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Original Article

The relationship between variation of preoperative coronal angle in the lumbosacral region and postoperative trunk shift after scoliosis surgery

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Abstract: The objective of this study was to investigate the relationship between the preoperative intervertebral interspace angle and postoperative trunk shift (TS) in patients who have received scoliosis correction. Anteroposterior (AP) whole spine standing radiographs and right and left lateral bending radiographs were taken preoperatively, and AP whole spine standing radiographs were obtained postoperatively and at the final follow-up. TS was measured in the coronal plane, and intervertebral interspace angle change was the sum of the absolute values of L4-S1 intervertebral angle changes in the coronal plane, and was determined before surgery, postoperatively, and at final follow-up. A total of 38 patients with a mean age of 16.42±8.36 years who received posterior scoliosis correction and internal fixation with a mean follow-up of 12.4 months (range, 6 to 25 months) were included. Groups were defined by two methods: bending angle > 10° and ≤ 10°, and postoperative TS < 20 mm and ≥ 20 mm. TS at the final follow-up was significantly greater in the > 10° group than the ≤ 10° group (32.45 vs. 12.44 mm, *P* = 0.001), and was significantly greater in the ≥ 20 mm group compared with the < 20 mm group (38.5 vs. 9 mm, respectively, *P* < 0.001). A median negative correlation were found between TS at the final follow-up and total variance of bending (r = -0.51, *P* = 0.001). Postoperative TS which will not compensate spontaneously can be predicted by measurement of the preoperative intervertebral interspace angle in the lumbosacral region.

Keywords: Intervertebral angle, lumbar curve, scoliosis, thoracic curve, trunk shift

Introduction

Postoperative trunk shift (TS) could occur in patients undergoing surgical correction of scoliosis, and the reported incidence was as high as 10% [1-3]. TS could generally attribute to poor flexibility of the spine or an inappropriate surgical procedure [4-6]. Three factors are considered to be related to the occurrence of postoperative TS: excessive correction of the thoracic curve [7], inappropriate selection of the lowest instrumented vertebra (LIV) [5, 8-10], and a smaller ratio of the major thoracic: thoracolumbar/lumbar (MT: TL/L) curve [6, 11].

Most studies have focused on evaluation of the compensatory capability of the lumbar curve or thoracic curve for determining the flexibility of the spine in patients with scoliosis. Few reports, however, have evaluated the preoperative compensatory capability of the lumbosacral region [12, 13]. Without assessment of the compensatory capability of the lumbosacral spine an appropriate surgical procedure cannot be selected, and the incidence of TS which will not compensate spontaneously may be increased. No study has examined the relationship between TS after scoliosis correction and the preoperative intervertebral lumbosacral angle.

Thus, the purpose of this study was to investigate the relationship between the intervertebral interspace angle change and postoperative TS in patients who have received surgical correction of scoliosis. Our hypothesis was that if the sum of the intervertebral interspace angle change is < 10° on preoperative lateral bending lumbosacral spine radiography in scoliosis patients undergoing surgery, there will likely be

Table 1. Patient characteristics

	Total (N = 38)
Gender	
Female	30 (78.95)
Male	8 (21.05)
Age (y)	16.42±8.36
Follow-up time (mo)	12.45±5.5
Type of scoliosis	
Idiopathic	14 (36.84)
Congenital	17 (44.74)
Adult*	5 (13.16)
Other#	2 (5.26)

Data are presented as mean ± standard deviation or number (percentage). *Characteristics of fusion segments and follow-up time of the five adult patients are as follow: T10-L5 with follow-up of 28 months; T5-L5 with follow-up of 36 months; T1-L5 with follow-up of 50 months; T9-L5 with follow-up of 12 months; and T11-L5 with follow-up of 24 months, respectively. #There are included one case of neuromuscular and one rare type. Both are close to congenital scoliosis but not typical congenital scoliosis.

insufficient compensation and postoperative TS will not likely correct itself.

Methods

We retrospectively reviewed the records of patients who underwent posterior scoliosis correction and internal fixation at our institution between January 2012 and January 2015. Patients were included in the analysis if the postoperative coronal TS was ≥ 20 mm immediately after posterior scoliosis correction and complete follow-up data was available. Patients who had undergone an osteotomy were not included to exclude the impact of differences in the extent and method of osteotomy on postoperative spinal deviation. Patients of all ages and both genders were considered for inclusion. This study was approved by the ethics committee of Honghui Hospital, Xi'an Jiaotong University.

Standing anteroposterior (AP), lateral, and bending radiographs of the full spine were obtained preoperatively and standing AP and lateral radiographs of the full spine were obtained postoperatively and at final follow-up. The coronal Cobb angle, flexibility of the curves, correction rate, apical vertebral rotation (AVR), apical vertebral translation (AVT), and coronal balance (CB) were determined. Vertebra rotation was determined according to Nash-Moe method [14] as follows: 0 rotation, no asymmetry of either the position or shape of either pedicle; 1+ rotation, medial migration of the convex pedicle limited to the most convex segment selected, and there was slight flattening of the oval of both pedicles with the concave border of the concave pedicle starting to disappear; 2+ rotation, further migration of the convex pedicle into the second convex vertebral segment while the concave pedicle gradually became indistinct; 3+ rotation, the convex pedicle reached the mid-line and was completely contained by the third segment; 4+ rotation, the convex pedicle passed through the mid-line into the fourth segment on the concave side of the body.

AVT was defined according to the definition of the Scoliosis Research Society as the perpendicular distance in millimeters from the midpoint of the apex to the plumb line drawn from the spinous process of C7 for the thoracic curve, or to the central sacral vertical line (CSVL) for the lumbar curve on standing AP films, and the coronal balance was defined as the horizontal distance of the midpoint of the C7 from CSVL on standing AP films [15].

The lowest instrumented vertebra (LIV) was defined as the most cephalad vertebrae touched by central sacrum vertical line with grade I or less rotation on the standing AP radiograph, and two-thirds of its vertebral body falls within the Harrington stable zone, and there was no kyphosis. TS was defined as the vertical distance from the midpoint of the sacrum to the C7 plumb line [11, 16-18] and TS ≥ 20 mm or < 20 mm in the coronal plane was recorded.

The intervertebral interspace angles on preoperative, postoperative, and final follow-up radiographs were also recorded. If the angle was opened toward the convex side of the scoliosis, it was assigned it as "+", otherwise it was assigned a "-" [19]. The intervertebral interspace angle change was defined as the sum of the absolute values of the L4-S1 intervertebral angle changes in the coronal plane on lateral-bending radiographs of the lumbosacral region [19].

Statistical analysis

Continuous variables were presented as mean and standard deviation (SD), and the indepen-

Table 2. Characteristic of trunk shift and bending by group

	Total (N = 38)	Grouping by Preoperative Intervertebral Bending Angle				Grouping by final follow-up TS			
		> 10° (n = 20)	≤ 10° (n = 18)	Difference {(> 10°)-(≤ 10°)}	*P*-value	< 20 mm (n = 20)	≥ 20 mm (n = 18)	Difference {(< 20 mm)-(≥ 20 mm)}	*P*-value
TS before surgery (mm)	25±21.58	27.95±27.58	21.72±11.89	6.23	0.382	27±24.54	22.78±18.17	4.22	0.554
TS after surgery (mm)	37.97±13.89	37.4±10.99	38.61±16.85	-1.21	0.793	38.9±16.03	36.94±11.42	1.96	0.671
TS at final follow-up (mm)	22.97±19.04	32.45±20.03	12.44±10.86	20.01	0.001*	9±4.12	38.5±16.9	-29.50	< 0.001*
L-bending L4-L5 (°)	3.55±5.54	2.05±5.74	5.22±4.95	-3.17	0.078	5.75±4.38	1.11±5.79	4.64	0.008*
R-bending L4-L5 (°)	-1.08±6.12	-0.55±5.28	-1.67±7.05	1.12	0.581	-0.55±6.48	-1.67±5.82	1.12	0.581
L-bending L5-S1 (°)	5±7.16	2.4±7.48	7.89±5.69	-5.49	0.016*	7.8±5.61	1.89±7.55	5.91	0.009*
R-bending L5-S1 (°)	1.37±7.96	0.1±6.45	2.78±9.35	-2.68	0.307	3.4±8.6	-0.89±6.71	4.29	0.098
Bending L4-L5 change (°)	5.58±4.11	2.6±1.54	8.89±3.48	-6.29	< 0.001*	8.1±4.06	2.78±1.59	5.32	< 0.001*
Bending L5-S1 change (°)	4.74±3.17	2.7±1.81	7±2.81	-4.30	< 0.001*	6.1±3.26	3.22±2.32	2.88	0.004*
Bending (total change) (°)	10.32±6.11	5.3±2.43	15.89±3.5	-10.59	< 0.001*	14.2±5.43	6±3.29	8.20	< 0.001*

Data are presented as mean ± standard deviation or number (percentage). TS, trunk shift; L, left; R, right.

Table 3. Comparisons of thoracic curve and lumbar curve

	Before Surgery	After Surgery	Last Follow-up	*P*-value Time Effect	*P*-value Group Effect
Bending angle					
Thoracic curve					0.187
> 10° group	47.80±36.05	23.10±25.55*	26.05±25.88*	< 0.001	
≤ 10° group	32.44±28.83	13.56±12.91*	20.44±13.81†	< 0.001	
Lumbar curve					0.979
> 10° group	54.15±22.56	16.55±13.11*	19.70±14.77*	< 0.001	
≤ 10° group	58.50±16.65	14.50±12.00*	17.06±12.66*,†	< 0.001	
Trunk Shift					
Thoracic curve					0.151
< 20 mm group	32.75±30.65	13.65±11.91*	20.4±10.95†	< 0.001	
≥ 20 mm group	49.17±34.85	24.06±26.99*	26.72±28.3*	< 0.001	
Lumbar curve					0.363
< 20 mm group	55.00±15.23	12.90±11.17*	16.65±11.99*	< 0.001	
≥ 20 mm group	57.56±24.37	18.56±13.46*	20.44±15.47*	< 0.001	

*$P < 0.05$ compared with before surgery. †$P < 0.05$ compared with after surgery.

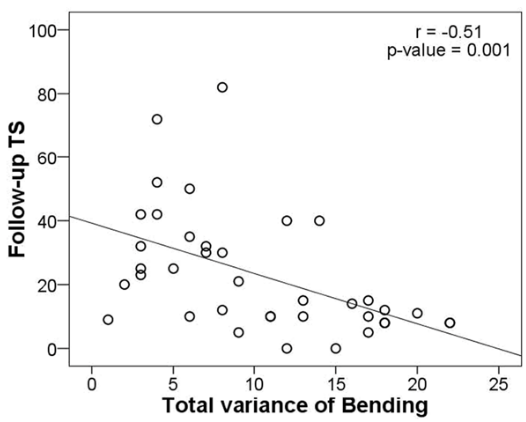

Figure 1. Correlation between trunk shift (TS) at last follow-up and total variance of bending. R represents Pearson correlation coefficient.

dent t-test was applied to compare data between two groups. Categorical variables were presented as count and percentage, and the chi-square test or Fisher's exact test was applied to compare data between two groups, as appropriate. Two-way mixed design ANOVA was performed to compare differences among different times (time effect) and groups (group effect) in the degree of thoracic curve and lumbar curve, together with Bonferroni post-hoc tests.

Groups were defined by two methods: preoperative bending angle > 10° and ≤ 10°, and TS < 20 mm and ≥ 20 mm in the coronal view at final follow-up. The Pearson correlation coefficient was used to detect the correlation between TS at final follow-up and the total variance of bending, and results presented as a scatter plot. All statistical analyses were performed with SPSS 17.0 statistics software (SPSS Inc., Chicago, IL). A two-sided value of $P < 0.05$ was considered to indicate statistical significance.

Results

Among 1,272 patients who underwent posterior scoliosis correction and internal fixation between January 2012 and January 2015, 38 patients met the inclusion criteria and were included in the analysis. In these 38 patients, five were adults and the mean follow-up was 12.4 months (range, 6 to 25 months). Patient characteristics are shown in **Table 1**.

TS data are summarized in **Table 2**. The mean TS before surgery was 25±21.58 mm, postoperatively was 37.97±13.89 mm, and at final follow-up was 22.97±19.04 mm. When patients were classified by TS at the final follow-up (< 20 mm vs. ≥ 20 mm), the L-bending L4-L5 angle, L-bending L5-S1 angle, bending L4-L5 change, bending L5-S1 change, and bending total change were all significantly higher in the < 20 mm group than in the ≥ 20 mm (all, $P < 0.05$).

The total bending change difference between the < 20 mm vs. ≥ 20 mm groups (bending

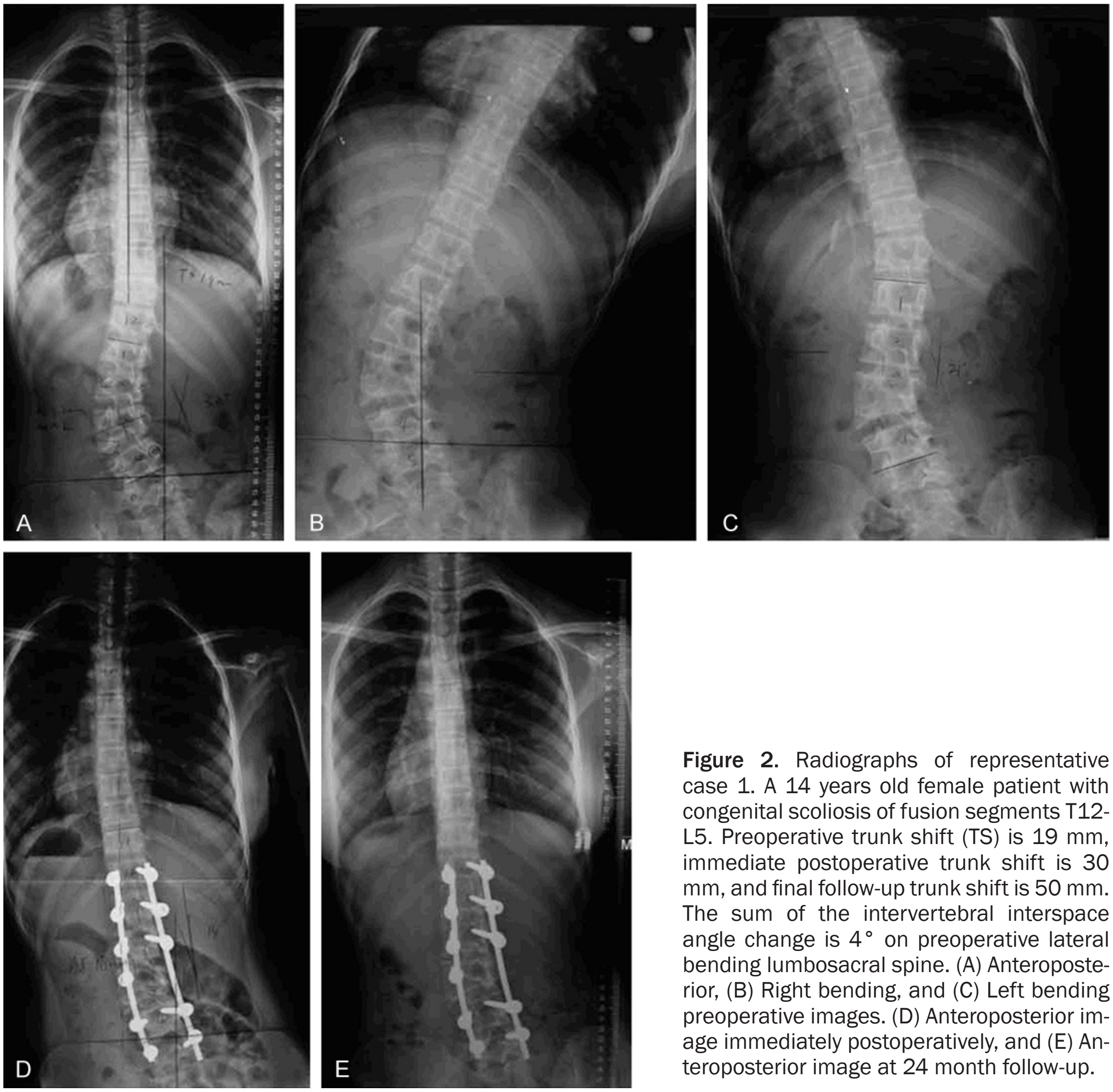

Figure 2. Radiographs of representative case 1. A 14 years old female patient with congenital scoliosis of fusion segments T12-L5. Preoperative trunk shift (TS) is 19 mm, immediate postoperative trunk shift is 30 mm, and final follow-up trunk shift is 50 mm. The sum of the intervertebral interspace angle change is 4° on preoperative lateral bending lumbosacral spine. (A) Anteroposterior, (B) Right bending, and (C) Left bending preoperative images. (D) Anteroposterior image immediately postoperatively, and (E) Anteroposterior image at 24 month follow-up.

change of < 20 mm minus bending change of ≥ 20 mm) was 8.20°. Thus, we divided patients into two groups: patients with > 10° of total bending change and ≤ 10° of total bending change. TS at the final follow-up was significantly greater in the > 10° group than the ≤ 10° group (32.45 vs. 12.44 mm, $P = 0.001$). Additionally, the L-bending L5-S1 angle, bending L4-L5 change, bending L5-S1 change, and bending total change were significantly higher in the ≤ 10° group than in the > 10° group (all, $P < 0.05$).

Comparisons of thoracic and lumbar curves at different times are presented in **Table 3**. There were no significant differences between the bending angle > 10° vs. ≤ 10° groups in thoracic or lumber curves (group effect $P = 0.187$ and 0.979, respectively). In addition, there were no significant differences between the TS < 20 mm vs. ≥ 20 mm groups at final follow-up in thoracic or lumber curve before surgery (group effect $P = 0.151$ and 0.363, respectively).

A median negative correlation was found between the last follow-up TS and the total variance of bending (r = -0.51, $P = 0.001$; **Figure 1**). Representative pre- and postoperative radiographs of cases in which the sum of the absolute values of the lumbosacral curve intervertebral angle changes in the coronal plane were < 10° suggesting insufficient flexibility of the lumbosacral curve and poor self-compensation ability are shown in **Figures 2** and **3**.

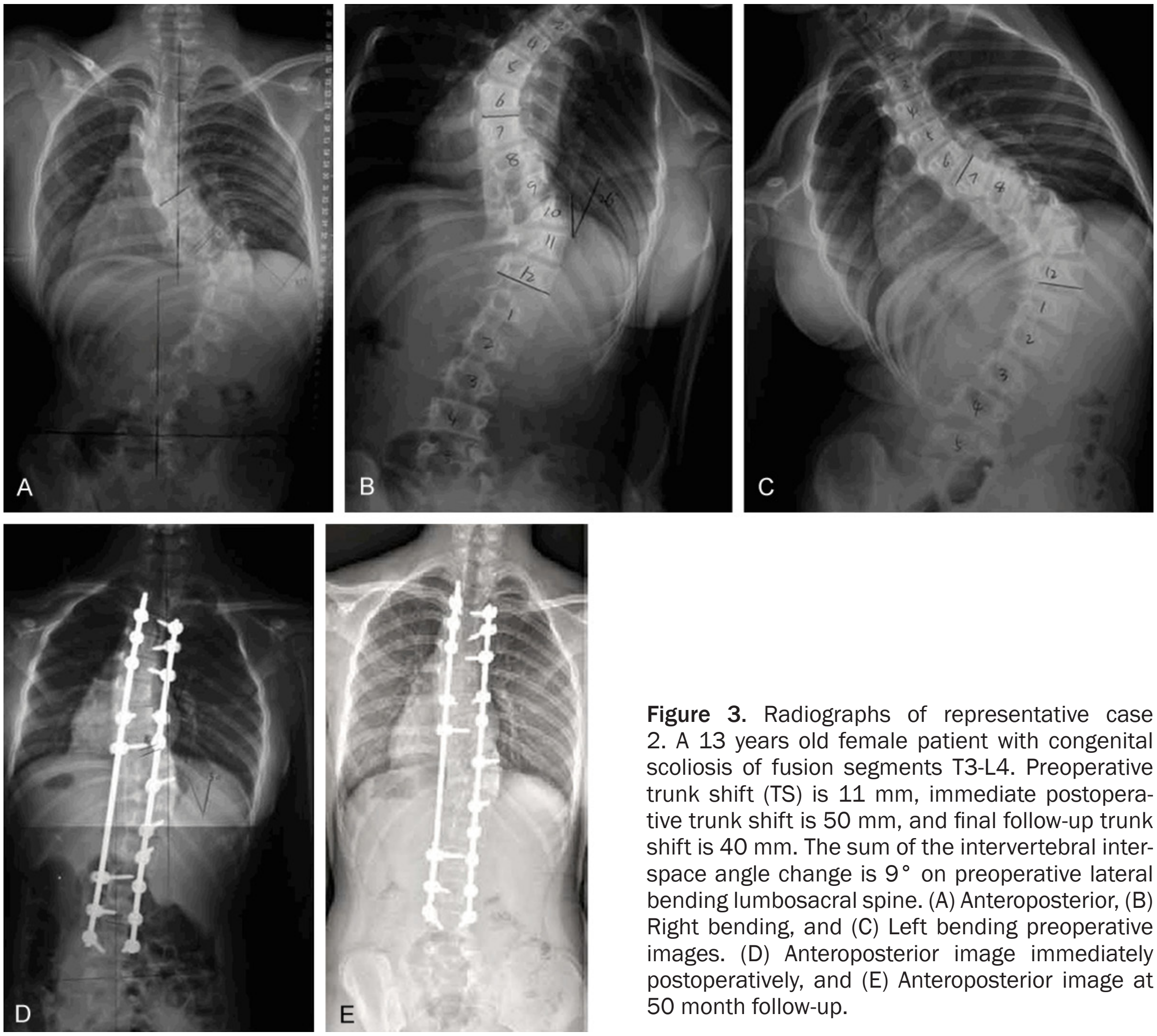

Figure 3. Radiographs of representative case 2. A 13 years old female patient with congenital scoliosis of fusion segments T3-L4. Preoperative trunk shift (TS) is 11 mm, immediate postoperative trunk shift is 50 mm, and final follow-up trunk shift is 40 mm. The sum of the intervertebral interspace angle change is 9° on preoperative lateral bending lumbosacral spine. (A) Anteroposterior, (B) Right bending, and (C) Left bending preoperative images. (D) Anteroposterior image immediately postoperatively, and (E) Anteroposterior image at 50 month follow-up.

The two methods of categorizing patients (bending angle and TS) were compared with respect to *P*-values; a smaller *P*-value indicates a better method. The *P*-value of the bending angle > 10° vs. ≤ 10° method was 0.0005 and that of the TS < 20 mm vs. ≥ 20 mm after surgery method was < 0.0001. Thus, the bending angle method is not inferior to the TS method of predicting TS at final follow-up.

Discussion

The results of this study suggest that the preoperative lumbosacral intervertebral bending angle can predict postoperative coronal compensation and Cobb angle. If sum of preoperative coronal angle changes in the lumbosacral region are > 10°, the deviation occurring immediately after surgery may self-correct during follow-up; if the preoperative coronal angle changes in the lumbosacral region value is < 10°, which suggests insufficient flexibility of the lumbosacral curve and poor self-compensation, TS occurring immediately after surgery is not likely to correct by itself.

Trobisch et al. [3] retrospectively studied 1,555 patients with adolescent idiopathic scoliosis AIS with Lenke type 1 or 2 curves who received surgery, and 273 had a postoperative TS > 20 mm, and under correction of the lumbar curve was found to be a potential risk factor, whereas thoracic correction, coronal balance, and angulation and translation of the lowest instrumented vertebra LIV were not related to postoperative TS. Wang et al. [1] studied postoperative TS in patients with Lenke 1C scoliosis treated with selective thoracic fusion using posterior pedicle screw-only constructs with the LIV ending at the L1 level or above, and found that LIV and the ratio of MT: TI/L curve were highly correlated with postoperative TS, whereas the amount of surgical correction was not an independent causative factor.

Preoperative thoracic or lumbar curve flexibility has been reported to be predictive of scoliosis correction outcomes [4, 20]. The results of this study suggest that the intervertebral interspace angle change in the lumbosacral region on lateral bending radiographs can be used as an indicator of lumbosacral flexibility and the compensatory capability of the spine. The intervertebral angle is the angle between the inferior endplate of the upper vertebra and the superior endplate of the adjacent lower vertebra, and is also known as disc wedging or intervertebral angulation. Zhao et al. [2] studied 64 AIS patients who underwent posterior pedicle screw-only instrumentation, and found that at 2-years postoperatively disc wedging, LIV tilt, and LIV translation occurred most often when disc wedging and LIV deviation or obliquity existed immediately postoperatively. Zhao et al. [21] also showed that the intervertebral angle gradually increases during follow-up in patients with AIS after surgical correction, and that fusion level, preoperative apical vertebra translocation, and the preoperative intervertebral angle may be correlated with changes of the postoperative intervertebral angle.

In the current study the lumbosacral intervertebral angle obtained from lateral bending radiographs in most patients with self-compensation of TS was > 10°, while it was ≤ 10° in patients without self-compensation. These results suggest that if the intervertebral interspace angle change in right and left lateral-bending radiographs is ≤ 10° before surgery, the compensatory capability of the lumbosacral region is insufficient. In addition, the major curve was to the left in 15 patients with self-compensation, while the major curve was to the right in 11 cases without self-compensation. This suggests that non-compensatory TS easily occurs in patients with a right-sided main curve if the compensatory capability is insufficient before surgery (intervertebral interspace angle change is ≤ 10°).

Self-compensation of TS only occurred in the > 10° group, and the lumbar and thoracic curve angles exhibited a statistically significant loss in the > 10° group, while the thoracic curve change was greater. However, no significant loss of the thoracic or lumbar curve angle was observed at the last follow-up in the ≤ 10° group. These data indicate that in the > 10° group compensation not only occurred in the lumbosacral spine, but also in the thoracic curve, which further aggravated the deformity resulting in TS. During surgical correction we applied intraoperative vertebral body derotation and segmental correction with compressive fixation. As a result, TS that could not be compensated for spontaneously occurred after surgery. Thus, maintaining coronal balance, while difficult, is very important during the scoliosis surgery.

The compensatory capability of the lumbosacral spine was poor in the ≤ 10° group. During surgical correction we applied intraoperative vertebral body derotation and segmental correction with compressive fixation. As a result, TS that could not be compensated for spontaneously occurred after surgery. Thus, maintaining coronal balance, while difficult, is very important during the scoliosis surgery. We suggest that an osteotomy can be applied in cases of a rigid lumbosacral spine to treat the "base" of the spine as much as possible. Commonly used methods of for spinal osteotomy include Smith-Peterson osteotomy (SPO), pedicle wedge osteotomy (PSO), and vertebral column resection (VCR) [22]. The SPO technique can enhance spinal flexibility by removing posterior column structures including the facet joint, and is suitable for correcting rigid oblong kyphoscoliosis. The PSO technique is considered a closing wedge osteotomy, and can avoid buckling and wrinkling of the spinal cord caused by excessive shortening of the posterior column. VCR can correct the deformities in the coronal and the sagittal planes, and allows complete removal of rigid lumbosacral vertebrae to obtain a satisfactory trunk balance. Since the lumbosacral spine is relatively rigid and the compensatory capability is poor in patients in which TS does not correct spontaneously, PSO and VCR are the most appropriate procedures. However, osteotomy of a rigid lumbosacral spine is more complicated as compared to osteotomy of the thoracic spine or the upper lumbar spine, and is associated with a relatively high incidence of complications and relatively low functional satisfaction [22].

Several limitations of this study need to be mentioned. This is a retrospective study with a relatively small number of patients and a short follow-up period. We did not evaluate the number of free lumbar vertebrae which may have an influence on TS, and the influences in the sagittal and horizontal planes were not studied. Details of the pelvis, lifted on the same side as the concavity of the lumbar curve or lifted on the convex side of the lumbar curve, as were as the levels of instrumentation and fusion were not examined. Patients with congenital and idiopathic scoliosis, as well as adolescent and adult scoliosis were included in the analysis. However, the inclusion criterion for all patients was the same, all underwent simple correction without osteotomy, and the standard of selecting the range of fusion was the same for all patients.

In summary, postoperative TS which will not compensate spontaneously in scoliosis patients undergoing posterior fixation can be predicted by measurement of the preoperative intervertebral interspace angle in the lumbosacral region. Knowing when TS will not compensate spontaneously can aid in the appropriate choice of surgical procedure.

Acknowledgements

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Disclosure of conflict of interest

None.

Abbreviations

AIS, adolescent idiopathic scoliosis; FB, fulcrum bending; L4-5 and L5-S1, lumbosacral region; LAV, lumbar apical vertebra; LIV, lowest instrumented vertebra; MT, major thoracic; TL/L curve, thoracolumbar/lumbar curve; PSO, pedicle wedge osteotomy; SPO, Smith-Peterson osteotomy; TS, trunk shift; VCR, vertebral column resection.

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