loss (ml)	455 ± 72	458 ± 88	0.840
Surgical time (mns)	263 ± 40	261 ± 41	0.748
Fused segments	7.0 ± 2	8.7 ± 2	*0.001*
Ponte	3.0 ± 0	2.0 ± 0	

Italic value indicates the statistical significant value of *P* is less than 0.05

The preoperative flexibility curve in both groups (DVR and NDVR) in the bending radiographs was not statistically significant. The perioperative main thoracic curves in both groups (24.9 ± 10 and 23.2 ± 4 respectively, $P = 0.284$) and the major lumbar curve (52.3 ± 3 and 51.7 ± 3, $P = 432$) were corrected to 5.3 ± 4 and 6.2 ± 4, $P = 0.260$ and 4.2 ± 3 and 4.8 ± 2, $P = 0.409$, respectively, at four years follow-up. There was no statistically significant difference between the groups in the non-structural thoracic or major TL/L curve correction at the 6- or 4-year follow-up.

The coronal and sagittal balances between the two groups improved significantly, although the results were not statistically significant, as shown in Table 2. However, both group's perioperative measurements of L3-CSVL, L4-CSVL, LIV tilt, LIVDA, and LIV translation were statistically insignificant (Table 2). Additionally, neither group showed statistically significant differences during the postoperative follow-up visits.

The perioperative radiography data, such as L3-S1 LL, adding-on phenomenon (AO), pelvic obliquity (PO), and radiography shoulder height (RSH), were statistically insignificant at postoperative follow-up visitation.

The study found no intraoperative or postoperative complications, and patients did not develop coronal or sagittal imbalances. The groups did not differ significantly regarding any domain or the overall SRS-22 scores (Table 3).

Discussion

In treating structural TL/L curves of adolescent idiopathic scoliosis (AIS), selecting the lowest instrumented vertebra (LIV) is a critical decision, though there is no substantial agreement on the selection criteria [14]. In the selection process, fundamental attributes to consider include mobility, flexibility, and the prevention of adjacent intervertebral disc degeneration coupled with lower back pain [4].

Table 2 Comparison of radiography parameters between the two groups

	DVR	NDVR	*P* value
Pre TK (°)	24.0 ± 10	22.8 ± 5	0.279
6-month Post	23.7 ± 12	19.7 ± 13	0.119
Follow-up	27.9 ± 7	28.8 ± 5	0.507
Pre LL (°)	29.9 ± 45	23.6 ± 41	0.469
6-month post	34.7 ± 42	26.5 ± 43	0.340
Follow-up	35.5 ± 46	27.7 ± 44	0.393
Pre C.alignment (mm)	24.1 ± 6	20.8 ± 5	0.794
6-month post	6.3 ± 13	7.0 ± 9	0.773
Follow-up	6.2 ± 12	7.6 ± 10	0.527
Pre SVA	24.0 ± 13	20.8 ± 8	0.124
6-month post	2.4 ± 18	2.6 ± 20	0.958
Follow-up	6.2 ± 23	7.6 ± 21	0.783
Thoracic curve (°)			
Pre	24.9 ± 10	23.2 ± 4	0.284
6-month post	5.2 ± 5	4.4 ± 2	0.362
Follow-up	5.3 ± 4	6.2 ± 4	0.260
Lumbar curve (°)			
Pre	52.3 ± 3	51.7 ± 3	0.432
6-month post	3.3 ± 3	3.6 ± 3	0.643
follow-up	4.2 ± 3	4.8 ± 2	0.409
RSH			
Pre	1.7 ± 1	1.6 ± 1	0.706
6-month post	1.1 ± 1	1.4 ± 1	0.203
follow-up	1.3 ± 1	1.4 ± 1	0.713
LIV tilt (°)			
Pre	21.3 ± 3	20.4 ± 4	0.273
6-month post	1.0 ± 0	1.2 ± 1	0.411
Flexibility (°)			
Thoracic	20.5 ± 17	24.4 ± 10	0.188
Lumbar	56.2 ± 3	56.5 ± 3	0.706
Adding on (°)			
Pre	2.7 ± 1	3.2 ± 1	0.180
6-month post	1.1 ± 1	1.1 ± 1	0.939
follow-up	1.1 ± 0	1.3 ± 1	0.394
LIV disc angle (°)			
Pre	3.1 ± 3	3.1 ± 3	0.977
Post	1.2 ± 0	1.1 ± 0	0.714
Follow-up	1.2 ± 1	1.1 ± 1	0.860
PO pelvic oblique (°)			
Pre	2.1 ± 1	2.6 ± 2	0.238
6-month post	1.9 ± 1	2.0 ± 1	0.575
Follow-up	1.9 ± 1	2.2 ± 1	0.447
LIV trans (pre) (mm)	12.3 ± 4	11.3 ± 3	0.236
6-month post	1.6 ± 1	1.6 ± 1	0.932
Follow-up	1.6 ± 1	1.7 ± 1	0.616
L3-CSVL pre (mm)	27.9 ± 7	27.7 ± 8	0.907
6-month Post	9.9 ± 3	10.2 ± 2	0.666
Follow-ups	7.8 ± 3	7.3 ± 4	0.518
L4-CSVL pre (mm)	13.3 ± 6	13.4 ± 6	0.963
6-month	6.4 ± 3	6.2 ± 3	0.735
Follow-up	4.5 ± 3	4.4 ± 3	0.764
DJA pre	*19.5 ± 5*	21.4 ± 6	0.116
6-month post	17.4 ± 5	17.8 ± 6	0.761
Follow-up	17.2 ± 4	17.6 ± 5	0.659
L3-S1 LL pre	45.0 ± 14	44.4 ± 11	0.806
6-month post	43.0 ± 22	43.3 ± 9	0.935
Follow-up	48.6 ± 18	44.3 ± 10	0.137

Italic value indicates the statistical significant value of *P* is less than 0.05

Table 3 SRS-22

	DVR	NDVR	*P* value
Function (pre)	4.4 ± 0	4.4 ± 0	0.518
Follow-up	4.3 ± 0	4.4 ± 0	0.633
Pain (pre)	4.4 ± 0	4.4 ± 0	0.497
Follow-up	4.5 ± 0	4.6 ± 0	0.862
Sim (pre)	3.2 ± 0	3.3 ± 0	0.320
Follow-up	4.2 ± 0	4.1 ± 0	0.251
MH (pre)	3.7 ± 0	3.8 ± 0	0.468
Follow-up	4.4 ± 0	4.4 ± 0	0.615
Sat (pre)	3.1 ± 0	3.1 ± 0	0.824
Follow-up	4.4 ± 0	4.3 ± 0	0.323

In this study, we compared the selection of L3 as the LIV with the use of DVR to L4 as the LIV without DVR, even though we aimed to stop the instrumentation of one segment caudal to the LEV if possible. Therefore, we selected the TL/L curves with L4 as the LEV to homogenise the curve type and position. We then applied different techniques with a prospective follow-up of at least 4 years.

DVR is a popular technique for the correction of AIS [10, 11] However, despite various reports demonstrating its superior corrective power over non-DVR techniques, there is still no consensus on whether DVR is suitable for selecting the lowest instrumented vertebrae (LIV).

In our study, L3 was selected as the LIV for patients undergoing DVR with major TL/L curves when the LEV was L4. Recent reports suggested that the lowest instrumentation level should be a stable vertebra [3, 7, 15–17] However, preserving more levels for mobility is another concept that requires reconsideration of different patterns. Nevertheless, mobility and flexibility remain significant considerations when selecting the appropriate LIV level in patients with TL/L curves.

In our study, selecting LIV one level caudal to LEV vertebrae is a priority to retain more vertebrae for mobility and avoid post-surgical adjacent disc degeneration and back pain.

Past studies have highlighted the importance of DVR for correcting spine deformity in adults and adolescents, especially with AIS patients. One of the integral parts of AIS correction is axial rotation. Axial rotation in scoliosis is a fundamental component of the deformity and contributes to the coronal and sagittal features, according to biomechanical studies. The term used to describe the "coupling" of translation and rotation between anatomic axes is the phenomena. 3-dimensional correction using DVR seems to be an evident part of scoliosis correction and should produce an overall superior result based on coupled motions of the spine [9–11].

The Direct Vertebral Rotation (DVR) manoeuvre significantly reduces apical rotation of the spine and enhances coronal balance correction. Furthermore, the significant impact of DVR on axial lumbar rotation has been reported in past studies with 31.8% correction over non-DVR, with 8.6% [11]. However, the study didn't report how this influence could affect LIV selection to correct AIS Lenke 5C and 6C.

In this study, the preoperative LIV translation, LIVDA, and LIV tilt in patients with DVR are statistically insignificant compared to non-DVR patients due to the selection of L3 for the DVR group according to grade II in Nash vertebra rotation [12, 13]. The LIV tilt and LIV translation are two of the criteria that have been reported to influence the choice of LIV selection according to grade II of bending films. Furthermore, the L3-CSVL and L4-CSVL are essential factors that previous studies have indicated as one of the criteria to consider before selecting LIV for TL/L curves. Some studies suggest that when L3-CSVL is greater than 10 mm [3], the L4 should be chosen as the LIV, while the L3 could be selected when the L3-CSVL is less than 10mm due to the influence of coronal decompensation. In contrast, L3-CSVL and L4-CSVL measurements showed no statistical significance preoperatively, with the DVR group having an L3-CSVL of 27.9 mm and the non-DVR group having 27.7 mm, while L4-CSVL for both groups were 13.3mm and 13.4 mm. However, on follow-up visitations, the L3-CSVL was significantly reduced to 7.8mm and 7.3 mm for the DVR and non-DVR groups, respectively, while L4-CSVL was decreased to 4.5 mm and 4.4 mm.

Previous research found that when the preoperative L3 vertebra crosses the mid-sacral line with a rotation of less than grade II in bending films, the curve is typically determined to be fused to L3 [7]. This indicates that the fusion level is based on the position and rotation of the L3 vertebra in the preoperative bending films. In contrast, in our study, both groups had similar preoperative bending films. The selection of LEV for LIV in the group with non-DVR indicated a preference for a more stable vertebra selection for patients without DVR, which is why L4 was chosen as the LIV for these patients.

There were no significant differences in the LIV tilts, LIV translation, and LIVDA during the post-operative follow-ups between the DVR group and non-DVR group, which are important factors influencing the selection of L3 and L4 as LIV. The DJA was also assessed postoperatively; there was no statistical significance in either group, with both groups having a DJA of 48.6° and 44.3°.

In the DVR group, stopping the instrumentation level at L3 using an advanced manoeuvre device like Smartlink Medtronic offers additional benefits, such as preserving mobility segments of the spine. One specific scenario is the presence of a lumbosacral transitional vertebra (LSTV). In these patients, where the L5-S1 disc region is immobile, preserving an additional mobile segment becomes increasingly important. For this patient group, stopping the fusion at L3 with DVR can help avoid early degeneration of the L4-L5 disc. Figures 1 and 2.

One of the other factors that most surgeons consider before considering LIV level is the adding-on (AO) phenomenon, which is why most surgeons prefer stable vertebrae for selecting LIV in patients with major TL/L curves [3, 7]. In our study regarding AO, there were no significant differences between the two groups at follow-up visitation.

Furthermore, Sacral slanting plays a crucial role in determining the appropriate level for fusion in patients with adolescent idiopathic scoliosis [6, 18–20]. If the L4 tilt is directed to the left in cases of left-sided sacral slanting, fusing to L4 may result in coronal decompensation and overcorrection of the lumbar curve. Although restoring sagittal and pelvic balance is essential for the patient's post-surgical outcome, the L3-S1 lumbar lordosis was measured in our study. At follow-up, both groups had no statistical significance while maintaining a normal range value. Pelvic obliquity was also measured in both groups, and there were no differences at the post-surgical follow-up visits.

Using a DVR not only influences better coronal and sagittal balance correction but also preserves more segments than non-DVR.

This study showed no significant differences in the clinical assessment using SRS-22 during the follow-up visitation. Still, the strong point in this study is the prospective nature of patient follow-ups. This is the first study with a large cohort under the same surgeon directive for the correction of AIS Lenke 5C and 6C, comparing the selection of L3 for DVR and L4 for non-DVR for the lowest instrumented vertebrae (LIV) when LEV is L4.

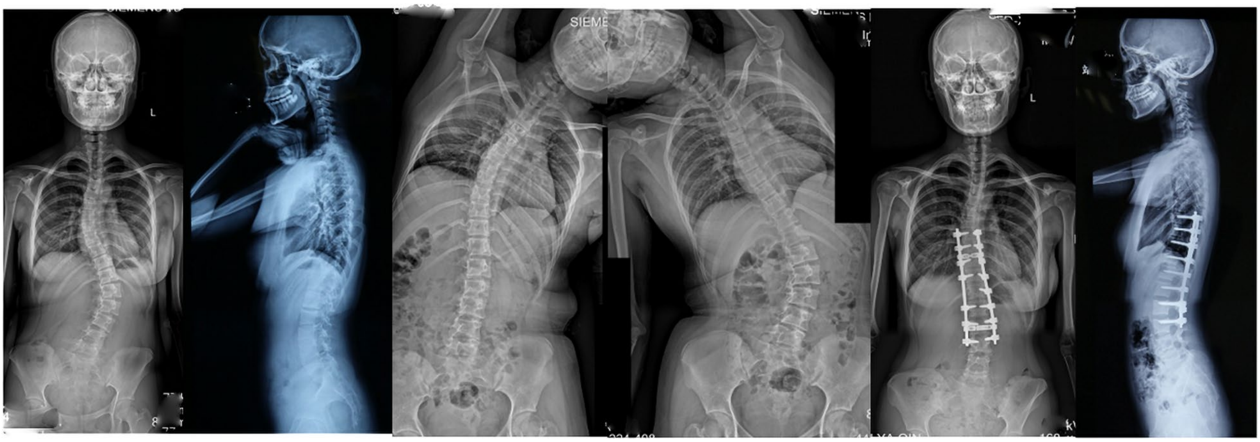

Fig. 1 A female patient with Lenke 5C underwent DVR selective fusion at age 13 and demonstrated outstanding coronal balance and a correction rate maintained at 4 years

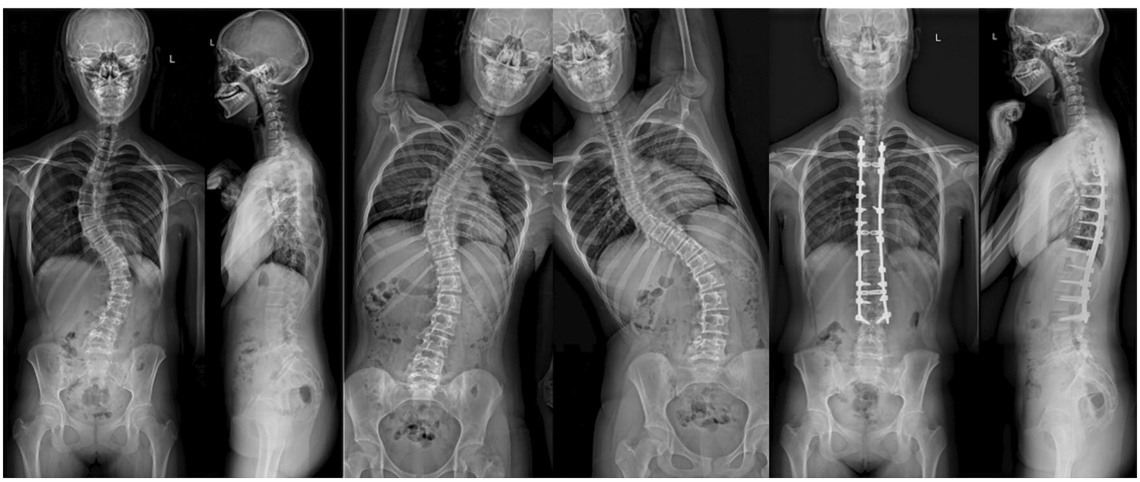

Fig. 2 A female patient with Lenke 6C underwent non-DVR selective fusion at age 16 and demonstrated outstanding coronal balance and correction rate maintained at 4 years

Nevertheless, one of the limitations of this study is the minimum follow-ups of four years. Therefore, future studies with longer follow-ups should be done to strengthen this research.

Conclusion

The selection of the lowest instrumented vertebra (LIV), L3, using the DVR technique is suitable and yields satisfactory results for correcting AIS Lenke 5C and 6C curves, which have L4 as the LEV. Furthermore, on follow-up visitation, there were no significant differences between groups; however, more lumbar segments were preserved with DVR than non-DVR techniques.

Acknowledgements
None.

Author contributions
All named authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship for this article, take responsibility for the integrity of the work as a whole, and approve this version to be published. EA was responsible for the concept and design of the overall study. Data were retrieved and assembled by EA and ZHQ. All authors contributed to the writing and final approval of the manuscript.

Funding
None.

Availability of data and materials
Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
All named authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship for this article, take responsibility for the integrity of the work, and approve this version to be published. The ethical committee for Xiangya Hospital Central South University approved the study,

and informed consent was obtained from all subjects and/or legal guardian(s). Furthermore, all methods were performed per our hospital's relevant guidelines and regulations. Ethics approval number 21017033559.

Competing interests
The authors declare no competing interests.

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Received: 26 June 2024 Accepted: 29 July 2024
Published online: 19 August 2024

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