Postoperative Lumbar Curve Progression Deteriorates Shoulder Imbalance in Patients with Lenke Type 2B/C Adolescent Idiopathic Scoliosis Who Underwent Selective Thoracic Fusion

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■ OBJECTIVE: **To evaluate the association between postoperative lumbar curve progression and the shoulder height in patients with Lenke type 2B/C adolescent idiopathic scoliosis (AIS).**

■ METHODS: **A total of 25 patients with Lenke type 2B/C AIS underwent posterior correction surgery in our institution from 2005–2014 were included. Standing x-ray films of the whole spine obtained before surgery, immediately after surgery, and at the last follow-up were analyzed with respect to the following parameters: proximal thoracic Cobb angle, main thoracic (MT) Cobb angle, lumbar Cobb angle, lumbar apical vertebral translation, distance between C7 plumb line and the central sacral vertical line, and radiographic shoulder height (RSH). Correlations between the change of RSH and the changes of other parameters were analyzed both immediately after surgery and at the last follow-up.**

■ RESULTS: **The change of RSH was significantly negatively correlated with both the change of MT Cobb angle ($P < 0.05$) and that of lumbar Cobb angle ($P < 0.05$) immediately after surgery, whereas the interval-time change of RSH was significantly positively correlated with the interval-time change of lumbar Cobb angle ($P < 0.05$) and that of lumbar apical vertebral translation ($P < 0.05$) at the last follow-up. The change of MT Cobb angle was an independent predictor for the change of RSH immediately after surgery, whereas the interval-time change of lumbar Cobb angle was an independent predictor for the interval-time change of RSH at the last follow-up.**

■ CONCLUSIONS: **Postoperative lumbar curve progression is a risk factor for deterioration of shoulder imbalance in patients with Lenke 2B/C AIS during the follow-up period.**

INTRODUCTION

Selective thoracic fusion (STF) has gained popularity in the surgical treatment of patients with adolescent idiopathic scoliosis (AIS) with structural thoracic curve and nonstructural lumbar curve, which could achieve a balanced spine while preserving as many mobile distal segments as possible.[1,2] It has been confirmed that a flexible compensatory lumbar curve could be spontaneously corrected after sole fusion of the structural thoracic curve.[3,4] However, the inadequate selection of lower instrumented vertebra (LIV) often led to complications occurring distal to the fusion area, such as adding-on characterized by progressive deviation of the lumbar spine or wedging of the intervertebral disc below LIV.[5,6] The occurrence of adding-on was often accompanied by unsatisfactory radiographic and clinical outcomes, increasing the risk of reoperation in patients with AIS.[5-7]

Although the development of adding-on might cause clinical adverse effects on patients with AIS, it was found to be associated with the improvement of postoperative shoulder balance in patients with Lenke type 2 AIS during the follow-up time,[8] which was also observed in our clinical experience (Figure 1A-C). Cao et al.[8] thought the possible explanation for this phenomenon

Key words
- Curve
- Lumbar
- Radiographic shoulder height
- Scoliosis

Abbreviations and Acronyms
AIS: Adolescent idiopathic scoliosis
AVT: Apical vertebral translation
C7PL: C7 plumb line
CSVL: Central sacral vertical line
LIV: Lower instrumented vertebra
MT: Main thoracic
PT: Proximal thoracic
RSH: Radiographic shoulder height
STF: Selective thoracic fusion
UIV: Upper instrumented vertebra

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Citation: World Neurosurg. (2019) 125:e175-e182.
https://doi.org/10.1016/j.wneu.2019.01.032

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

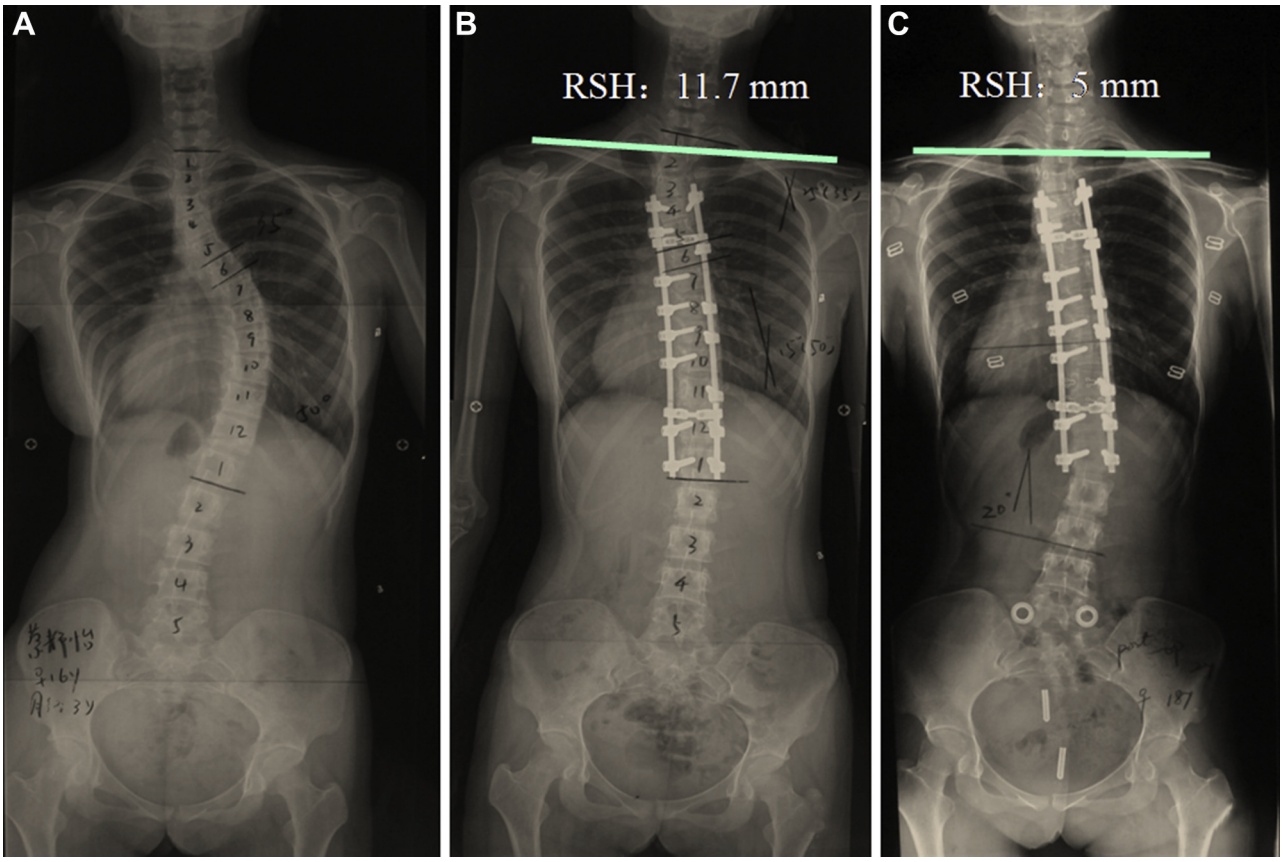

Figure 1. A 16-year-old girl with Lenke type 2A curve (**A**). This patient underwent selective thoracic fusion with the lower instrumented vertebra of L1 and had a left-elevated shoulder after surgery (**B**). This patient had improved shoulder balance (radiographic shoulder height decreased from 11.7–5 mm) with the development of distal adding-on 2 years after surgery (**C**). RSH, radiographic shoulder height.

was that patients who underwent STF had more unfused mobile lumbar segments, which can more effectively accommodate the shoulder imbalance. However, this is not always the case. It was observed that adding-on mostly occurred in patients with thoracic scoliosis with a lumbar modifier of A.[5-7] The inadequate selection of LIV in patients with a lumbar modifier of B or C might result in postoperative lumbar curve progression, which was a complication completely different from adding-on.[9-12] We found that patients with Lenke type 2B/C who underwent STF could experience the deterioration of shoulder imbalance during the follow-up period, with the occurrence of progression of unfused lumbar curve to the left side (the opposite side of adding-on). To date, such a phenomenon had not been reported in English literatures. The purpose of this study was to evaluate the correlation between the postoperative lumbar curve progression and shoulder imbalance deterioration in patients with Lenke type 2B/C AIS.

MATERIALS AND METHODS

Subjects

With the approval from the institutional review board in our hospital, a total of 130 patients with AIS and with a Lenke type 2 curve from 2005–2014 in our institution were retrospectively reviewed. The inclusion criteria were: 1) underwent posterior correction surgery; 2) with lumbar modifier B (central sacral vertical line [CSVL] passing between the medial edge of the concave pedicle and the concave border of the lumbar apex) or C (CSVL passing completely medial to the lumbar apex); and 3) a minimum of 1-year radiographic follow-up. Finally, a total of 25 patients with AIS and with a Lenke type 2 curve met the criteria described earlier and were included. There were 23 female patients and 2 male patients with an average age of 14.1 ± 2.2 (ranged from 11–19) years. The lumbar modifier was B in 11 cases and C in 14 cases. We selected the upper instrumented vertebra (UIV) based on the preoperative shoulder height. The UIV was selected at T2 or above in patients with preoperative left-higher shoulder, T3 in patients with leveled shoulder, and T4 or below in patients with preoperative left-higher shoulder. We selected the LIV using the following criteria: 1) the LIV should be derotated to neutral in patients with Risser sign from 0–3 on the convex side-bending films, whereas it should be derotated to no more than Nash-Moe I degree in patients with Risser sign ≥4, with the disc below the LIV opened to at least 0°; and 2) the disc immediately below the LIV must be opened to the convex side by at least 5° on the convex side.[13] The UIV was T1 in 3 cases, T2 in 11

Table 1. Correction Outcomes Immediately After Surgery and at the Last Follow-Up (n = 25)

	Preoperative	Immediately After Surgery	At the Last Follow-Up
PT curve (°)	43.1 ± 6.5	24.4 ± 5.6*	27.0 ± 6.2*
MT curve (°)	56.1 ± 9.1	20.0 ± 5.7*	22.9 ± 5.0*
Lumbar curve (°)	38.0 ± 7.3	13.6 ± 3.9*	16.4 ± 3.8*
Lumbar AVT (mm)	15.7 ± 5.2	8.5 ± 4.2*	10.1 ± 5.1*
C7PL-CSVL (mm)	−9.2 ± 10.6	−3.6 ± 12.2*	−2.7 ± 5.9*
RSH (mm)	−8.5 ± 10.7	4.3 ± 8.3*	8.7 ± 8.6*

PT, proximal thoracic; MT, main thoracic; AVT, apical vertebral translation; C7PL, C7 plumb line; CSVL, central sacral vertical line; RSH, radiographic shoulder height.
*Difference is statistically significant when compared to the preoperative parameter.

cases, T3 in 5 cases, and T4 in 6 cases. The LIV was T12 in 1 case, L1 in 12 cases, L2 in 2 cases, and L3 in 10 cases. The average follow-up time was 20.2 ± 8.3 months (ranged from 12–36 months).

Radiographic Measurements and Grouping

Standing posteroanterior radiographs of the whole spine taken preoperatively, immediately after surgery, and at the last follow-up were obtained in all the subjects. The parameters measured included the following: 1) proximal thoracic (PT) Cobb angle; 2) main thoracic (MT) Cobb angle; 3) lumbar Cobb angle; 4) PT side-bending Cobb angle; 5) MT side-bending Cobb angle; 6) lumbar side-bending Cobb angle; 7) lumbar apical vertebral translation (AVT), which is the horizontal distance from the coronal center of the lumbar apical vertebrae to the CSVL; 8) C7 plumb line (C7PL)-CSVL, which is the distance between C7PL and CSVL (the value was positive if the C7PL shifted to the left with respect to CSVL and was negative if the C7PL shifted to the right); and 9) radiographic shoulder height (RSH), which is the difference in the soft tissue shadow directly superior to the acromioclavicular joint.[14,15] The curve flexibility was calculated as (Cobb angle-side bending Cobb angle)/Cobb angle*100%. The RSH was defined as positive when the left shoulder was higher and negative when the right shoulder was higher. All these parameters were measured twice and averaged by the first author (J.J.) using Surgimap software version 2.0 (Surgimap, New York, New York, USA).

Postoperative shoulder imbalance was defined as RSH >2 cm.[8] The change of the parameter immediately after surgery was calculated by "the value immediately after surgery minus the value before surgery," whereas the interval-time change of parameter was calculated by "the value at the last follow-up minus the value immediately after surgery." We defined the postoperative lumbar curve progression as an increase of >5° in the lumbar curve to the left side from immediately after surgery to the last follow-up. According to this definition, all the subjects were divided into a progression group (Group A, n = 8) and non-progression group (Group B, n = 17).

Statistical Analysis

Statistical analysis was performed using SPSS software version 14.0 (SPSS, Chicago, Illinois, USA). These parameters immediately after surgery and at the last follow-up were compared with those before surgery by the paired-sampled t test. Correlation analysis was used to determine the associations between the change of RSH and the changes of other parameters both immediately after surgery and at the last follow-up. After the initial correlation analysis, factors with a value of $P < 0.05$ were entered in a stepwise multiple regression analysis to identify the independent factor. The interval-time changes of the parameters were compared between progression group and non-progression group by an independent t test. A P value <0.05 was considered statistically significant.

RESULTS

Correction Outcomes

The mean flexibility of PT, MT, and lumbar curve were 26.7% ± 10.3%, 47.3% ± 11.5%, and 79.7% ± 13.3%, respectively. The average preoperative Cobb angles of PT, MT, and lumbar curves were 43.1° ± 6.5°, 56.1° ± 9.1°, and 38.0° ± 7.3°, which were corrected to 24.4° ± 5.6° ($P < 0.05$), 20.0° ± 5.7° ($P < 0.05$), and 13.6° ± 3.9° ($P < 0.05$) immediately after surgery with the mean correction rates of 42.1% ± 16.4%, 63.9% ± 11.0%, and 63.6% ± 12.0%, respectively (Table 1). At the last follow-up, the mean Cobb angles of PT, MT, and lumbar curves were 27.0° ± 6.2° ($P < 0.05$), 22.9° ± 5.0° ($P < 0.05$), and 16.4° ± 3.98° ($P < 0.05$) with the mean correction loss of 2.6° ± 3.9°, 2.9° ± 2.8°, and 2.8° ± 3.6°, respectively (Table 1).

The average preoperative lumbar AVT, C7PL-CSVL, and RSH were 15.7 ± 5.2 mm, −9.2 ± 10.6 mm, and −8.5 ± 10.7 mm, which were corrected to 8.5 ± 4.2 mm ($P < 0.05$), −3.6 ± 12.2 mm ($P < 0.05$), and 4.3 ± 8.3 mm ($P < 0.05$) immediately after surgery, respectively (Table 1). There was only 1 patient with postoperative shoulder imbalance. At the last follow-up, the mean lumbar AVT, C7PL-CSVL, and RSH were 10.1 ± 5.1 mm ($P < 0.05$), −2.7 ± 5.9 mm ($P < 0.05$), and 8.7 ± 8.6 mm ($P < 0.05$) with the average changes of 1.6 ± 4.0 mm, 1.3 ± 12.0 mm, and 4.5 ± 9.0 mm, respectively (Table 1). Three patients had residual shoulder imbalance at the last follow-up, but no patient required revision surgery.

Factors Associated with the Change of RSH

Correlation analysis demonstrated that both the change of MT Cobb angle and that of lumbar Cobb angle were negatively correlated with the change of RSH immediately after surgery, whereas both the interval-time change of lumbar Cobb angle and that of lumbar AVT were positively correlated with the interval-time change of RSH from immediately after surgery to the last follow-up ($P < 0.05$, Table 2).

The subsequent stepwise multiple regression analysis revealed that only the change of MT Cobb angle was the independent factor related to the change of RSH immediately after surgery, whereas only the interval-time change of lumbar Cobb angle was the independent factor related to the interval-time change of RSH at the last follow-up.

Differences of Interval-Time Changes of Parameters Between Progression Group and Non-Progression Group

There were 8 cases (8 female patients with an average age of 14.5 ± 2.6 years) in the progression group (Group A), and 17 cases (15

Table 2. Associations Between the Change of RSH and the Changes of Other Parameters

	Preoperative to Postoperative		Postoperative to Follow-Up	
	Correlation Coefficient (r)	*P* Value	Correlation Coefficient (r)	*P* Value
PT curve	−0.001	0.995	0.019	0.297
MT curve	−0.667	<0.001*	−0.113	0.592
Lumbar curve	−0.420	0.036*	0.793	<0.001*
Lumbar AVT	−0.107	0.612	0.644	0.001*
C7PL-CSVL	0.210	0.313	0.266	0.199

PT, proximal thoracic; MT, main thoracic; AVT, apical vertebral translation; C7PL, C7 plumb line; CSVL, central sacral vertical line.
*Association is statistically significant.

Table 3. Differences of Interval-Time Changes of Parameters from Immediately After Surgery to the Last Follow-Up Between Patients with Lumbar Curve Progression (Group A) and without (Group B)

	Group A (n = 8)	Group B (n = 17)
Age (years)	14.5 ± 2.6	13.8 ± 2.0
Lumbar modifier	4B/4C	7B/10C
UIV	T1:1, T2:5, T3:1, T4:1	T1:2, T2:6, T3:4, T4:5
LIV	T12:1, L1:5, L2:2	L1:7, L3:10
Follow-up time (months)	18.3 ± 6.7	21.2 ± 9.0
Change of PT curve (°)	3.9 ± 2.4	2.1 ± 4.4
Change of MT curve (°)	3.6 ± 1.8	2.6 ± 3.2
Change of lumbar curve (°)	6.9 ± 1.9	0.8 ± 2.2*
Change of lumbar AVT (mm)	5.5 ± 1.5	−0.2 ± 3.4*
Change of C7PL-CSVL (mm)	1.5 ± 12.7	1.3 ± 12.4
Change of RSH (mm)	11.9 ± 8.3	1.0 ± 7.1*

UIV, upper instrumented vertebra; LIV, lower instrumented vertebra; PT, proximal thoracic; MT, main thoracic; AVT, apical vertebral translation; C7PL, C7 plumb line; CSVL, central sacral vertical line; RSH, radiographic shoulder height.
*Difference is statistically significant.

female patients and 2 male patients with an average age of 13.8 ± 2.0 years) in the non-progression group (Group B). These 2 groups were equivalent regarding the average age and mean follow-up time ($P > 0.05$, Table 3). In Group A, the UIV was T1 in 1, T2 in 5, T3 in 1, and T4 in 1, whereas the LIV was T12 in 1, L1 in 5, and L2 in 2. In Group B, the UIV was T1 in 2, T2 in 6, T3 in 4, and T4 in 5, whereas the LIV was L1 in 7 and L3 in 10.

No significant differences were observed between these 2 groups with respect to the interval-time changes of the PT Cobb angle, MT Cobb angle, and C7PL-CSVL from immediately after surgery to the last follow-up ($P > 0.05$, Table 3). The interval-time changes of the lumbar Cobb angle, lumbar AVT, and RSH were significantly larger in Group A when compared with Group B ($P < 0.05$, Table 3).

DISCUSSION

Maintaining satisfactory shoulder balance is 1 of the main goals of the surgical treatments in patients with AIS, especially for patients with Lenke type 2 with a structural PT curve.[16-18] The postoperative shoulder imbalance was a crucial factor contributing to the patients' non-satisfactions with correction outcomes, and was thought to be caused by surgeons' failure to properly select the surgical strategy. Spine surgeons should be aware of the risk factors for postoperative shoulder imbalance in patients with Lenke type 2, both immediately after surgery and during the follow-up time. It has been reported that 28% of healthy adolescents had the difference of shoulder height >10 mm and a left-elevated shoulder >2 cm was considered as the cause of the dissatisfaction with the cosmetic appearance.[19,20] Therefore, postoperative shoulder imbalance was defined as RSH >2 cm in our study.

Factors Associated with the Change of RSH Immediately After Surgery

Previously, a structural PT curve was often recommended to be fused in patients with Lenke type 2 AIS because the untreated PT curve had low ability to compensate the correction gained from the MT curve correction, which often resulted in a residual left-elevated shoulder. However, currently, it has been increasingly accepted that whether a structural PT should be fused also depends on the preoperative directionality of shoulder height. Partial or non-fusion of PT curve is advocated if patients with Lenke type 2 AIS have preoperative right-elevated shoulder because the correction of MT curve will elevate the left shoulder, which helps to restore the shoulder balance in these patients.[18] Rose and Lenke[21] also suggested that in Lenke type 2 patients with left higher shoulder required fusion extending to T2, whereas patients with right higher shoulder can be fused only to T3. In our study, all the patients proximally fused to T3 or T4 (n = 11) had preoperative right-elevated shoulder and not 1 had residual shoulder imbalance immediately after surgery, which further confirmed that Lenke type 2 curve did not always necessitate the fusions of both PT and MT curves and preoperative shoulder height should be taken into account when making a surgical decision for these patients.

Besides the UIV, the postoperative behavior of the PT curve was also affected by the degree of MT curve correction. With the application of more powerful instrumentation such as pedicle screw in the surgical treatment of AIS, patients gained better correction of deformity when compared with conventional hook or wire construct.[22] However, it was believed that the overcorrection of the MT curve beyond the flexibility of the PT curve could result in residual shoulder imbalance.[23,24] There was 1 patient experiencing shoulder imbalance immediately after surgery, with the correction rate of the MT curve as high as 77.6% (the average correction rate was 63.9%), although the PT curve had been proximally fused to T2. In theory, the correction of right MT curve will elevate the left shoulder, whereas the correction of left PT

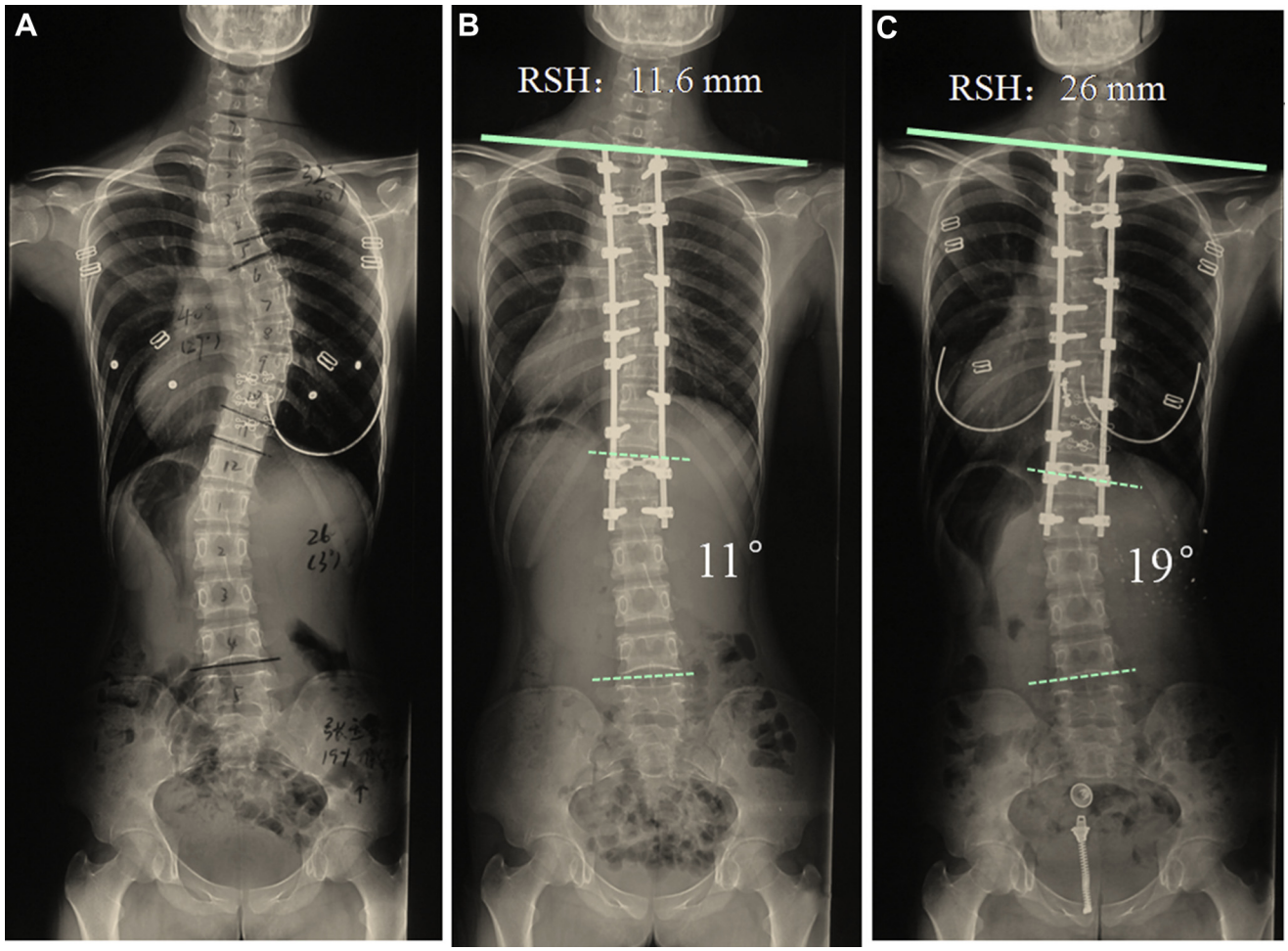

Figure 2. A 16-year-old girl with Lenke type 2B curve (**A**). This patient underwent selective thoracic fusion with the lower instrumented vertebra of L1 and had a left-elevated shoulder after surgery (**B**). This patient had the left shoulder further elevated (radiographic shoulder height increased from 11.6–26 mm) with the occurrence of lumbar curve progression (lumbar Cobb angle increased from 11° to 19°) 1 year after surgery (**C**). RSH, radiographic shoulder height.

curve will elevate the right shoulder during the operation. However, the correlation analysis of our study demonstrated that only the correction of MT curve was related to the change of RSH immediately after surgery, whereas the correction of PT curve was not. The PT curve was often more rigid than the MT curve with lower correction rate in surgery,[23] which was also confirmed by our study (MT curve flexibility vs. PT curve flexibility: 47.3% vs. 26.7%; MT correction rate vs. PT correction rate: 63.9% vs. 42.1%). Therefore, the effect of left-shoulder elevation gained from MT curve correction was much larger than the effect of right-shoulder elevation gained from PT curve correction. This may explain non-association between PT curve correction and shoulder height. Therefore, we highly suggest that the overcorrection of MT curve should be avoided in patients with Lenke 2 type AIS.

Factors Associated with the Change of RSH During the Follow-Up

Recently, the association between the shoulder balance and the distal unfused spinal segments in patients with AIS during the follow-up period had drawn the investigators' great interests. In the patients who underwent STF, the change of shoulder height mainly depended on the mobile lumbar curve considering that the thoracic curve had been fixed. Cao et al.[8] had observed improvement of shoulder imbalance with development of postoperative adding-on phenomenon in patients with Lenke type 2. Significant associations between the RSH and parameters related to distal adding-on were observed in his study.

The phenomenon of distal adding-on was defined as a progressive or extension of the primary curve after STF because of the inadequate selection of LIV, with either the first vertebra below the instrumentation deviated from CSVL or the angle of the first disc below the instrumentation increased.[5,6] Because the primary thoracic curve was on the right-side, the distal adding-on made the thoracic curve further shift to the right, elevating the right shoulder. Therefore, it is not difficult to understand that the residual left-elevated shoulder imbalance can be compensated by the progression of adding-on. It is worth noting that the

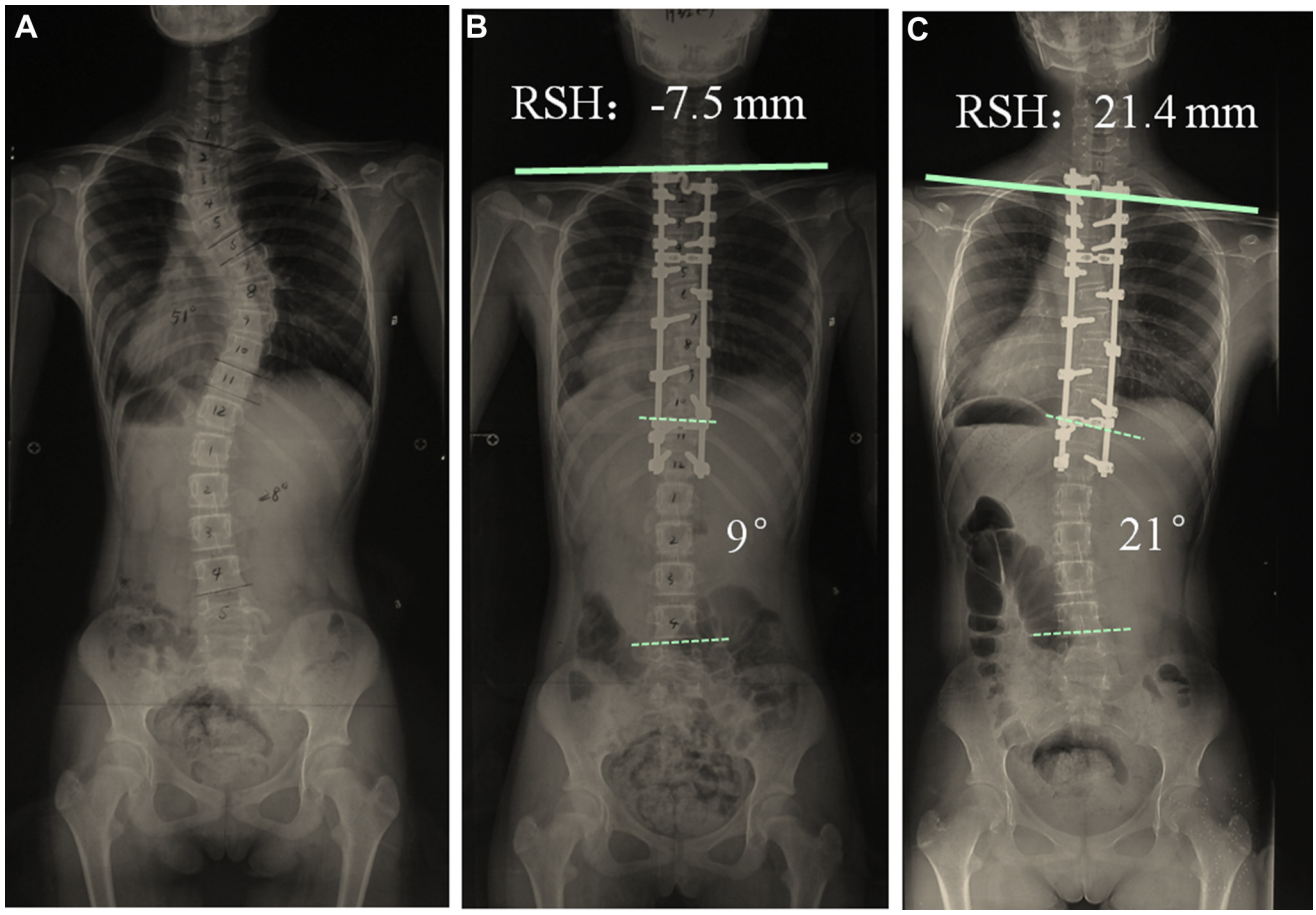

Figure 3. A 14-year-old girl with Lenke type 2B curve (**A**). This patient underwent selective thoracic fusion with the lower instrumented vertebra of T12 and had a mild right-elevated shoulder after surgery (**B**). However, this patient had a significant left-elevated shoulder (radiographic shoulder height increased from −7.5 to 21.4 mm) with the occurrence of lumbar curve progression (lumbar Cobb angle increased from 9° to 21°) 1 year after surgery (**C**). RSH, radiographic shoulder height.

complication of adding-on was almost observed in patients with thoracic scoliosis with lumbar modifier of A. The lumbar spine modifier (A, B, and C) in the Lenke classification was developed to evaluate the severity of lumbar deformity, according to the relationship between the CSVL and lumbar apex.[25] Essentially, patients with a lumbar modifier of A only had a right thoracic curve without a true lumbar curve, which was similar to the King type 3 or 4 curve.[26] The improper choice of LIV will lead to the distal extension of the primary thoracic curve, which is named as "adding-on." However, the patients with a lumbar modifier of B or C had both a right thoracic curve and a left lumbar curve, which corresponded to the King type 2 curve.[26] For these patients, the unfused lumbar curve may further progress in case of either incorrect selection of LIV or improper intraoperative manipulation.[10,11,27] Because the lumbar curve progressed to the left side, the left shoulder would be further elevated, which made the postoperative shoulder imbalance deteriorate during the follow-up time. The results of our study also revealed that the time-interval change of the lumbar curve Cobb angle was the independent factor for the time-interval change RSH at the last follow-up. The patients with postoperative lumbar progression (Group A) had more interval-time changes of RSH than those without (Group B). All these patients in Group A had deteriorated shoulder imbalance with the average elevation of the left shoulder as high as 11.9 ± 8.3 mm during the follow-up time. Two patients with shoulder balance immediately after surgery met the criteria of shoulder imbalance at the last follow-up in Group A (Figures 2 and 3). Therefore, we propose that the postoperative behavior of the lumbar curve should be closely followed-up because the lumbar curve progression could not only bring possible adverse effects on the distal mobile segments but also make the shoulder imbalance worse in the future.

Risk Factors Associated with Lumbar Curve Progression After STF

Until now, the application of STF remained a controversial issue in the surgical treatment of patients with AIS with "non-structural" lumbar curve based on the Lenke classification. Some surgeons on spinal deformity insisted that a flexible non-structural lumbar

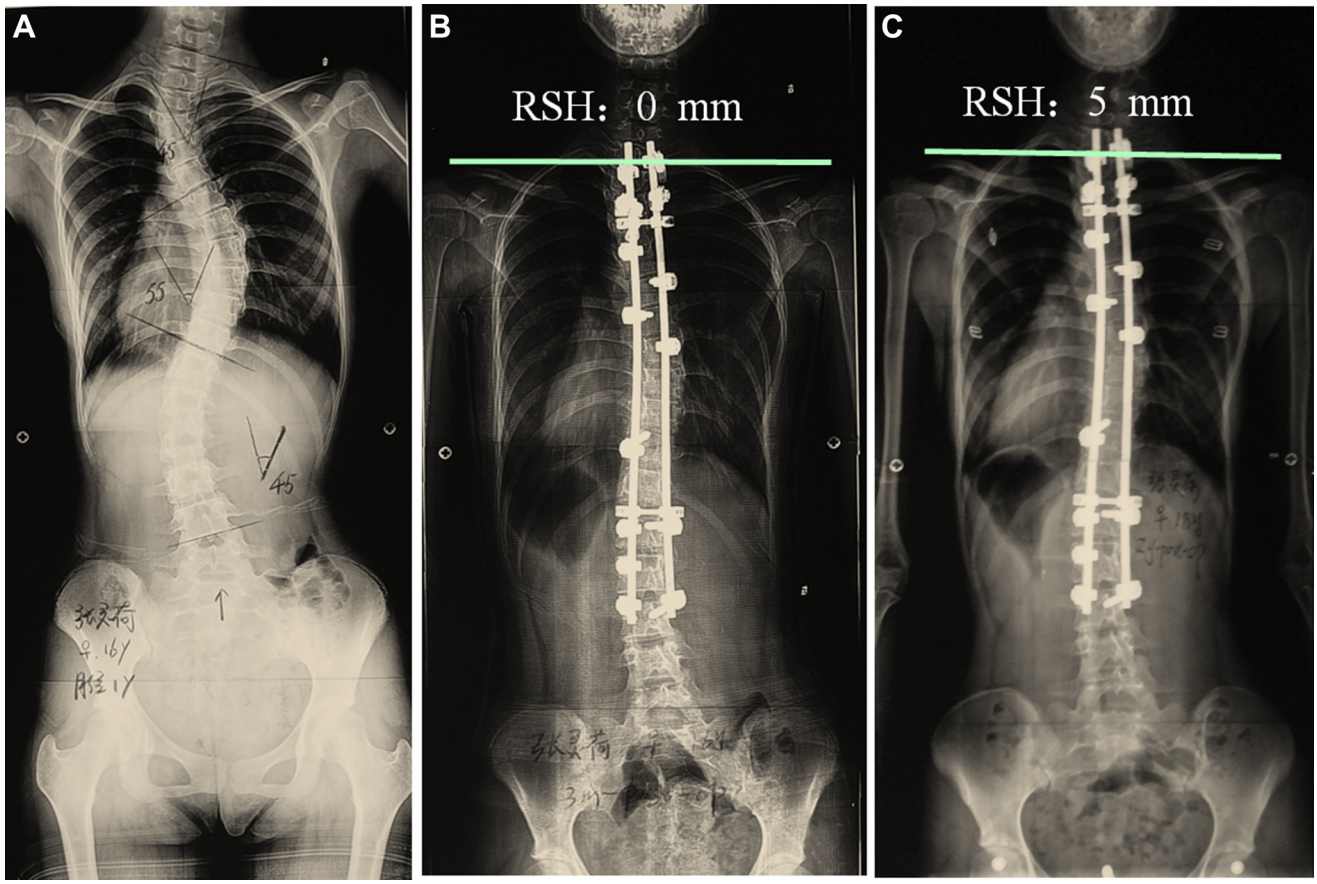

Figure 4. A 16-year-old girl with Lenke type 2C curve (**A**). This patient underwent non-selective thoracic fusion with the lower instrumented vertebra of L3 and had satisfactory shoulder balance after surgery (**B**). At 2-year follow up, the patient had the shoulder balance maintained without obvious progression of distal lumbar curve (**C**).

curve was able to be spontaneously corrected after sole fusion of the thoracic curve. However, others recommended long fusion including both structural thoracic curve and non-structural lumbar curve to decrease the risk of postoperative complications, such as adding-on and lumbar curve progression.[5,6,10,11] Although STF was recommended if the deformity severity of the thoracic curve (AVT, apical vertebral rotation, or Cobb angle) was larger than that of the lumbar curve with a ratio of >1.2,[25,28] no widely-accepted criteria for STF had been reported thus far. However, several risk factors for postoperative complications of unfused lumbar curve had been identified, including relative stiffness of the lumbar curve,[25,29] skeletal immaturity,[30] overcorrection of thoracic curve,[23,24,31] et cetera. Unfortunately, we cannot confirm these views, especially in patients with Lenke type 2B/C, because of the small sample size in our study (only 13 cases distally fused to L1 or above). We noticed that both the proportions of lumbar modifier B and C were very small (B: 8.5% [11/130]; C: 10.8% [14/130]) in patients with Lenke type 2. In the study by Cao et al.,[8] although all the cases were collected from 4 spine centers, there were only 11 (7.7%) cases with modifier B and 15 (10.6%) cases with modifier C among a total of 142 patients with Lenke type 2 with the proportions of modifier B and C similar to our study. We postulated that the opposing deformities of the PT curve and the MT curve might help to balance the trunk, which made a less severe lumbar curve responsible for maintaining the trunk symmetry in patients with Lenke type 2 AIS. Although no risk factor associated with postoperative lumbar curve progression in patients with Lenke type 2B/C who underwent STF had been identified in our study, we noticed that no patient distally fused to L3 (n = 10) had the lumbar curve further progressed with the deterioration of shoulder imbalance at the last follow-up. Non-selective fusion strategy did help to diminish the risk of postoperative lumbar curve progression (Figure 4).

Several limitations should be mentioned in our study. First, this is only a radiographic study without the patient's self-assessment/satisfaction evaluated. Second, this is a mid-term study with the average follow-up time of 20.2 months. The behavior of the unfused lumbar curve in later stage and whether the revision surgery is indicated in these patients need further study with a longer follow-up period to investigate. Third, because of the small

sample size, we cannot subdivide these patients into subgroups to explore other important factors associated with postoperative lumbar curve progression, such as LIV, range of motion of disc below LIV, age, bony maturity, et cetera. A multicenter study involving several large spine research institutions may be helpful.

CONCLUSIONS

To the best of our knowledge, this is the first study reporting the deterioration of shoulder imbalance with the development of postoperative lumbar curve progression in patients with Lenke type 2B/C. The magnitude of lumbar curve progression had been confirmed to be significantly associated with the interval-time change of RSH in these patients. The postoperative behavior of the unfused lumbar segments and its effects on the shoulder height should be closely monitored during the follow-up time. Whether the deteriorated shoulder imbalance can be spontaneously compensated or not in the future needs the further study with longer follow-up time to investigate.

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Conflict of interest statement: This work was supported by the Natural Science Foundation of China (81601867) and the Natural Science Foundation of Jiangsu Province, China (BK20160107).

Received 18 August 2018; accepted 2 January 2019

Citation: World Neurosurg. (2019) 125:e175-e182.
https://doi.org/10.1016/j.wneu.2019.01.032

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