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Where to stop distally in Lenke modifier C AIS with lumbar curve more than 60°: L3 or L4?

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ABSTRACT

Objective: Selecting lowest instrumented vertebra (LIV) in adolescent idiopathic scoliosis (AIS) with large lumbar curve can be difficult. Stopping the distal fusion at L3 could save more mobile lumbar segments but may increase the risk of decompensation. This study was designed to evaluate preoperative radiographic factors that were associated with the selection of either L3 or L4 as LIV in posteriorly treated AIS patients with large lumbar curve.
Patients and methods: A total of 84 AIS patients with lumbar curve > 60° were analyzed with a minimum of 2-year follow-up after posterior instrumentation with lumbar curves included in fusion. Patients were grouped according to the selection of LIV, either L3 or L4 group. All radiograph parameters were measured pre- and post-operatively including Cobb angle, lumbar flexibility, L3 translation and rotation on posteroanterior (PA) and side-bending (SB) film, etc. The SRS-22 score was used to assess clinical outcomes. Radiographic and clinical parameters were compared between the two groups.
Results: There were 24 patients in L3 group and 60 patients in L4 group. At last follow-up, no difference was found in the clinical and radiographic parameters between the two groups. Preoperatively, the L3 group had lower L3 translation on PA view, L3 translation on concave SB film, L3 rotation on convex SB film, more L3/4 disc opening on convex SB film and larger lumbar flexibility. Multivariate regression found L3 translation on concave SB film was the single most important predictor of LIV selection. Specifically, L3 translation on concave SB film < 10 mm was a potential threshold for selecting L3 as LIV.
Conclusions: For AIS patients with large lumbar curve, instrumentation can be reliably stopped at L3 if L3 translation on preoperative concave SB film was less than 10 mm, with the same radiographic and clinical outcomes as fusing to L4.

1. Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the spine with axial rotation and thoracic hypokyphosis. Surgical treatment should be performed for patients with Cobb angle more than 45° [1]. The surgical correction of AIS is aimed to fuse the least number of motion segments to achieve a good global balance [2].

In 2001, Lenke et al. [3] proposed a new classification adapted to posterior segmental instrumentation for AIS. The classification system contained three components: curve type, lumbar modifier and sagittal thoracic modifier. Statistically, the proportion of lumbar modifier is A (30%), B (21%) and C (49%), respectively [3]. As lumbar modifier C has the largest proportion, spine surgeons treating these patients encounter more difficulties, such as which vertebra should be selected as the lowest instrumented vertebra (LIV) [4].

Although the Lenke classification is now widely used to guide which curves to fuse, it does not clearly define the fusion level [3]. Hence, selecting the LIV in Lenke modifier C AIS with large lumbar curve can be difficult. The selection of LIV is important because it is highly related to postoperative clinical outcomes. For thoracolumbar/lumbar (TL/L) curves, stopping the distal fusion at L3 could save more mobile lumbar spinal segments but may increase the risk of decompensation, especially for large lumbar curves; On the other hand, stopping the distal fusion below L3 may improve coronal correction while lead to a higher incidence of disc degeneration and low back pain [5–7].

Although numerous studies have investigated the choice of fusion levels [7], there is still some controversy on whether to fuse the TL/L curves at L3 or L4. It remains unknown which radiographic parameters correlate best with the LIV selection. The purpose of the study is to evaluate pre-operative radiographic factors that are associated with the selection of either L3 or L4 as LIV in posteriorly treated AIS patients with large lumbar curve (> 60°).

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1.1. Patients and methods

This study was approved by the University Institutional Review Board. AIS patients who received posterior surgery from April 2007 to March 2015 were retrospectively reviewed. Patients were recruited into this study with the following inclusion criteria: Lenke type 3C, 4C, 5C and 6C with lumbar Cobb angle more than 60°; aged from 11 to 18 years; followed up more than 2 years; L3 or L4 selected as LIV. The demographic data were recorded including sex, age, Risser grades, follow-up time and type of constructs used. Patients were grouped according to the selection of LIV, either L3 group or L4 group.

1.2. Radiographic measurements

The radiographic parameters were measured on upright posteroanterior (PA) and lateral radiographs preoperatively and at the final follow-up. Besides, preoperative concave and convex supine side-bending (SB) coronal radiographs were also evaluated. The measurements included the Cobb angle, curve flexibility and apical vertebral translation (AVT) of the thoracic curves and lumbar curves, 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, coronal balance, sagittal balance, thoracic kyphosis (TK) and lumbar lordosis (LL). AVT was defined as the distance between the central sacral vertical line (CSVL) and the midpoint of the apical vertebral body [8]. L3 translation was measured by the distance between the CSVL and the midpoint of L3 vertebra on PA film and concave SB film. L3 rotation was defined by Moe-Nash's method [9]. TK was measured by the angle between upper endplate of T1 and lower endplate of T12. LL was measured by the upper endplate of L1 and S1. Coronal balance was measured by the deviation of the coronal C7 plumbline (C7PL) from CSVL, with a value > 20 mm defined as imbalance [10]. Sagittal balance was measured by the deviation of the sagittal C7PL from the posterior edge of sacrum, with a value > 50 mm defined as imbalance [11]. Flexibility was calculated as follows: (preoperative Cobb angle – preoperative SB Cobb angle)/preoperative Cobb angle × 100 (%) [12]. Curve correction was calculated as follows: (preoperative Cobb angle - postoperative Cobb angle)/preoperative Cobb angle × 100 (%) [11]. The coronal balance and sagittal balance were averaged using absolute values. All measurements were performed with Surgimap software (Spine Software, version 2.1.2, New York, NY, USA). Also, the last vertebra touching the CSVL (last touching vertebra, LTV) was determined for each patient. Two of the authors (X. Q. and C. X.) completed the measurement together. In addition, 20 patients were randomly selected to calculate the intra- and inter-observer variability of the measurement. Strong intraobserver and interobserver agreements were obtained for all the parameters with the kappa correlation coefficients exceeding 0.8. The mean values of the data measured by the two investigators were recorded.

Satisfactory outcomes were defined as no coronal decompensation (such as coronal imbalance, proximal and distal adding-on), no sagittal decompensation (such as sagittal imbalance, proximal and distal junctional kyphosis) and no need for revision surgery at the last follow-up.

1.3. Evaluation of quality of life

Patients were all required to complete the Scoliosis Research Society questionnaires (SRS-22) at the last follow-up to assess clinical outcomes, which covers five domains including function/activity, pain, self-perceived image, satisfaction with treatment, and mental health [13].

1.4. Statistical analyses

The Student t test, chi-square test or Fisher's exact test was used to compare continuous or categorical variables between L3 group and L4 group. Factors related to the LIV selection were further investigated by stepwise logistic regression analysis. The receiver operating

Table 1
Demographic data.

	L3 Group (n = 24)	L4 Group (n = 60)	P
Sex (Male/Female)	2/22	10/50	0.495
Age (years)	16.0 ± 2.8	15.2 ± 2.1	0.081
Construct (PS/Hybrid)	22/2	56/4	0.789
Risser grade	3.1 ± 1.3	2.8 ± 1.2	0.158
Follow-up time (month)	35.7 ± 19.2	36.6 ± 20.1	0.426
Lenke type			
3C	8	12	0.259
5C	12	29	
6C	4	19	
LTV			
L3	5	3	0.062
L4	16	42	
L5	3	15	

Table 2
Preoperative radiographical data.

	L3 Group (n = 24)	L4 Group (n = 60)	P
Thoracic curve (°)	35.8 ± 6.1	35.9 ± 9.7	0.485
Flexibility (%)	54.1 ± 13.2	56.4 ± 14.6	0.252
TAVT	11.0 ± 9.0	14.2 ± 11.9	0.119
Lumbar curve (°)	64.3 ± 4.2	67.0 ± 9.8	0.102
Flexibility (%)	61.7 ± 11.4	55.2 ± 14.0	0.022
LAVT	55.1 ± 13.4	60.6 ± 14.5	0.055
L3 translation	29.2 ± 7.4	33.1 ± 8.1	0.024
Coronal balance (mm)	16.3 ± 8.5	21.2 ± 14.4	0.062
Concave bending L3 translation	6.9 ± 3.3	14.5 ± 4.2	< 0.001
Convex bending L3 rotation	1.6 ± 0.7	2.1 ± 0.7	0.002
Convex bending L4 tilt	9.9 ± 4.5	14.1 ± 7.8	0.075
Convex bending L3/4 disc opening	58.3%	33.3%	0.035
Thoracic kyphosis (°)	22.3 ± 9.8	22.4 ± 10.9	0.489
Lumbar lordosis (°)	56.2 ± 15.0	52.8 ± 9.5	0.109
SVA (mm)	32.7 ± 22.8	29.2 ± 21.4	0.258

TAVT : thoracic apical vertebral translation.
LAVT : lumbar apical vertebral translation.
SVA: sagittal vertical axis.

Table 3
Radiographical data at the last follow-up.

	L3 Group (n = 24)	L4 Group (n = 60)	P
Thoracic curve (°)	10.5 ± 7.5	12.3 ± 6.2	0.139
Correction rate (%)	69.9 ± 17.6	66.5 ± 16.3	0.212
Lumbar curve (°)	12.9 ± 5.8	14.0 ± 7.2	0.244
Correction rate (%)	79.8 ± 9.2	79.1 ± 10.4	0.379
Coronal balance (mm)	10.9 ± 11.9	10.2 ± 6.9	0.376
Thoracic kyphosis (°)	22.0 ± 9.7	24.4 ± 9.8	0.156
Lumbar lordosis (°)	55.5 ± 11.2	51.7 ± 12.0	0.094
SVA (mm)	24.8 ± 19.2	28.6 ± 20.5	0.221

SVA: sagittal vertical axis.

Table 4
SRS-22 Scores at the last follow-up.

	L3 Group (n = 24)	L4 Group (n = 60)	P
Function	3.8 ± 0.7	3.7 ± 0.6	0.256
Pain	4.2 ± 0.5	4.2 ± 0.6	0.502
Self-image	3.9 ± 0.7	3.8 ± 0.5	0.232
Mental health	3.9 ± 0.8	4.0 ± 0.6	0.289
Satisfaction	4.1 ± 0.6	4.0 ± 0.8	0.291
Total	4.0 ± 0.6	3.9 ± 0.6	0.246

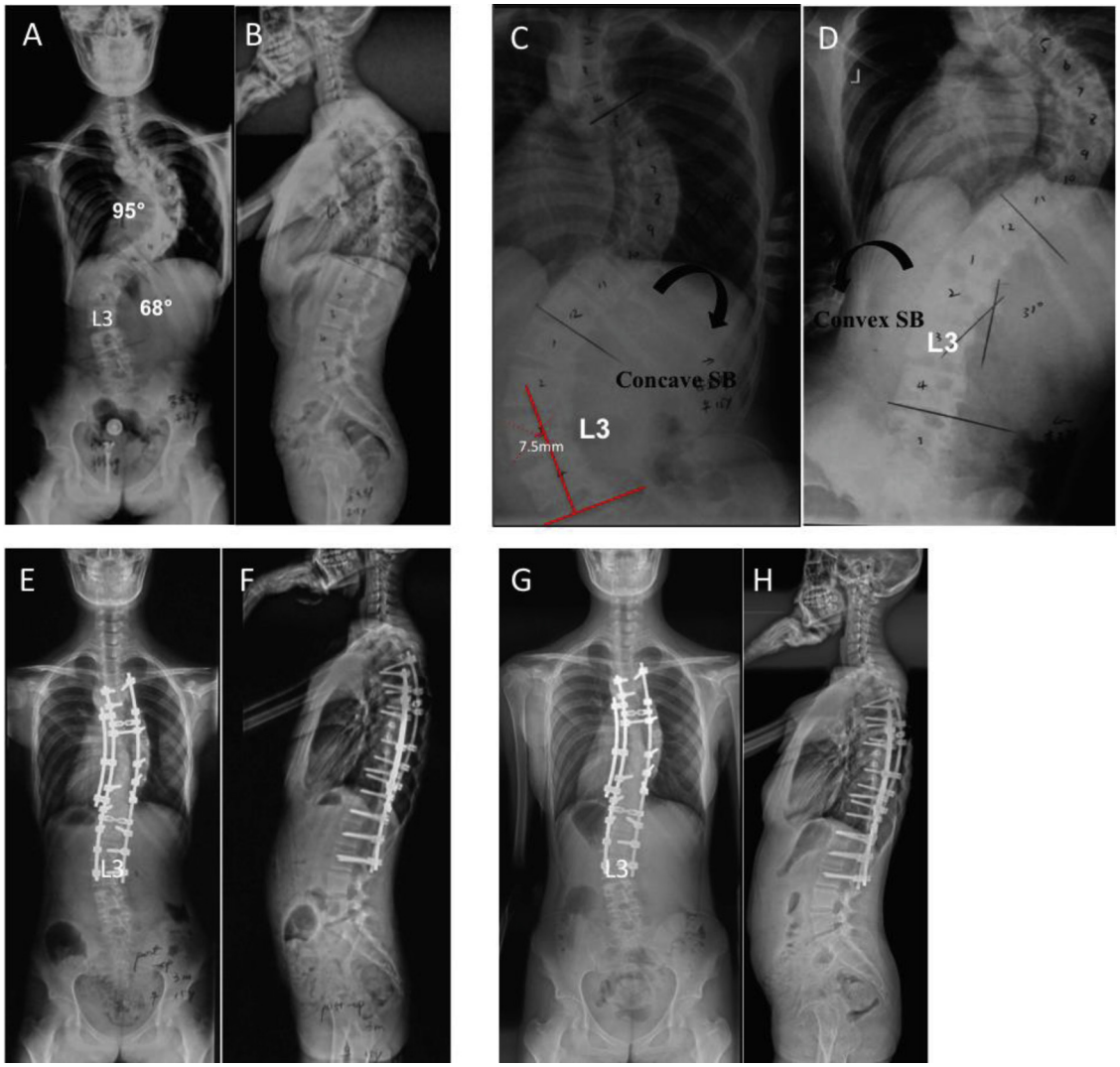

Fig. 1. (A,B) Preoperative standing PA and lateral radiographs of a 15-year-old girl with Lenke 3C curve, the lumbar curve was 68°. (C) L3 translation was 7.5 mm on concave side-bending film. (D) L3 rotation was grade I, L4 tilt was 6° and L3/4 disc opened on convex side-bending film. (E,F) Immediately postoperative standing PA and lateral radiographs with fusion to L3. (G,H) 2.4 years postoperative standing PA and lateral radiographs showed the lumbar curve was corrected to 10°with satisfactory results.

characteristics (ROC) curve was created to determine the best cutoff point for statistically significant variables. Statistical analyses were performed with SPSS 21.0 statistical software (SPSS Inc., Chicago, IL). A *P* value less than 0.05 was considered statistically significant.

2. Results

2.1. Demographic data

A cohort of 84 patients were enrolled in the study, among which, 72 were female and 12 were male. The mean age at the time of surgery was 15.4 ± 2.3 years. The mean follow-up time was 36.4 ± 19.6 months (24–90 months). The mean Risser Grade was 2.9 ± 1.2. All pedicle-screw (PS) based instrumentations were used in 78 patients, and hybrid instrumentations (hooks and PSs) were used in 6 patients. The specific Lenke types were 3C (n = 20), 5C (n = 41) and 6C (n = 23). There were 24 patients in L3 group and 60 patients in L4 group. There was no significant difference between the two groups with regard to demographic data or curve types. As regard to the position of LTV, L3 group had the LTV at L3 (20.8%), L4 (66.7%) and L5 (12.5%); L4 group had the LTV at L3 (5.0%), L4 (70.0%) and L5 (25.0%). No significant difference of LTV distribution was observed between the two groups (Table 1).

2.2. Radiographical data

Preoperative and postoperative radiographic data of the patients were summarized in Tables 2 and 3. The mean preoperative Cobb angles of the thoracic and lumbar curves were 35.9 ± 8.8° and 66.5 ± 7.0°, with a mean flexibility of 55.8 ± 14.1% and 57.0 ± 14.1%. They were corrected to 11.7 ± 6.4° and 13.7 ± 6.6°, with a mean correction rate of 67.5 ± 16.3% and 79.3 ± 9.8% at the final follow-up. There were 9 cases of coronal imbalance. No patient required revision surgery at the last follow-up.

Preoperatively, the L3 group had lower L3 translation (29.2 mm vs. 33.1 mm, p = 0.024), L3 translation on concave SB film (6.9 mm vs. 14.5 mm, p < 0.001), L3 rotation on convex SB film (1.6 vs. 2.1, p = 0.002), more L3/4 disc opening on convex side-bending film (58.3% vs. 33.3%, p = 0.035) and larger lumbar flexibility (61.7% vs. 55.2%, p = 0.022). There were no significant differences of the thoracic and lumbar curve magnitude between the two groups. The logistic regression found that L3 translation on concave SB film was the single most important predictor of LIV selection (OR = 4.01, 95% CI = 1.10–9.68, P = 0.011). ROC analysis showed that the optimal

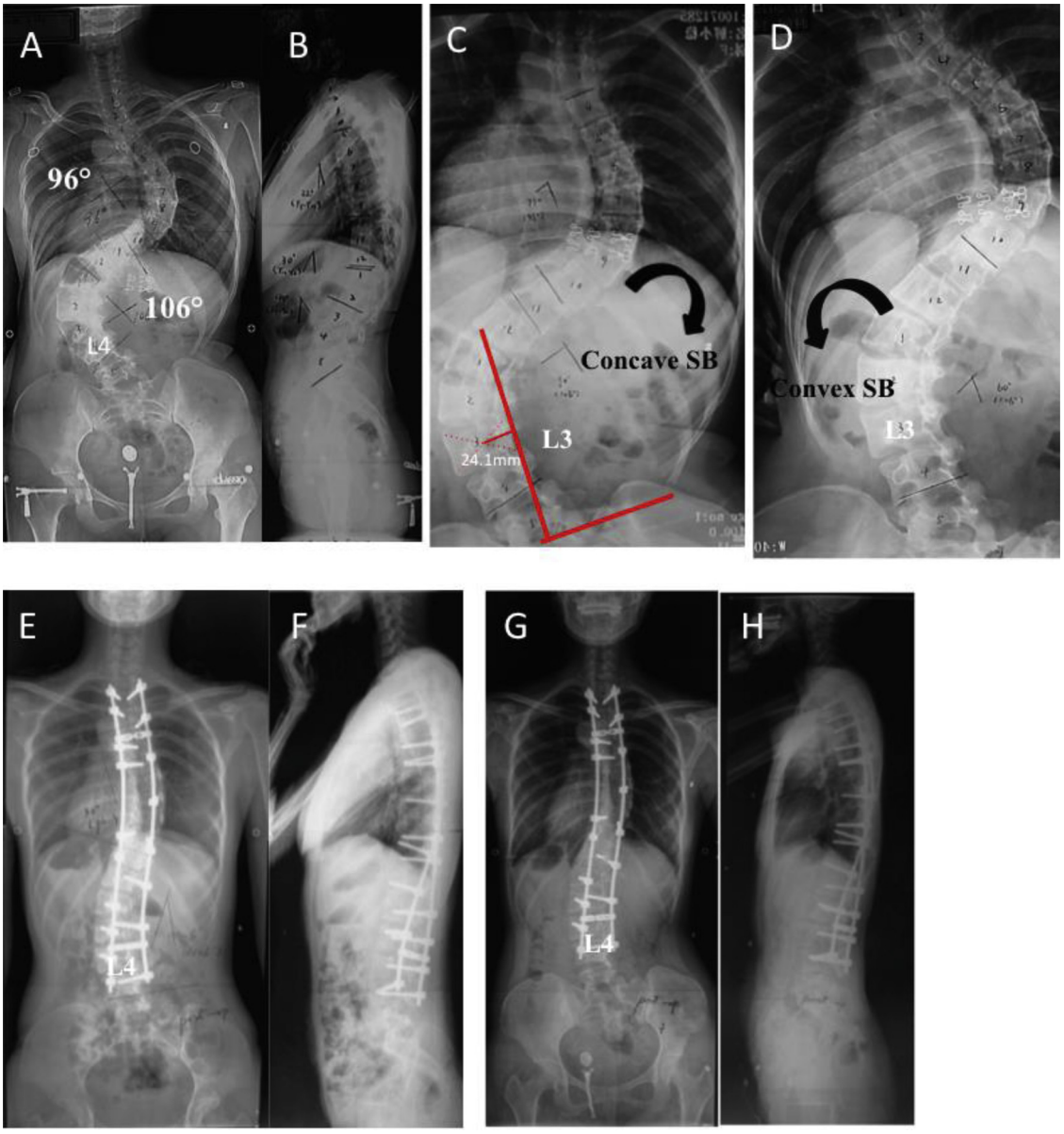

Fig. 2. (A,B) Preoperative standing PA and lateral radiographs of a 17-year-old girl with Lenke 6C curve, the lumbar curve was 106°. (C) L3 translation was 24.1 mm on concave side-bending film. (D) L3 rotation was grade II, L4 tilt was 16° and L3/4 disc closed on convex side-bending film. (E,F) Immediately postoperative standing PA and lateral radiographs with fusion to L4. (G,H) 3 years postoperative standing PA and lateral radiographs showed the lumbar curve was corrected to 18° with satisfactory results.

cutoff point of concave bending L3 translation was 10 mm, which had the best overall indicative value of LIV selection. At this point, the sensitivity and the specificity for LIV selection were 83.3% and 90.9%, respectively.

At the last follow-up, no difference was found in the radiographic parameters between the two groups. Both the two groups achieved good correction outcomes of lumbar curve at last follow-up: 79.8 ± 9.2% for L3 group and 79.1 ± 10.4% for L4 group. The frequency of satisfactory outcomes was slightly lower in L3 group (87.5%, 21/24) than in L4 group (90.0%, 54/60), but with no significance ($P = 0.710$). Besides, as for the SRS-22 questionnaire total score and each domain score, there were no significant differences between the two groups (Table 4).

3. Discussion

The selection of LIV in AIS patients with TL/L curves has been widely discussed. Li et al. [14] reviewed 27 Lenke 5C scoliosis patients with the mean Cobb angle of 44.8°, and found preoperative LIV tilt was an important radiographical parameter that strongly associated with postoperative global and regional coronal balance. Wang et al. [15] analyzed 30 Lenke 5C patients with the mean Cobb angle of 49.1°, and concluded that a preoperative LIV translation of 28 mm and a LIV tilt of 25° might be used as a general criterion for LIV selection. Liu et al. [10] observed 40 Lenke 5C cases with the mean Cobb angle of 48.9°, and suggested preoperative upper instrumented vertebra (UIV) translation and LIV tilt were two important parameters that can predict the immediate postoperative coronal balance. Kim et al. [16] studied 66 TL/L AIS patients with the mean Cobb angle of 54.1°, and found the curve could be fused to L3 when preoperative L3 crossed the mid-sacral line with rotation of less than grade II in bending films.

However, these previous studies included mild to moderate lumbar curves with a relative small sample size. The decision-making of LIV selection would be more complex when correcting large lumbar curves,

since the risk of postoperative decompensation might increase when fusion to L3. The present study had the advantage of investigating a relative large cohort of AIS patients with lumbar curves more than 60°. In this study, we observed a trend towards saving fusion to L3 in cases where the preoperative L3 translation, L3 translation on concave SB film and L3 rotation on convex SB film were lower, while L3/4 disc was open bilaterally on convex SB film and lumbar flexibility was larger. Among which, L3 translation on concave SB film was the most important predictor of LIV selection by multivariate regression. When the preoperative concave bending L3 translation was less than 10 mm, 20 among 21 patients (95.2%) fused down to L3 showed satisfactory results (Fig. 1). When the preoperative concave bending L3 translation was more than 10 mm, 45 among 51 patients (88.2%) fused down to L4 showed satisfactory results (Fig. 2). Unsatisfactory results were occurred in 2 among 3 patients (66.7%) in whom preoperative concave bending L3 translation was more than 10 mm when saving fusion to L3. Although the preservation of lumbar motion is important in lumbar curve correction surgery, in our opinion, the lowest fusion mass must be placed in the stable zone with balanced spine to prevent postoperative coronal decompensation. When preoperative L3 translation on concave SB film is less than 10 mm, L3 would be within the stable zone postoperatively, and satisfactory results would be achieved.

Surgeons tend to fuse the least number of motion segments to achieve a good global balance for AIS patients. However, it remains unknown whether saving more motion segments leads to increased functional activity or decreased back pain, which makes the decision-making of LIV selection in TL/L curves more complex. Several studies demonstrated an increased incidence of back pain was associated with lower LIV. Fabry et al. [17] reported the incidence of back pain was 17%, 37% and 46% for patients fused to L3, L4 and L5, respectively, and concluded that lower fusions were prone to give more back pain. Hayes et al. [18] reviewed 48 AIS patients with a long-term follow-up, and found retrolisthesis occurred in 81% of patients instrumented to L4, in 40% of those fused to L3, which was strongly associated with low back pain. Meanwhile, several studies did not demonstrate any correlation of the back pain and lowest level of fusion. Bartie et al. [19] investigated 171 AIS patients with fusion to L2, L3, L4 and L5 in a long-term follow-up. They found there were no significant differences of low back pain among L2, L3 and L4 groups. Ding et al. [20] compared the quality of life between AIS patients fused to L3 and L4 by using SRS-22, Oswestry Disability Index (ODI), visual analogue scale (VAS), and Short Form-36 (SF-36) questionnaires. They did not found any significant differences in these questionnaire scores between the 2 groups in a short-term follow-up. In the current study, no significant difference was found in the clinical and radiographic parameters between the two groups at the last follow-up, which was similar to previous studies.

One of the limitations of this study was the relative short duration of follow-up. As disc and facet degeneration is a slow process, few differences of degeneration would be observed between the two groups in a short-term follow-up. However, in a long-term follow-up, it can be speculated that L3 group would have the advantage of lower degeneration rate and better functional outcome. Future study with a longer duration of follow-up is warranted for a sound conclusion. Second, our findings could be biased for its retrospective nature and relatively small number of patients. Future, prospective study with a larger sample size is warranted for a sound conclusion.

4. Conclusion

For AIS patients with lumbar curve larger than 60°, L3 translation on concave SB film was the most important predictor of LIV selection. One can reliably stop at L3 if preoperative L3 translation on concave SB film was less than 10 mm, with the same radiographic and clinical outcomes as fusing to L4.

Conflict of interest

The authors have no conflict of interest to declare.

This study was approved by the University Institutional Review Board.

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