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Relationship between Fusion Mass Shift and Postoperative Distal Adding-on in Lenke 1 Adolescent Idiopathic Scoliosis after Selective Thoracic Fusion

Yang Li[1,*], Jianlong Li[2,*], Keith D. K. Luk[3], Chenggui Zhang[1], Jianmin Sun[1], Guodong Wang[1]

[1]*Department of Spine Surgery, Shandong Provincial Hospital Affiliated to Shandong First Medical University, Jinan, China*
[2]*Department of Spine Surgery, Public Health Clinical Center of Shandong Province, Jinan, China*
[3]*Orthopaedics and Sports Medicine Center, The Hong Kong Sanatorium and Hospitals, Hong Kong SAR, China*

Study Design: This is a retrospective cohort study.

Purpose: This study aims to investigate the risk factors for postoperative distal adding-on in Lenke 1 adolescent idiopathic scoliosis (AIS) and validate the relationship between fusion mass shift (FMS) and postoperative distal adding-on.

Overview of Literature: Postoperative distal curve adding-on is one of the complications in AIS. FMS has been proposed to prevent postoperative distal adding-on, which requires further validation from different institutions.

Methods: This study included 60 patients with Lenke 1 AIS who underwent selective thoracic fusion surgery. Coronal spinal alignment parameters were analyzed preoperatively, postoperatively, and at the final follow-up. The postoperative FMS was divided into two groups: the balanced group (FMS ≤20 mm) and the unbalanced group (FMS >20 mm). An independent *t*-test was used to compare quantitative data between groups, and a chi-square test was used for qualitative data. Furthermore, binary logistic regression and receiver operating characteristics curve analyses were used to identify the risk factors for postoperative distal adding-on in AIS.

Results: At 2-year follow-up, the unbalanced group was more likely to have adding-on (17 of 24 patients) than the balanced group (six of 36 patients; $p<0.001$). Twenty-three patients with distal adding-on had significantly greater preoperative and postoperative lower instrumented vertebrae (LIV) rotation, FMS, and FMS angle (FMSA) than those without postoperative distal adding-on. Binary logistic regression analysis selected three independent risk factors for adding-on incidence after surgery: FMS (odds ratio [OR], 1.115; 95% confidence interval [CI], 1.049–1.185; $p<0.001$), FMSA (OR, 1.590; 95% CI, 1.225–2.064; $p<0.001$), and postoperative LIV rotation (OR, 6.581; 95% CI, 2.280–19.000; $p<0.001$).

Conclusions: Achieving a balanced fusion mass intraoperatively is important to avoid postoperative distal adding-on, with FMS of <20 mm and FMS angle of <4.5°. Furthermore, correcting LIV rotation helps to decrease the incidence of postoperative distal adding-on.

Keywords: Adolescent idiopathic scoliosis; Fusion mass shift; Fusion mass shift angle; Lenke 1 type; Postoperative distal adding-on

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Corresponding author: Guodong Wang
Department of Spine Surgery, Shandong Provincial Hospital Affiliated to Shandong First Medical University, No. 9677, Jingshi Road, Jinan City, Shandong Province, China
Tel: +86-0531-68776029, Fax: +86-0531-68773208, E-mail: wanggd1986@163.com
*These authors contributed equally to this work as first authors.

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Introduction

The etiology of adolescent idiopathic scoliosis (AIS), which affects 1%–3% of adolescents, remains unknown [1]. The incidence of Lenke type 1 scoliosis accounts for 51% of AIS [2]. Selected thoracic fusions (STFs) are performed on these patients to achieve coronal and sagittal balance and to preserve more lumbar motion segments. Postoperative distal adding-on is one of the complications after STF in Lenke 1 AIS.

Postoperative distal adding-on is defined as a progressive increase in the number of vertebrae included distally in the primary curvature, combined with a deviation of <5 mm from the center sacral vertical line (CSVL) to the lower instrumented vertebrae (LIV) or angulation of the first disk caudal to the LIV of more than 5° [3]. The occurrence of postoperative distal adding-on is closely related to decreased postoperative satisfaction, back pain, increased cost, and reoperation [4,5].

In 2017, the concept of fusion mass shift (FMS) was proposed, with an intraoperative aim of balanced fusion mass with FMS of <20 mm to avoid postoperative distal adding-on [3]. Therefore, we retrospectively reviewed the Lenke 1 AIS cases from the last decade to validate the influence of FMS on the occurrence of postoperative distal adding-on and to investigate the risk factors for postoperative distal adding-on in Lenke 1 AIS.

Materials and Methods

This is a retrospective study of patients from a single institution. Permission to conduct this retrospective study was obtained from the ethics committee of Shandong Provincial Hospital Affiliated to Shandong First Medical University (IRB approval no., NSFC-2020-528), and written informed consent was obtained from all subjects who participated in this study.

The study included 78 patients with Lenke 1 AIS who underwent selective thoracic fusion surgery between 2008 and 2019. Of them, 60 patients were included in the study, and 18 were excluded (Fig. 1). They all underwent surgical treatment by the same surgeon in a university-affiliated hospital. The fusion levels for selective thoracic fusion in Lenke 1 AIS were assessed using the fulcrum bending radiograph, a method described by Luk et al. [6].

The inclusion criteria of this study are as follows: (1) patients aged between 10 and 18 years, (2) patients with AIS who have main thoracic (MT) scoliosis, (3) the surgical procedure is selective thoracic fusion, (4) fixation with pedicle screw system, and (5) patients with a minimum of 2 years of follow-up.

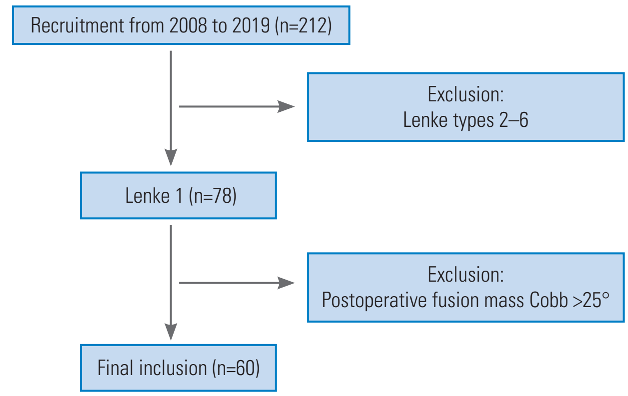

Fig. 1. A flowchart shows the recruitment process of patients in this study.

The exclusion criteria of this study are as follows: (1) patients with other types of AIS, (2) patients with other types of scoliosis, (3) patients with a prior history of spinal surgery, (4) patients with a history of spinal infection, and (5) patients with postoperative fusion mass Cobb (FMC) angle of more than 25°.

Coronal spinal alignment parameters on standing anteroposterior (AP) plain radiographs were analyzed preoperatively, postoperatively, and at the final follow-up according to the established positioning protocol. The coronal spinal alignment parameters included the proximal thoracic (PT) curve, MT curve, thoracolumbar/lumbar (TL/L) curve, clavicle angle (CA), thoracic trunk shift (TTS), T1 tilt, LIV rotation, FMC angle (Cobb angle between the superior endplate of the upper instrumented vertebrae and the inferior endplate of LIV), FMS (distance from the center of the superior endplate of upper instrumented vertebrae to a perpendicular line of the inferior endplate of LIV erected from the center of the LIV), FMSA (angle between a line from the center of the superior endplate of upper instrumented vertebrae to the center of the inferior endplate of LIV and a perpendicular line of the inferior endplate of LIV) (Fig. 2). FMC, FMS, and FMSA were measured on the postoperative films. In CA and T1 tilt, the left higher was positive, and the right higher was negative. Furthermore, age, sex, triradiated cartilage, and Risser sign were recorded before surgery. The Scoliosis Research Society 22-item patient questionnaire (SRS-22) was used to evaluate clinical improvement preoperatively, postoperatively, and at the final follow-up

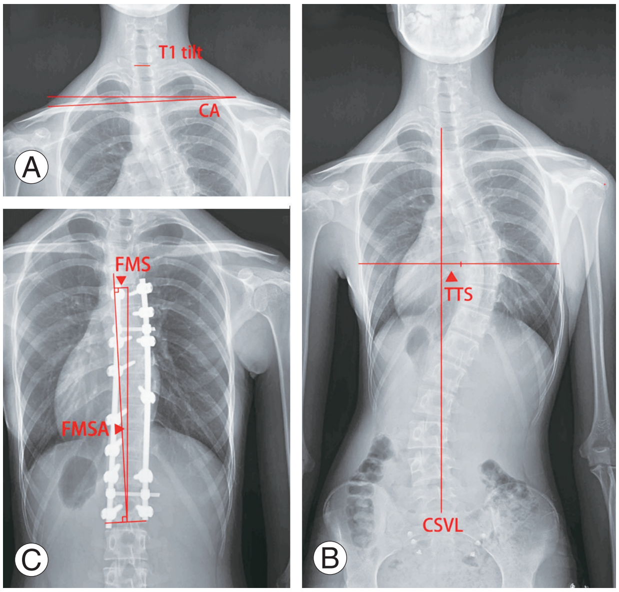

Fig. 2. The graph shows the measurement guide of coronal spinal alignment parameters. **(A)** Clavicle angle (CA) represents the angle between the line connecting the highest points of the clavicles and the horizontal plane, and T1 tilt represents the angle between the upper endplate of T1 vertebra with the horizontal plane. **(B)** Thoracic trunk shift (TTS) represents the distance between center sacral vertical line (CSVL) and the midpoint of the two widest points of the rib cage along a horizontal parallel line. **(C)** Fusion mass shift (FMS) and fusion mass shift angle (FMSA) is measured in fluorography intraoperatively.

[7].

The distal adding-on phenomenon was assessed by comparing postoperative standing AP radiographs with final follow-up standing AP radiographs. The postoperative FMS was divided into two groups: the balanced group (FMS ≤20 mm) and the unbalanced group (FMS >20 mm).

Statistical analysis was analyzed using the IBM SPSS ver. 27.0 software (IBM Corp., Armonk, NY, USA). An independent *t*-test was used to compare quantitative data between groups, and a chi-square test was used for qualitative data. In addition, binary logistic regression and receiver operating characteristics (ROC) curve analyses were used to identify the risk factors for postoperative distal adding-on in Lenke 1 AIS. The distribution of parameters was presented as mean and standard deviation. The significance level was set to $p<0.05$.

Table 1. Comparison of coronal spinal alignment parameters between non-PJK and PJK group

Variable	No adding-on group (n=37)	Adding-on group (n=23)	*p*-value
PT (°)			
Preoperative	29.97±9.25	31.43±12.07	0.6
Postoperative	20.06±9.1	17.98±10.89	0.43
Final follow-up	18.37±9.08	16.16±9.09	0.37
MT (°)			
Preoperative	56.06±14.3	58.4±12.06	0.51
Postoperative	20.32±14.68	18.32±9.29	0.52
Final follow-up	10.63±8.52	18.84±10.04	0.71
TL/L (°)			
Preoperative	33.5±10.23	35.88±9.42	0.37
Postoperative	9.97±9.75	14.9±8.25	0.02*
Final follow-up	10.63±8.52	15.75±10.49	0.04*
Clavicle angle (°)			
Preoperative	-2.16±2.5	-1.26±2.6	0.42
Postoperative	1.42±2.15	2.35±3.34	0.25
Final follow-up	1.31±2.15	1.14±1.9	0.75
Trunk shift (mm)			
Preoperative	13.84±14.71	20.51±10.86	0.05*
Postoperative	-6.16±9.97	-6±10.42	0.95
Final follow-up	-4.24±7.95	-4.75±11.79	0.85
T1 tilt (°)			
Preoperative	0.01±5.59	0.7±4.38	0.62
Postoperative	4.28±4.18	4.11±5.21	0.89
Final follow-up	3.73±4.44	5.05±5.43	0.36
LIV rotation			
Preoperative	0.57±0.69	1.09±0.79	0.01*
Postoperative	0.35±0.59	1.13±0.81	<0.01*
Final follow-up	0.35±0.59	1.09±0.79	<0.01*
Postoperative FMC (°)	12.36±8.38	16.7±8.38	0.06
Postoperative FMS (mm)	12.13±9.27	27.15±14.65	<0.01*
Postoperative FMSA (°)	2.73±2.1	6.38±3.48	<0.01*

Values are presented as mean±standard deviation.
PJK, proximal junctional kyphosis; PT, proximal thoracic curve; MT, major thoracic curve; TL/L, thoracolumbar/lumbar curve; LIV, lower instrumented vertebrae; FMC, fusion mass Cobb angle; FMS, fusion mass shift; FMSA, fusion mass shift angle.
*$p<0.05$ (statistically significant).

Results

This study included 60 patients (13 males and 47 females). The mean age for surgery was 13.6 years old, with a 2-year follow-up. Twenty-three patients developed complications of distal adding-on at 2-year follow-up. Significant differences in preoperative parameters were identified between no adding-on and adding-on patients in trunk shift (13.84±14.71 mm versus 20.51±10.86 mm) and LIV rotation (0.57±0.69 grade versus 1.09±0.79 grade). In addition, significant differences in parameters were observed postoperatively between no adding-on and adding-on groups in the TL/L curve (9.97°±9.75° versus 14.9°±8.25°), LIV rotation (0.35±0.59 grade versus 1.13±0.81 grade), FMS (12.13±9.27 mm versus 27.15±14.65 mm), and FMSA (2.73°±2.1° versus 6.38°±3.48°). At the final follow-up, there were significant differences in parameters between no adding-on and adding-on groups in the TL/L curve (10.63°±8.52° versus 15.75°±10.49°) and LIV rotation (0.35±0.59 versus 1.09±0.79) (Table 1).

Age, gender, Risser sign, and preoperative and postoperative coronal spinal alignment parameters did not differ between balanced and unbalanced groups. On the other hand, patients in the unbalanced group had significantly lower mental health scores than those in the balanced group (Tables 2, 3). In addition, the TL/L curve showed significant differences between balanced and unbalanced groups at 2-year follow-up (10±8 versus 16±10), which was correlated with the incidence rate of the distal adding-on phenomenon.

Significant differences in FMC (11°±6° versus 19°±9°), FMS (11±6 mm versus 32±9 mm), and FMSA (2°±2° versus 7°±3°) were observed between balanced and unbalanced groups. Even though there were no significant differences in preoperative and postoperative LIV rotation between groups, postoperative LIV rotation was higher in the unbalanced group than preoperative LIV rotation (1.0±0.9 grade versus 0.7±0.9 grade). In addition, the unbalanced group was more likely to develop distal adding-on at 2-year follow-up (17 of 24 patients) than the balanced group (six of 36 patients) (Table 2).

Binary logistic regression analysis revealed three independent risk factors for distal adding-on incidence after surgery: FMS (odds ratio [OR], 1.115; 95% confidence interval [CI], 1.049–1.185; p<0.001), FMSA (OR, 1.590; 95% CI, 1.225–2.064; p<0.001), and postoperative LIV rotation (OR, 6.581; 95% CI, 2.280–19.000; p<0.001) (Table 4). ROC curve analysis confirmed the following risk factors: area under the ROC curve (AUC) of FMS was 0.831 (p<0.001) with an optimal cutoff value of 20°, AUC of FMSA was 0.856 (p<0.001) with an optimal cutoff value at 4.5°, and AUC of postoperative LIV rotation was 0.812 (p=0.031) with an optimal cutoff value of 1 (Fig. 3).

Discussion

Postoperative distal curve adding-on is a complication of

Table 2. Comparison of demographic and clinical information between the balanced and unbalanced group

Variable	Balanced group	Unbalanced group	*p*-value
Gender			0.536
Male	7	6	
Female	29	18	
Age (yr)	13.4±1.5	13.8±1.7	0.423
Risser sign			0.213
0	6	2	
1	5	3	
2	1	4	
3	4	4	
4	20	9	
5	0	2	
Preoperative SRS-22 outcome			
Function	4.461±0.278	4.575±0.259	0.111
Pain	4.711±0.175	4.700±0.213	0.833
Self-image	3.594±0.343	3.642±0.306	0.580
Mental health	4.217±0.353	3.908±0.425	0.005*
Satisfaction	4.583±0.604	4.667±0.637	0.615
Total	4.639±0.683	4.625±0.576	0.933
Final follow-up SRS-22 outcome			
Function	4.461±0.278	4.575±0.2593	0.116
Pain	4.711±0.175	4.700±0.213	0.826
Self-image	3.594±0.343	3.642±0.306	0.588
Mental health	4.217±0.353	3.908±0.425	0.003*
Satisfaction	4.583±0.604	4.667±0.637	0.610
Total	4.639±0.683	4.625±0.576	0.935
FMC	11±6	19±9	<0.001*
FMS	11±6	32±9	<0.001*
FMSA	2±2	7±3	<0.001*
UIV location			
T3 or 4	21	16	
T5 or 6	14	6	0.149
LIV location			
T11 or 12	10	4	
L1 or 2 or 3	25	18	0.285
Distal adding on			
Absence	30	7	
Presence	6	17	<0.001*

Values are presented as number or mean±standard deviation.
SRS-22, Scoliosis Research Society 22-item patient questionnaire; FMC, fusion mass Cobb; FMS, fusion mass shift; FMSA, fusion mass shift angle; UIV, upper instrumented vertebrae; LIV, lower instrumented vertebrae.
*p<0.05 (statistically significant).

Table 3. Comparison of radiographic parameter between the balanced and unbalanced groups

Variable	Balanced group	Unbalanced group	*p*-value
Preoperative parameters			
PT (°)	30±11	33±11	0.316
MT (°)	54±14	61±12	0.066
TL/L (°)	33±10	39±9	0.262
CA (°)	-2±2	-2±2	0.735
TTS (mm)	19±13	14±14	0.121
T1 tilt (°)	0±6	0±5	0.802
LIV rotation	0.9±0.7	0.7±0.9	0.420
Postoperative parameters			
PT (°)	18±9	22±10	0.115
MT (°)	18±15	22±9	0.208
TL/L (°)	15±9	10±7	0.169
CA (°)	1±2	2±3	0.739
TTS (mm)	-6±11	-6±9	0.885
T1 tilt (°)	5±6	4±4	0.631
LIV rotation	0.6±0.8	1.0±0.9	0.055
Final follow-up parameters			
PT (°)	16±9	20±9	0.390
MT (°)	17±14	23±9	0.097
TL/L (°)	10±8	16±10	0.009*
CA (°)	1±2	1±2	0.970
TTS (mm)	-5±11	-4±8	0.535
T1 tilt (°)	6±6	3±4	0.058
LIV rotation	0.5±0.7	0.9±0.8	0.092

Values are presented as number or mean±standard deviation.
PT, proximal thoracic; MT, main thoracic; TL/L, thoracolumbar/lumbar; CA, clavicle angle; TTS, thoracic trunk shift; LIV, lower instrumented vertebrae.
*$p<0.05$ (statistically significant).

AIS undergoing selective thoracic fusion surgery. In our study, the incidence of postoperative distal adding-on was 38.3%, similar to the previous study (21%–51%) [3,8]. Previous studies reported that a low Risser grade predicted a high growth potential and was more likely to develop distal adding-on after selected thoracic fusion surgery [9,10]. The selection of LIV was another important factor influencing the incidence of postoperative distal adding-on [8,11]. According to He et al. [12], preoperative rota-

Table 4. Binary logistic regression analysis of risk factors for distal adding on after correction surgery of Lenke 1 adolescent idiopathic scoliosis

Variable	OR (95% CI)	*p*-value
FMS	1.115 (1.049–1.185)	<0.001*
FMSA	1.590 (1.225–2.064)	<0.001*
FMC	1.040 (0.973–1.111)	0.251
CA preop	1.024 (0.823–1.273)	0.834
CA postop	1.234 (0.963–1.582)	0.096
CA f/u	0.855 (0.641–1.140)	0.285
Shoulder imbalance	0.425 (0.111–1.632)	0.213
Age	0.897 (0.629–1.280)	0.550
Risser sign	1.063 (0.740–1.521)	0.654
UIV location	1.025 (0.662–1.585)	0.913
LIV location	0.700 (0.462–1.060)	0.092
LIV rotation preop	1.222 (0.626–2.384)	0.557
LIV rotation postop	6.581 (2.280–19.000)	<0.001*
LIV rotation f/u	6.230 (2.251–17.245)	<0.001*
MT correction rate	0.565 (0.009–36.596)	0.788

OR, odds ratio; CI, confidence interval; FMS, fusion mass shift; FMSA, fusion mass shift angle; FMC, fusion mass Cobb; CA, clavicle angle; preop, preoperative; postop, postoperative; f/u, follow-up; UIV, upper instrumented vertebrae; LIV, lower instrumented vertebrae; MT, main thoracic.
*$p<0.05$ (statistically significant).

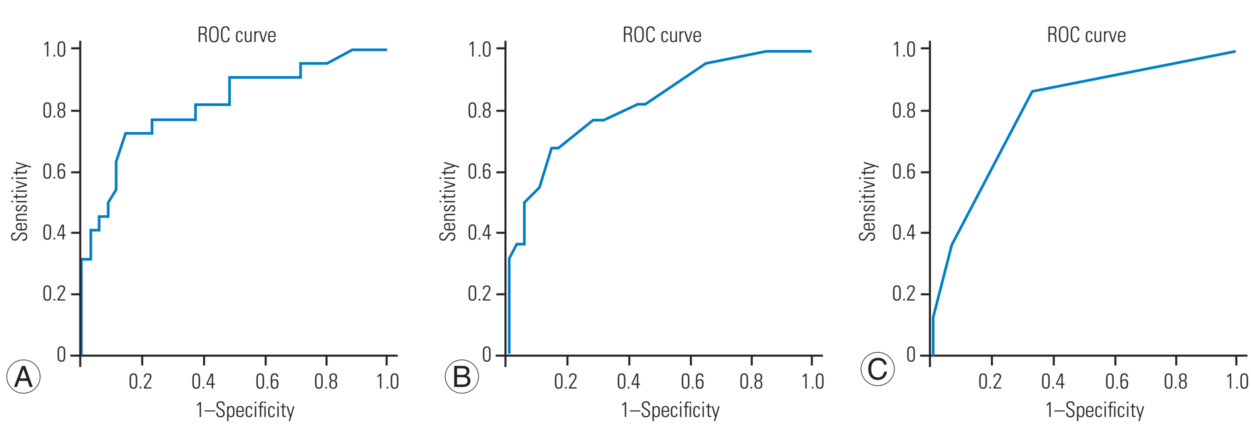

Fig. 3. The graph shows the result of receiver operating characteristics (ROC) curve analysis for risk factors of distal adding-on: fusion mass shift **(A)**, fusion mass shift angle **(B)**, and postoperative lower instrumented vertebrae rotation **(C)**.

tion of LIV was also an independent predictor of postoperative distal adding-on in Lenke 1A or 2A AIS patients.

In 2017, the concept of balanced fusion mass was proposed [3], which helped to reduce postoperative distal adding-on. In the present study, a distal adding-on phenomenon was observed in 16.7% (six of 36 patients) of the balanced group (FMS ≤20 mm) and 70.8% (17 of 24 patients) of the unbalanced group (FMS >20 mm). This was consistent with previous results, which showed that 12.2% (five of 41 patients) were in the balanced group, and 54.5% (six of 11 patients) were in the unbalanced group [3]. Therefore, the aim of corrective surgery should be to achieve a balanced fusion mass. This should be done intraoperatively to reduce the risk of postoperative distal adding-on. FMS, FMSA, and rotation of LIV are parameters that determine whether a balanced fusion mass is achieved.

Aside from FMS, FMS angle was found to be an independent risk factor for postoperative distal adding-on. FMS could help us preoperatively determine fusion levels through fulcrum bending radiographs [6]. We can also use FMS and FMSA during the surgery to assess whether the balanced fusion mass is achieved. However, intraoperative fluoroscopy was typically performed using a C-arm X-ray machine, and measuring the FMS without scale was challenging. FMSA, which is highly correlated with FMS, is easier to be measured in fluorography without scale. Furthermore, intraoperative FMS is not weight-bearing, and FMSA may be more sensitive than FMS in short fusion in Lenke 1 AIS patients undergoing selected thoracic fusion surgery. In our study, avoiding a residual FMSA of more than 4.5° could help reduce the incidence of the postoperative distal adding-on phenomenon.

FMS occurred before the postoperative distal adding-on phenomenon. It occurred during the operation at the completion of the fixation and remained unchanged after the operation. However, the postoperative distal adding-on phenomenon gradually developed at serial postoperative follow-up X-rays (Fig. 4). In our study, an FMS of >20 mm was one of the causes of the postoperative distal adding-on phenomenon.

FMS can be assessed intraoperatively using a long cross-metal bar perpendicular to the lower endplate of LIV. It facilitates the assessment of the fusion mass. However, be-

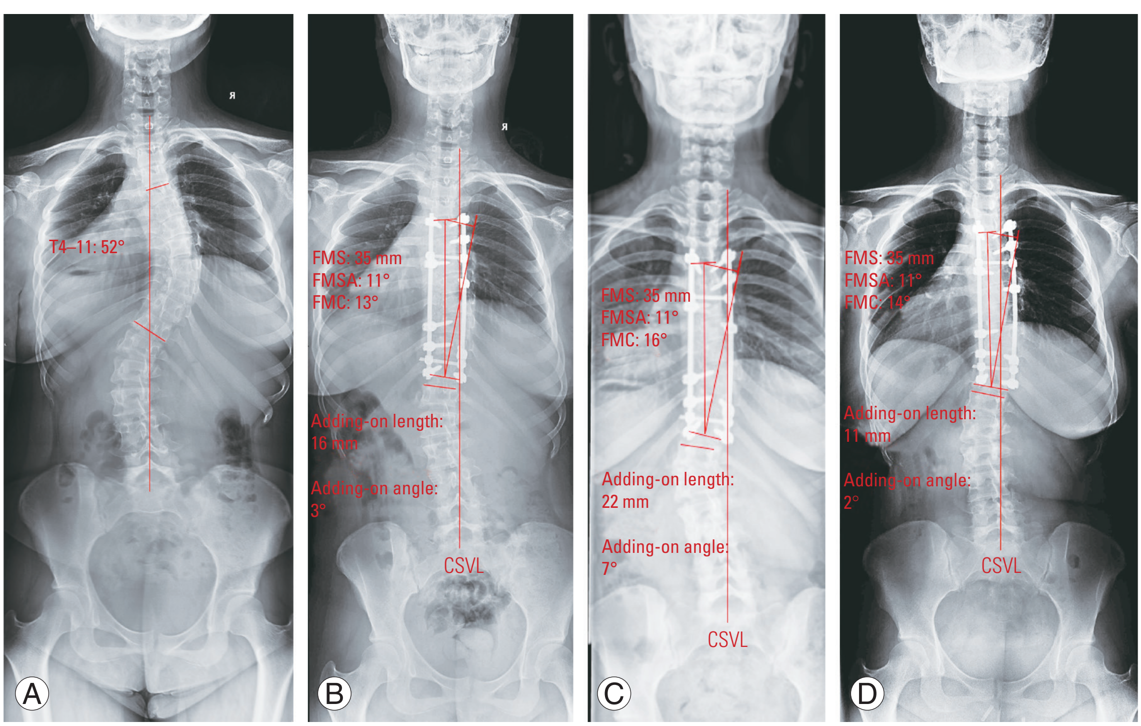

Fig. 4. (A) The graph shows a 14-year-old girl with a 52° main thoracic preoperatively. **(B)** She underwent a selective thoracic fusion with fusion mass Cobb (FMC) of 13°, but has fusion mass shift (FMS) of 35 mm and fusion mass shift angle (FMSA) of 11°. **(C)** The distal adding-on phenomenon was occurred at 6-month follow-up, which with an increase of 6 mm deviating from the center sacral vertical line (CSVL) to lower instrumented vertebrae (LIV) and an increase of 4° in angulation of the first disc caudal to the LIV. **(D)** At 4-year follow-up, the adding-on phenomenon improved better than 6-month follow-up.

cause this assessment is performed in a nonweight-bearing position, the unfused segments can further compensate postoperatively when the patient assumes an erect posture. Therefore, a postoperative adding-on phenomenon will occur in the presence of a large residual FMS or FMSA.

The postoperative LIV rotation was also an important risk factor contributing to postoperative distal adding-on in Lenke 1 AIS patients. The residual rotation could cause a distal adjacent segment to be offset. The concept of neutral vertebrae was proposed by Suk et al. [13], who suggested that it should be fused to neutral vertebrae when neutral vertebrae were two vertebrae caudal to lower end vertebrae. The selection of LIV should take into account the vertebrae rotation. Correction of LIV rotation may be beneficial in reducing distal adding-on.

A previous study reported that postoperative shoulder imbalance had significantly associated with distal adding-on in Lenke 2 AIS patients [14]. However, in our study, postoperative shoulder imbalance was not an independent risk factor for distal adding-on in Lenke 1 AIS. The PT curve was the main compensatory to balance the postoperative shoulder. Although postoperative CA was not significantly associated with distal adding-on in the present study, it may compensate for postoperative shoulder imbalance [15].

In our study, no patients with postoperative distal adding-on had a second surgery. In most cases, the truncal shift with distal adding-on phenomenon could be well controlled after strengthening the back muscles, as shown in Fig. 4. She was a 14-year-old female with a 52° MT preoperatively. After surgery, the MT was well corrected but with a large FMS and FMSA. The distal adding-on phenomenon occurred at the 6-month follow-up, with a deviation of 6 mm from the CSVL to the LIV. After strengthening the lumbar and back muscles, the adding-on phenomenon is controlled and does not require revision surgery at a 4-year follow-up.

This study has some limitations. First, the sample size is small due to the single-institution research design. A larger sample of multicenter studies is being conducted. Second, only Lenke 1 AIS was included in the study. Third, this study did not analyze whether sagittal lumbar alignment parameters influence the adding-on.

Conclusions

Distal adding-on phenomenon occurred in 38.3% of patients. Therefore, achieving a balanced fusion mass intraoperatively was important to avoid postoperative distal adding-on, with FMS of <20 mm and FMS angle of <4.5°. Furthermore, correcting LIV rotation helped decrease the incidence of postoperative distal adding-on.

Conflict of Interest

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

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ORCID

Yang Li: https://orcid.org/0000-0002-0694-7225
Jianlong Li: https://orcid.org/0000-0002-6055-1782
Keith D. K. Luk: https://orcid.org/0000-0003-0547-8890
Chenggui Zhang: https://orcid.org/0000-0001-5943-2586
Jianmin Sun: https://orcid.org/0000-0003-2327-4285
Guodong Wang: https://orcid.org/0000-0002-9374-5807

Author Contributions

Jianlong Li and Jianmin Sun did the data collection and analysis. Yang Li and Chenggui Zhang finished the measurement. Keith D. K. Luk did the critical revision. Guodong Wang designed the study and wrote the article.

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