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Choosing the Distal Fusion Levels in Lenke Type 1 Adolescent Idiopathic Scoliosis: How Do the Existing Classifications and Recommendations Guide Us?

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Abstract

Study Design: Retrospective cohort.

Objective: (*a*) To compare the recommendations of Lenke and Peking Union Medical College (PUMC) classifications in choosing distal fusion levels in Lenke 1 adolescent idiopathic scoliosis (AIS) curves and (*b*) to analyze whether the variability in distal fusion levels influences treatment outcomes.

Methods: Hospital records of Lenke 1 AIS patients operated for single stage, posterior-only deformity correction were analyzed. Distal fusion levels recommended by Lenke and PUMC classifications were calculated and were compared with the actual distal fusion levels. The study population was divided based on whether the actual distal fusion levels were in agreement, shorter or longer than those recommended by Lenke classification. Subgroup analysis of Lenke 1C curves was done. The groups were compared with regard to the following outcome measures: Cobb angle correction, postoperative sagittal vertical axis, post-operative C7 offset, and Scoliosis Research Society–22r (SRS-22r) score at 24 months.

Results: The distal fusion levels recommended by the 2 classifications were in agreement in 92 of 104 cases. In all the cases with disparity, Lenke classification recommended shorter fusions than the PUMC classification. No statistically significant difference was observed in the outcome measures—whether the actual distal fusion levels were in agreement, shorter, or longer than those recommended by the Lenke classification or whether or not the recommendations for selective fusion of any of these classifications were adhered to.

Conclusion: Lenke classification can save fusion levels without compromising on treatment outcomes when compared with PUMC classification. Variability in choice of distal fusion levels is not clinically significant at 24-month follow-up.

Keywords
adolescent idiopathic scoliosis, Lenke classification, PUMC classification, scoliosis, spinal deformity

Introduction

Adolescent idiopathic scoliosis (AIS) is the most common type of spinal deformity seen in patients aged between 10 and 18 years.[1,2] While there has been abundant literature in recent years on classification and treatment of AIS, deciding on the distal fusion levels—particularly, in patients with a major thoracic-compensatory lumbar (MTCL) curve, remains controversial.

With the evolution of classification systems and instrumentation techniques, the philosophy of treating MTCL curves has undergone a significant change. The goal has now shifted to minimizing the fusion segments and maximizing the lumbar motion segments, with the expectation that the unfused lumbar curve would spontaneously correct to compensate for the corrected position of the fused thoracic curve.[3] This would achieve

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the goal of a balanced, harmonious spine, with a fusion mass centred over the pelvis leaving a majority of lumbar spinal segments free, thus decreasing the theoretical risk of long-term lumbar spine degeneration.[4,5] The existing classification systems need to be seen in light of this philosophy. In the King classification,[6] the authors recommended fusion of the thoracic curve to the stable vertebra in patients with major thoracic and minor lumbar curve (King type II). Lenke et al[7] proposed a classification system and identified a subset of MTCL curves (Lenke 1C) where additional guidelines for selective fusion could be used to spare lumbar spinal segments from being fused. The Peking Union Medical College (PUMC) method was proposed in 2005 and was based on the number of curves present and the inherent characteristics of each curve.[8]

Even for thoracic curves without a compensatory lumbar curve, studies have shown a wide variation in the recommended distal fusion levels.[9,10] Fusing to the stable vertebra (SV) as recommended by King has been the conventionally accepted practice—however, this was meant for Harrington instrumentation, which relied on 2-point distraction and a uniplanar correction.[6] With modern pedicle screw based instrumentation affording 3-dimensional correction, derotation maneuvers leads to 3-dimensional rotational displacement bringing vertebrae proximal to the preoperatively determined stable vertebra into a stable zone.[11] Based on this, Suk et al[11] have recommended fusion to the neutral vertebra (NV) when it lies within 2 levels of the lower end vertebra (LEV), and to NV-1 when it lies outside the 2 levels of the LEV.[11] Other authors have proposed that the last touched vertebra (LTV) or the substantially touched vertebra (STV) be used as the choice of distal fusion level.[12,13] However, the clinical significance of this variability in choosing distal fusion levels is largely unknown.

With Lenke classification being the most commonly used classification and the PUMC classification being the most comprehensive classification, it is worthwhile to compare the 2 classifications with regard to their recommendations in deciding the distal fusion levels, in particular in double curves where selective fusion comes into play. It also remains to be seen whether sparing fusion levels with selective fusions or the quoted variability in determination of distal fusion levels influences treatment outcomes. In our retrospective study, we classified patients with Lenke type 1 curves into a Lenke subtype and a PUMC classification type. We attempted to answer the following questions: (1) What was the recommended distal fusion level in our patients with Lenke type 1 curves according to the Lenke or PUMC systems and how often do their recommendations differ? (2) How did our actual distal fusion level compare with the Lenke- and PUMC-recommended levels? (3) Which classification system leads to a more selective fusion? (4) Did the difference in distal fusion levels have any effect on the clinical and radiological outcome?

Methodology

The hospital records of all AIS patients with Lenke 1 curves operated at a single center between 2013 and 2017 were retrospectively analyzed. Patients who had undergone a single-stage posterior-only deformity correction and fusion using a pedicle screw construct were included. Patients who had undergone prior spinal surgery or patients with incomplete clinical or radiological data were excluded. A minimum follow-up of 24 months was deemed necessary. All cases were operated by the senior coauthor (BG). The study was approved by the Institutional Ethics Committee and informed, written consent was taken from all patients recruited in the study.

Radiological Assessment

Preoperative standing anteroposterior (AP), standing lateral, and side-bending radiographs of all included patients were independently assessed by 2 co-investigators. All patients were classified in accordance with the Lenke and PUMC classifications. In addition, the following radiological measurements were documented: Cobb angle of the main thoracic (MT) curve, Cobb angle of the thoracolumbar/lumbar (TL/L) curve—if present, apical vertebral translation (AVT), apical vertebral rotation (AVR), and the sagittal vertical axis (SVA). Flexibility of both curves was determined from Cobb measurements on the preoperative standing and side bending radiographs. The flexibility index was calculated as described by King et al.[6]

Postoperative AP and lateral radiographs taken at 24-month follow-up were independently assessed by 2 co-investigators. The postoperative MT and TL/L Cobb angle were measured in addition to the postoperative SVA. The postoperative C7 offset—C7 plumb-line to central sacral vertical line (CSVL) distance—was also measured.

Clinical Assessment

Scoliosis Research Society (SRS)–22r scores[14] at 24-month follow-up were retrieved from hospital records. In addition, note was made of any complications in the postoperative period.

Comparison of Fusion Levels

For each included patient, recommended distal fusion levels according to Lenke and PUMC classifications was determined from the preoperative radiographs. For Lenke 1A or 1B subtype, selective fusion of the MT curve up to the stable vertebra is recommended. For Lenke 1C curve subtype, the following criteria suggested by Lenke et al[7] is used: MT:TL/L Cobb ratio $\geq$1.2, MT:TL/L AVT ratio $\geq$1.2, MT:TL/L AVR ratio $\geq$1.2, and a positive flexibility index (ie, TL/L flexibility more than MT flexibility). Failure to satisfy any single one of these criteria is considered to be an indication to perform a nonselective fusion. A Lenke type 1 curve could possibly belong to PUMC type I, type IIb, or type IIc curve types. All our included patients either had a PUMC type I or type IIb curve—no patient had a PUMC type IIc curve. All PUMC type I curves (single curve) are fused selectively up to the stable vertebra. For type II

PUMC curves (with presence of both MT and TL/L curves), the following criteria are used to categorize them into IIb1 and IIb2 curves: (1) without thoracolumbar/lumbar kyphosis; (2) a Cobb angle of thoracolumbar/lumbar curve $\leq 45°$; (3) rotation of thoracolumbar/lumbar curve less than 2°; and (4) flexibility of thoracolumbar/lumbar curve $\geq 70\%$.[8] Subtype IIb1 should meet each of these 4 criteria. If any of these 4 criteria were not met, it was designated as subtype IIb2. PUMC IIb1 curves are selectively fused whereas PUMC IIb2 curves are nonselectively fused.

Our actual distal fusion level was determined on the postoperative radiographs. Since this is a retrospective study, the actual distal fusion levels did not represent recommendations of any classification and were not based on any single set of criteria. Rather they represented a single surgeon's operative experience and intraoperative decision—and was more likely based on an amalgamation of various factors including the clinical appearance of the spine during surgery and on fluoroscopy. The usual practice was to fuse to the stable vertebra if the curve was structural—however, there were exceptions when there was overwhelming rotation or tilting of the vertebra when the surgeon chose a different vertebra than the stable vertebra as the lowest instrumented vertebra (LIV). The difference between the Lenke-recommended and PUMC-recommended distal fusion levels and the actual distal fusion levels was calculated and designated as delta-Lenke (ΔL) and delta-PUMC (ΔP), respectively. A negative delta value meant that the spine was fused shorter than recommended by the concerned classification whereas a positive delta value meant that the spine was fused longer than recommended.

Operative Technique

All study patients underwent posterior-only deformity correction using a pedicle screw construct. Posterior column osteotomies or Ponte's osteotomies were done as deemed necessary. Rods contoured to normal sagittal bend were used—with the deformity being corrected by several maneuvers, which included differential rod contouring, sequential multiaxial rod translation, derotation maneuvers with or without manual pressure on rib cage and in situ rod bending. Compression and distraction between pedicle screws was done on the convex and concave sides of the deformity respectively. Fusion bed was created by performing decortication with a burr or an osteotome and applying locally harvested autograft.

Statistical Analysis

Study patients were divided into 3 groups: (1) cases where there was an agreement between our distal fusion level and the Lenke- and PUMC-recommended levels, (2) cases where we fused shorter than the Lenke- and PUMC-recommended levels, and (3) cases where we fused longer than the Lenke- and PUMC-recommended levels. The groups were compared with each other with regard to the following outcome measures: (1) MT and TL/L Cobb angle correction (expressed in percentage of the pre-operative Cobb angle), (2) postoperative global sagittal balance (SVA), (3) number of cases with a C7 offset > 30 mm, and (4) SRS-22r scoring at 24-month follow-up. In addition, a subgroup analysis was done for Lenke 1C curves, that is, MTCL curves where both curves crossed the midline. Our actual choice of distal fusion level (selective or nonselective) was compared to the recommendations of each of the 2 classifications. Comparison across the afore mentioned outcome measures was done for groups divided on the basis of whether the recommendations of each of the 2 classifications was adhered to or not.

Table 1. Distribution of Study Population According to Age, Gender, and Curve Types.

Gender	
Male	29
Female	75
Lenke classification	
1A	56
1B	28
1C	20
Peking Union Medical College (PUMC) classification	
I	
IIB1	34
IIB2	24
Age, y, mean $\pm$ SD	15.2 $\pm$ 4.0
Mean Cobb's angle, deg	
Main thoracic curve (MT)	75.52
Thoracolumbar/lumbar curve (TL/L)	19.83

Results

Our study group included 104 patients having Lenke Type I AIS who underwent single-stage posterior-only deformity correction. This included 75 females and 29 males with an average follow-up of 33.4 months (range: 24-59 months). These patients were further classified as per the Lenke and PUMC classifications. The category-wise distribution is given in Table 1.

The difference between our actual distal fusion levels and those recommended by the Lenke and PUMC classification was determined from radiographs (Table 2). Our actual distal fusion level was in agreement with the Lenke-recommended levels in 48 of 104 cases (46%). Among the 44 of 104 cases (42%) that were fused shorter, our distal fusion level was only 1 level shorter than the Lenke-recommended levels in 26 of 44 cases. Compared with this, we fused longer than the Lenke-recommended levels in 12 of 104 cases (12%). Overall, we deviated by 3 or more levels from the Lenke-recommended levels in only 5 of 104 cases (5%)—all of which were fused shorter. Our actual distal fusion level was in agreement with the PUMC-recommended levels in 40 of 104 cases (39%). We fused shorter than the PUMC-recommended levels in 55 of 104 cases (53%) and longer in only 9 of 104 cases (8%). Overall, we noticed a tendency on our part to fuse shorter than the levels recommended by these classifications. When comparing

Table 2. Difference in Our Actual Distal Fusion Levels Compared With Those Recommended by Lenke and Peking Union Medical College (PUMC) Classifications.

Difference Between Our Distal Fusion Level and Recommended Level	Lenke Recommended	PUMC Recommended
≤−3	5	14
−2	13	14
−1	26	27
0	48	40
+1	7	5
+2	5	4
≥+3	0	0

Table 3. Recommendation of Distal Fusion Levels in Lenke Type 1C Curves.

	Selective	Nonselective
Lenke recommendation	13	7
Peking Union Medical College (PUMC) recommendation	3	17
Our actual distal fusion levels	15	5

the distal fusion levels recommended by the 2 classifications, we noted a lack of agreement in 12 of 104 cases (12%). In all of them, the Lenke classification recommended a shorter fusion as compared with the PUMC classification. Thus, there was a greater tendency to perform nonselective fusions with the PUMC classification.

We performed a subgroup analysis of only Lenke type 1C curves. There were 20 such cases in which both the MT and TL/L curves crossed the midline completely. Table 3 shows the recommendations according to the Lenke and PUMC classifications compared with each other and our actual distal fusion levels in these cases. There was a lack of agreement between Lenke and PUMC classifications in 10 of 20 cases (50%), and in all of these the PUMC classification recommended a nonselective fusion including both the curves whereas the Lenke classification recommended a selective fusion (see Figures 1A and B; 2A and B) However, the adherence to any of the 2 classifications did not make a difference as far as the clinical and radiological outcomes were concerned (Table 4).

The study population was subclassified into 3 study groups for each classification: (1) agreement of our distal fusion levels with the Lenke/PUMC classification, (2) fused shorter than the Lenke/PUMC recommendations, and (3) fused longer than the Lenke/PUMC recommendations. These study groups were compared with each other with regard to the following outcome measures: (1) MT Cobb angle correction, (2) postoperative SVA, (3) C7 offset >30 mm, and (4) SRS-22r scores at 24-month follow-up. The findings are summarized in Table 5. No statistically significant difference was observed between the study groups for any of the aforementioned outcome measures.

Discussion

A good classification system for idiopathic scoliosis should be (1) comprehensive—include all the different curve types, (ii) unambiguous—clear criteria for classifying the curves, (3) easily understood and remembered, (4) effective as a means of communication among surgeons, (5) reliable and reproducible, and (6) able to guide surgical planning. Compared with earlier classification systems,[15,16] which made no such recommendations, the later classification systems—King,[6] Lenke,[7] and PUMC[8]—all attempted to provide recommendations relevant to the surgical planning.

Choosing the fusion levels in scoliosis has always been contentious. With a single curve, the ambiguity among surgeons with regard to the surgical strategy is less and is largely restricted to their choice of surgical approach and variability in preferring the SV/NV/STV/LTV as the distal fusion level. However, when there are 2 curves, deciding whether a particular curve needs to be fused is important because a wrong choice can lead to progression of the curve, pose a risk of postoperative coronal decompensation and affect patient outcomes.[6,17,18] Newer classification systems have incorporated the "selective" fusion concept—based on the rationale that when certain criteria were met, a minor, nonstructural curve crossing or deviating completely from midline can be left unfused and that a mobile, residual curve is better than a fused one.[2,19] The King classification did not take into account the magnitude, rotation, and apical vertebral translation of the lumbar curve.[6] The Lenke classification took these parameters into account and recommended selective fusion on the basis of how these parameters differed between the thoracic and lumbar curves.[7] The PUMC classification adopted a different approach—with the basis of recommending a selective fusion being inherent absolute measurements of the TL/L curve, rather than comparing its magnitude and rigidity to that of the thoracic curve.[8] Coming back to the requirements of a good classification system, if a classification is to be an effective means of communication, the mention of the curve type should instantly create an appropriately representative mental picture of the deformity in the mind of the listener.[20] In this aspect, the PUMC classification does better than Lenke classification. The type of curve (I, II or III) represents the number of curves in the deformity—irrespective of whether they are structural or nonstructural. The subtype then gives an idea about the location of the curve and further subdivision is based on the magnitude, rotation and flexibility of the minor curve and incorporates specific criteria for selective fusion. In contrast, in the Lenke classification, a double curve (MT + TL/L) may be grouped into Lenke Ib, Ic, III, or VI. Ward has reported on difficulties encountered in employing the Lenke criteria for selective fusion—being unable to calculate the AVT MT: TL/L ratio in 23% cases and the AVR MT: TL/L ratio in 57% cases as the landmarks in thoracic spine are often poorly visible on radiographs.[20]

In our study, the recommended distal fusion levels according to Lenke and PUMC classification were same in 92 of 104

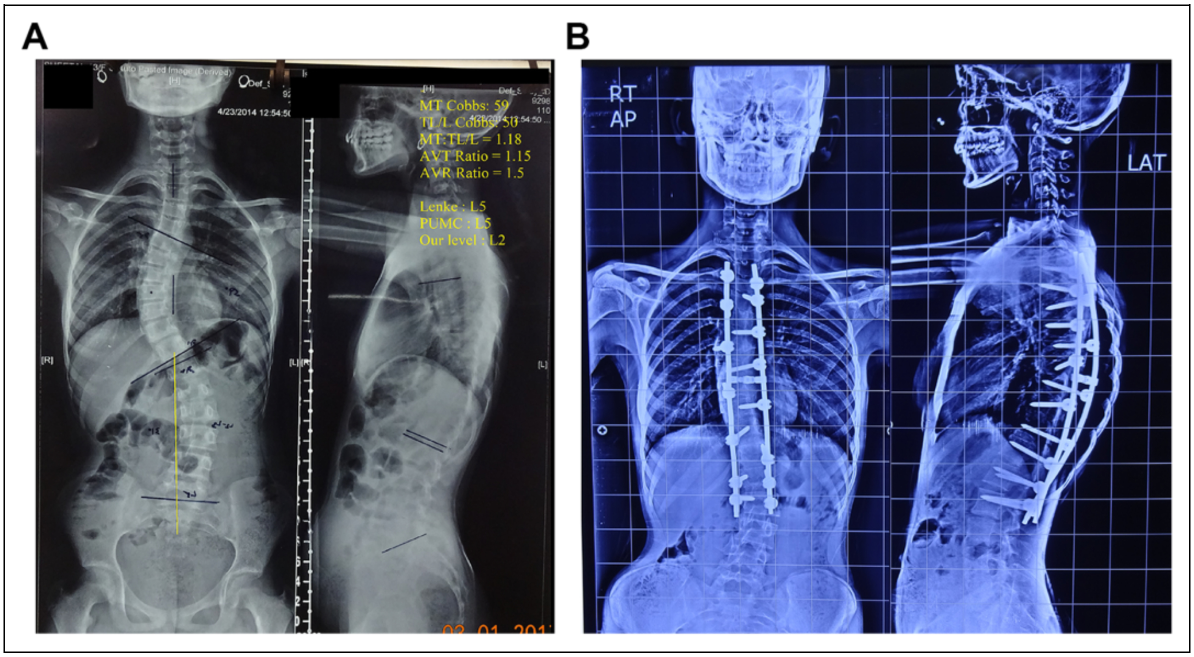

Figure 1. (A) Anteroposterior (AP) and lateral radiograph of a patient having a Lenke type 1C curve. Lenke-recommended fusion level: L5 (nonselective fusion) as the MT:TL/L Cobbs' ratio <1.2, AVT < 1.2. PUMC-recommended fusion level: L5 (subtype IIb2) as the TL/L Cobbs >45°, TL/L rotation = 2°. (B) Postoperative AP and lateral radiograph of the same patient shown in (A). Our actual distal fusion level = L2 (matches neither with the Lenke- nor with the PUMC-recommended levels). PUMC, Peking Union Medical College; MT, main thoracic; TL/L, thoracolumbar/lumbar; AVT, apical vertebral translation; AVR, apical vertebral rotation; SVA, sagittal vertical axis.

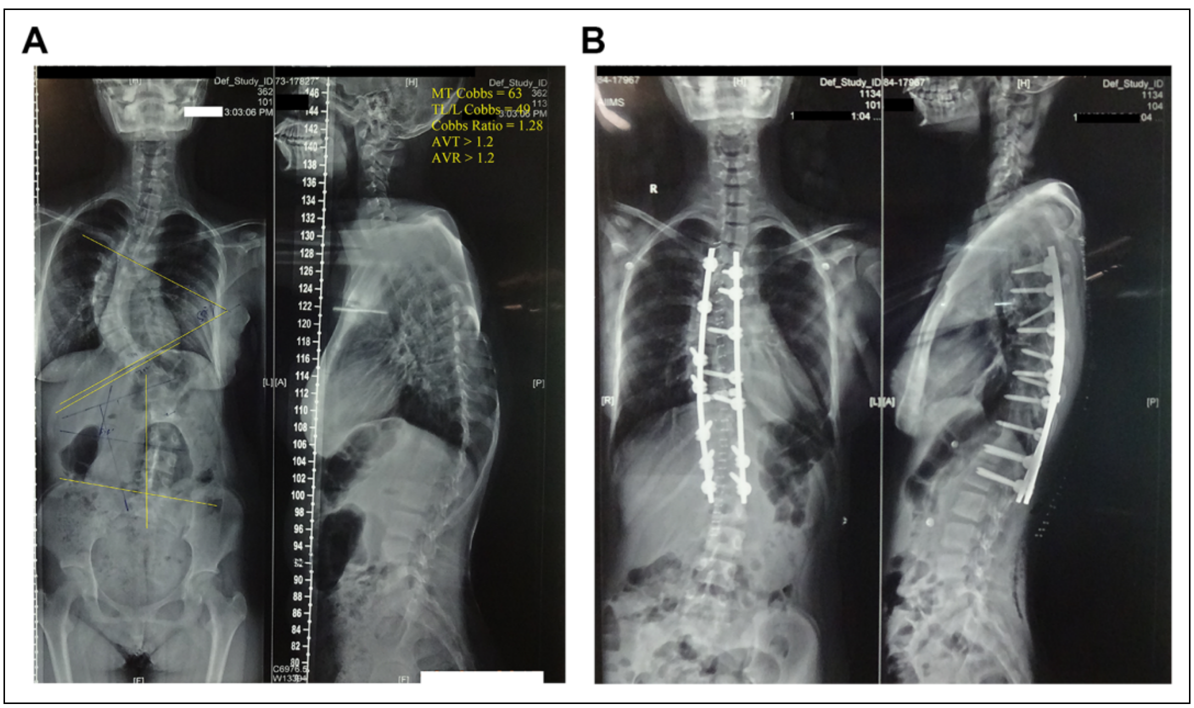

Figure 2. (A) Anteroposterior (AP) and lateral radiograph of a patient having a Lenke type 1C curve. Lenke-recommended fusion level: L1 (selective fusion) as the MT:TL/L Cobbs' ratio >1.2, AVT > 1.2, AVR > 1.2, positive flexibility index. PUMC-recommended fusion level: L5 (subtype IIb2) as the TL/L Cobbs >45°. (B) Postoperative AP and lateral radiograph of the same patient shown in (A). Our actual distal fusion level = L1 (matches with the Lenke recommended level but not with the PUMC recommended level). PUMC, Peking Union Medical College; MT, main thoracic; TL/L, thoracolumbar/lumbar; AVT, apical vertebral translation; AVR, apical vertebral rotation; SVA, sagittal vertical axis.

Table 4. Comparison of Various Clinical and Radiological Outcome Measures Between Groups Based on Adherence to Lenke or PUMC Classifications for deciding Selective Fusions in Lenke 1C Curves (MTCL Curves With Both Curves Crossing the Midline).

	Agreement Between Our Actual Distal Fusion Levels With Lenke-Recommended Levels			Agreement Between Our Actual Distal Fusion Levels With PUMC-Recommended Levels		
Outcome Measure	Yes (n = 14)	No (n = 6)	*P*	Yes (n = 6)	No (n = 14)	*P*
Cobb angle correction (%)[a]	50 (38, 67.1)	56.4 (35, 93.2)	.22	50 (46, 67.1)	53.1 (35, 93.2)	.94
Postoperative SVA[a]	−9 mm (−21, +8)	−4.5 mm (−15, +16)	.43	−11 mm (−21, +10)	−5 mm (−20, +16)	.54
Patients with C7 offset >30 mm[b]	4/14	2/6	.62	2/6	4/14	1.00
SRS-22r score[c]	81.26 ± 5.63	83.83 ± 5.23	.35	83.28 ± 3.77	81.35 ± 6.24	.46

Abbreviations: PUMC, Peking Union Medical College; MTCL, major thoracic-compensatory lumbar; SVA, sagittal vertical axis; SRS-22r, Scoliosis Research Society–22r.
[a] The distribution of data was not in a normal distribution. Hence, the median values with minimum and maximum values in parentheses have been quoted. Wilcoxon rank sum test was used to look for statistically significant difference.
[b] The data was categorical in nature; Fischer exact test was used to look for statistically significant difference.
[c] The distribution of data was in a normal distribution. Hence, the mean values with standard deviations have been quoted. Two-sample *t* test was used to look for statistically significant difference.

Table 5. Comparison of Various Clinical and Radiological Outcome Measures Between Groups Based on Agreement of Our Actual Distal Fusion Levels With Those Recommended by the Lenke Classification.

Outcome Measure	Fused Shorter (n = 44)	In Agreement (n = 48)	Fused Longer (n = 12)	*P*
Cobb angle correction (%)[a]	54.56 (20, 85.5)	54.35 (17.8, 93.2)	53.49 (24.1, 69.2)	.91
Postoperative SVA[a]	−8 mm (−30, +18)	−1 mm (−40, +18)	0 mm (−22, +11)	.26
Patients with C7 offset >30 mm[b]	4/44	4/48	3/12	.10
SRS-22r score[c]	78.53 ± 7.66	80.71 ± 6.43	79.48 ± 4.30	.47

Abbreviations: SVA, sagittal vertical axis; SRS-22r, Scoliosis Research Society–22r.
[a] The distribution of data was not in a normal distribution. Hence, the median values with minimum and maximum values in parentheses have been quoted. Kruskal-Wallis equality-of-populations rank test was used to look for statistically significant difference.
[b] The data was categorical in nature; Fischer exact test was used to look for statistically significant difference.
[c] The distribution of data was in a normal distribution. Hence, the mean values with standard deviations have been quoted. Analysis of variance test was used to look for statistically significant difference.

patients (88%). Only 12/104 of the cases had difference in recommendations with regard to selective and nonselective fusion. In all these cases, PUMC recommended nonselective fusion compared with the recommendation of a selective fusion by the Lenke system. The difference primarily arose due to PUMC system taking into consideration the absolute value of the curve magnitude and rotation. In these cases, Lenke still recommended selective fusion as the thoracic curve was considerably more severe and rigid than the lumbar curve. When it came to the Lenke 1C subtype however, there was disagreement between the 2 systems in 10 of 20 patients (50%) with PUMC recommending nonselective fusion in all those cases. The PUMC system thus recommends nonselective fusion of these curves in a larger proportion of patients based on the absolute magnitude and rotation of the lumbar curve. However, at 24-month follow-up, the deviation from recommended levels from either classification had no significant impact on the outcome parameters. This raises the question whether the PUMC system tends to unnecessarily sacrifice motion segments that would otherwise be preserved without affecting outcome. Even in Lenke 1A curves where the dilemma of selective or nonselective fusion does not come into play, the variability in the choice of distal fusion levels arises due to differing recommendations in literature about what the ideal distal fusion level should be (SV/NV/NV-1/STV/LTV). However, we found no difference in clinical and radiological outcomes in patients fused shorter, in agreement or fused longer than the Lenke-recommended levels.

We recognize certain shortcomings in our study. First, in view of its retrospective nature, the factors that may have contributed to selection of the actual distal fusion levels are not clear. These probably reflect the clinical judgement and intraoperative decisions of the operative team. The duration of follow-up (24 months) represents the results at an intermediate follow-up period. A longer follow-up may show different clinical outcomes with variation in the distal fusion levels. While we have only included patients who have undergone single-stage, posterior-only deformity correction, the cases were operated over a 4-year period during which the surgeon's choice or selection of deformity correction maneuvers may have undergone a change. Our study also has a small percentage of Lenke 1C curves where the actual question of a selective or nonselective fusion arises. A prospective study with a larger proportion of Lenke 1C patients and a longer follow-up would shed more light on this relatively unexplored aspect of literature.

Declaration of Conflicting Interests

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