


RESEARCH ARTICLE

Factors Related to Preoperative Coronal Malalignment in Degenerative Lumbar Scoliosis: An Analysis on Coronal Parameters

Zifang Zhang, PhD, MD^{1,2†} , Tao Liu, MM^{3†}, Yan Wang, MD, PhD^{2‡}, Zheng Wang, MD^{2‡}, Guoquan Zheng, MD²

¹The Spinal Surgery Department of the Affiliated Hospital of Jining Medical University and ³The Department of Orthopaedics, Yanzhou Branch of Affiliated Hospital of Jining Medical University, Jining and ²The Department of Orthopaedics, The First Medical Center of the Chinese PLA General Hospital, Beijing, China

Objectives: Recently the effects of coronal malalignment (CM) in degenerative lumbar scoliosis (DLS) have been reported, however, there was few studies on the correlated parameters of coronal alignments at pre-operation. The aims of this current study were to investigate the associations of coronal parameters with scoliosis and coronal alignment, and to explore the relationships between the coronal pelvic tilt and coronal alignment in DLS.

Methods: One hundred and sixty-one DLS patients in our hospital from May 2016 to December 2020 were reviewed and documented. The coronal balance distance (CBD, the offset between the center of C7 and the plumb line drawn from the center of S1), major Cobb (MC), fractional Cobb (FC), L4 coronal tilt, L5 coronal tilt, coronal pelvic tilt, apical rotation, and the vertebrae in major curve were measured and documented. CM was considered if the CBD \geq 30mm. All of those participants were assigned into group A (CBD \geq 30 mm) and group B (CBD < 30 mm). Comparisons of demographic and radiographic data were performed between groups A and B. Pearson correlation and further multiple regression with stepwise method analysis were used to investigate those coronal parameters correlated to MC and CBD, respectively.

Results: Thirty-one patients suffering from CM were assigned into group A, and the rest of 130 patients were assigned to group B accordingly. Then the incidence of CM was about 19.3% (31/161). Patients in group A had less vertebrae in the main curve ($P = 0.009$), however, the apical rotation ($P < 0.001$) and the L4 coronal tilt ($P = 0.007$) were much larger. Although the MC ($P = 0.426$) and FC ($P = 0.06$) had no difference between the two groups, the match between MC and FC was much smaller ($p = 0.021$) in group A. The coronal pelvic tilt correlated significantly with FC ($r = 0.552$, $p < 0.001$), but mildly with MC ($r = -0.366$, $p < 0.001$), L4 coronal tilt ($r = 0.348$, $p < 0.001$), and L5 coronal tilt ($r = 0.351$, $p < 0.001$), respectively. The CBD correlated strongly with L4 coronal tilt ($r = -0.471$, $p < 0.001$) and L5 coronal tilt ($r = -0.468$, $p < 0.001$), respectively, but mildly with FC ($r = -0.255$, $p = 0.016$). Further multiple regression analysis revealed that only L4 coronal tilt was the independent factor for MC ($r^2 = 0.549$, $p < 0.001$) and CBD ($r^2 = 0.221$, $p < 0.001$), respectively.

Conclusions: The prevalence of CM in DLS patients is about 19% at pre-operation. With similar major Cobb, the less the vertebrae in the major curve, the larger the CBD. L4 coronal tilt may correlate significantly to scoliosis and CBD. Coronal pelvic tilt may be just one of the compensations for the scoliosis deformity but effects CBD directly.

Key words: Coronal balance distance; Coronal malalignment; Coronal pelvic tilt; Degenerative lumbar scoliosis

Address for correspondence Guoquan Zheng, MD, PhD, The Department of Orthopaedics The First Medical Center of the Chinese PLA General Hospital Beijing, China. Email: zgq301spine2021@163.com

[†]Zifang Zhang and Tao Liu contributed equally to this manuscript.

[‡]Professor Zheng Wang and Yan Wang are the co-corresponding authors for this paper.

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Introduction

It is well-known that sagittal imbalance has undermined the quality of life (QoL) significantly in patients with degenerative lumbar scoliosis (DLS), however, there is no consistent conclusion about the effects of coronal malalignment (CM) that had on the QoL in those patients¹⁻³. CM may cause severe gait disturbance, less satisfaction, and low back pain^{4,5}. According to the spinal surgeon's experience, patients with adult scoliosis would have the severe reduction in QoL even with moderate grades of CM, which may be more serious in those coinciding with sagittal imbalance.

CM reflects the lateral deviation of the trunk over the pelvis and can be represented by the C7 plumb line (C7PL), with the offset from the midline of the pelvis, namely coronal balance distance (CBD), considered to be over 30 mm in patients with DLS^{1,6}. Recently, there have been studies illustrating CM may undermine the QoL significantly in DLS patients^{7,8}. CM in patients suffering from scoliosis would lead to pelvic obliquity, with subsequent gait disturbances^{4,5}. Haber *et al.*⁹ illustrated that patients with spinal scoliosis had to slow down and lengthen the stride time during walking.

The incidence of CM was over 30% both at pre- and post-operation for DLS patients in the study performed by Bao *et al.*¹ Zhang *et al.*¹⁰ reported the similar prevalence of CM, which was 19.3% and 31.34% at pre- and post-operation, respectively. Several risk factors have been identified for immediate CM postoperatively. Lewis *et al.*¹¹ insisted that L4 and L5 coronal tilt correction preoperatively correlated significantly to CM showing postoperatively in adult spinal deformity. Zhang *et al.*¹⁰ demonstrated that major curve correction perioperatively correlated strongly with the CBD postoperatively. Bao *et al.*¹ insisted that DLS patients with type C coronal alignment would be vulnerable to CM developing postoperatively. Moreover, Zhang *et al.*¹² demonstrated that patients even suffering from the consistency type coronal alignments, C7PL shifting to the convex side of scoliosis, may be at the risk for CM developing after surgery.

In order to deal with the coronal disorders effectively, kinds of coronal classifications in adult scoliosis have been proposed in recent years. According to CBD and lateral deviation of C7PL relative to the structural curves, Bao *et al.*¹ described the coronal classification in DLS, which involved few surgical strategies. Obeid *et al.*¹³ proposed a new classification as the surgical guideline for CM in adult spinal deformity. They described various surgical strategies for those patients with different coronal spine alignments in detail. Moreover, Hayashi *et al.*¹⁴ demonstrated that the Obeid-coronal malalignment classification may allow better surgical decision making for CM.

However, there were few studies focusing on investigating the characteristics of coronal spinal alignment preoperatively, which may be essential for the coronal realignment in correction surgery. Pelvis sagittal orientation may play a key role in keeping full-spine sagittal balance in sitting and standing positions^{15,16}. It was reported that coronal pelvic tilt

may lead to scoliosis increasing¹⁷, however, the relationships between the pelvic obliquity and the CBD preoperatively remain unclear as well.

We performed this retrospective observational study aiming to (i) explore the associations of coronal parameters with CM, and (ii) to determine the associations of the coronal pelvic tilt with CBD in DLS patients at pre-operation.

Methods

Patients

This current research was approved by the Ethics Committee of our hospital (No. 20190602113). A consecutive population of DLS patients in our single institution from May 2016 to December 2020 were enrolled.

The inclusion criteria included: (i) patients with DLS (age >45 years); (ii) major Cobb angle $\geq 20^\circ$; (iii) the related data were integrated.

The exclusion criteria were DLS patients who had: (i) prior spine surgeries; (ii) no structural curve (major Cobb angle <20°); (iii) spinal neoplasms; (iv) spinal tuberculosis; (v) ankylosing spondylitis; (vi) spinal or pelvic trauma; (vii) and/or the discrepancy in lower extremities over 2 cm.

Radiographic Evaluation

All patients in our current study were performed full-length radiographs with digital radiography equipment (Mode: Revolution XR/d; GE©, USA) in free-standing position, in which those patients rest their upper extremities on a support and flex the shoulders at 30° forward and the elbows slightly¹⁸. All of the radiographic parameters were measured with the spine software (Surgimap version: 2.3.2.1; New York, NY, USA), which was recognized as being accurate and reliable¹⁹.

Eight parameters measured on posteroanterior radiographs were as follows:

1. Major Cobb angle (MC): the Cobb angle between the superior endplate of the cranial end vertebra and the inferior endplate of the caudal end vertebra (left curve was recorded as negative [-], and right curve as positive [+]).
2. Fractional Cobb angle (FC): the Cobb angle between the superior endplate of L4 and the superior endplate of S1 (left curve was recorded as negative [-], and right fractional curve as positive [+]).
3. Coronal balance distance (CBD): the horizontal distance between the C7PL and the midline of the S1 on coronal plane, the left deviation of C7PL was recorded as negative (-), the right being as positive (+).
4. L4 coronal tilt: the angle formed by the superior endplate of L4 and the horizontal line (left tilt was recorded as negative [-], right side as positive [+]).
5. L5 coronal tilt: the angle formed by superior endplate of L5 and the horizontal line (left side was recorded as negative [-], right side as positive [+]).
6. Vertebrae in the major curve.

7. Coronal pelvic tilt (CPT): the angle between the line formed by iliac crests and the horizontal line (left side was recorded as negative [-], right side as positive [+]).
8. Apex rotation was measured with the Nash–Moe method (left side was recorded as negative [-], right side as positive [+]).

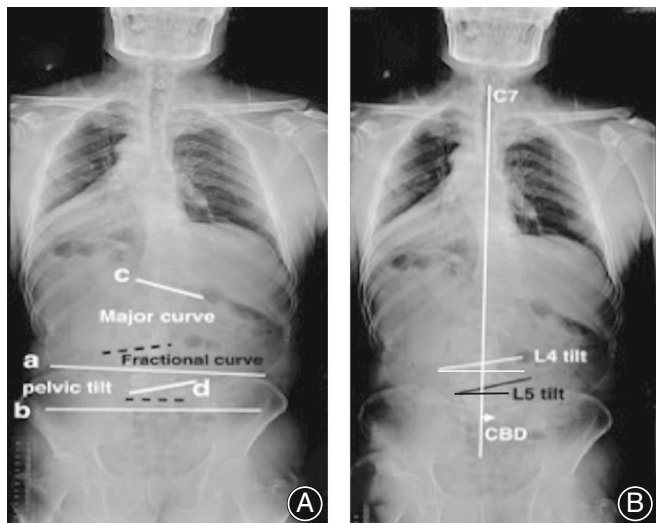


Fig. 1 Schematic diagram showed the measurement of each parameter including the major curve, coronal pelvic tilt, fractional curve (A); coronal balance distance (CBD), L4 coronal tilt, and L5 coronal tilt (B)

The details were shown in the Figure 1 A-B and Figure 2. The match between the major curve and the fractional curve was calculated by the equation as follows:

$$\text{Match} = \text{MC}/\text{FC}$$

Statistical Analysis

All of those measurements were performed by two independent spinal surgeons. The reliabilities of those measurements between the intra- and inter-observers were recorded. A total of 161 patients were assigned into groups A (CBD ≥ 30 mm) and group B (CBD < 30mm). Comparisons of demographic and radiographic data between groups A and group B were performed with either the independent-sample *t* test in those normal distributed variables or the Mann–Whitney *U* test in the abnormal distributed variables.

TABLE 1 The results of inter- and intra-observer reliability for each parameter		
Parameters	Inter-observer	Intra-observer
Major cobb (°)	0.918	0.938
Apical rotation (°)	0.908	0.913
Fractional cobb (°)	0.896	0.926
CBD (mm)	0.903	0.920
L4 tilt (°)	0.917	0.936
L5 tilt (°)	0.921	0.915
CPT (°)	0.889	0.909

Note: CBD, coronal balance distance; CPT, coronal pelvic tilt

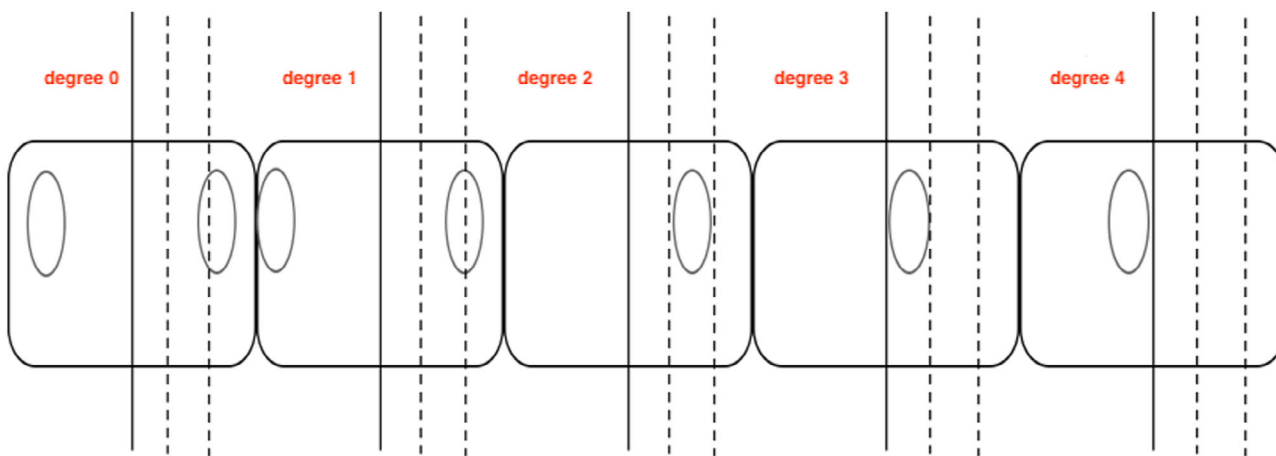


Fig. 2 Nash–Moe method categorizes vertebral rotation into five degrees. According to this method, the vertebra is first bisected longitudinally and then each half is further divided into three equal portions. No significant vertebral rotation exists when the distance from the vertebral pedicle shadow to the bilateral edges of the vertebral body is equal, indicating that the Nash–Moe grade is 0. There is significant vertebral rotation when the vertebral pedicle shadow on the concave side is closer to the edge than that on the convex side or disappears completely. Grade 1 is defined when most of the vertebral pedicle shadow on the convex side is still within one-third of the edge portion; grade 2 is defined when it is within one-third of the central portion; grade 3 is refined when it is within one-third portion close to the midline; grade 4 is defined when it exceeds the midline

TABLE 2 The parameters of the patients in the group A and B. (Mean \pm SD)

	Group A (n = 31)	Group B (n = 130)	t/ χ^2 values	p values
Gender (M:F)	8:23	21:109	1.579	0.205
Left:Right	22:9	84:46	0.449	0.536
Age (years)	63.52 \pm 10.64	63.96 \pm 7.84	0.219	0.828
MC ($^\circ$)	28.28 \pm 11.4	26.66 \pm 9.84	-0.798	0.426
AR ($^\circ$)	2.81 \pm 0.60	2.32 \pm 0.77	-3.532	<0.001*
FC ($^\circ$)	17.08 \pm 10.0	14.4 \pm 6.25	1.886	0.06
Match	2.58 \pm 2.63	5.15 \pm 5.99	2.319	0.021*
Vertebras	3.87 \pm 0.85	4.36 \pm 0.95	2.631	0.009*
CBD (mm)	41.03 \pm 11.83	8.92 \pm 6.7	20.27	<0.001*
L4 tilt ($^\circ$)	16.29 \pm 5.59	12.01 \pm 8.41	2.692	0.007*
L5 tilt ($^\circ$)	7.99 \pm 3.95	6.59 \pm 5.24	1.395	0.165
CPT ($^\circ$)	2.52 \pm 2.15	2.25 \pm 1.68	0.759	0.448

* indicates $p < 0.05$.; Note: M, male; F, female; MC, major Cobb; AR, apical rotation; FC, fractional Cobb; CBD, coronal balance distance; SD, standard deviation; CPT, coronal pelvic tilt

TABLE 3 Mean value and range of parameters

Parameter	Mean	SD	Range
CBD(mm)	0.14	20.49	-57.6 - 68.2
Major Cobb ($^\circ$)	-2.83	26.82	-48.8-61.7
Fractional Cobb ($^\circ$)	3.18	10.83	-33-24.5
L4 tilt ($^\circ$)	3.77	14.51	-22.9 - 28.7
L5 tilt ($^\circ$)	1.91	8.3	-16.2 - 19.6
Coronal pelvic tilt ($^\circ$)	-0.18	2.89	-6.7 - 8.7

Note: CBD indicates coronal balance distance; SD, standard deviation

Categorical variables being expressed as counts or percentages were compared using chi-squared test or Fisher exact test.

The associations of the CBD or MC with other coronal parameters were investigated using linear correlations analysis, and Pearson correlation coefficients (r) were calculated subsequently. Then, parameters having statistical significance ($p < 0.05$) were further investigated using multiple regression analysis in stepwise method and the coefficient of determination (r^2) was calculated. Statistics were performed with SPSS package software (Mac version: 26.0, IBM© Statistics, Chicago, IL). The statistical significance was set at $p < 0.05$ (two-sided).

Results

Group Description

A population of 161 patients, including 132 men and 29 women, with the mean age 63.88 years (SD 8.42) were enrolled in this current study. One hundred and six patients had left side structural curve, and right side curve appeared in the rest of the 55 patients. All of the patients had

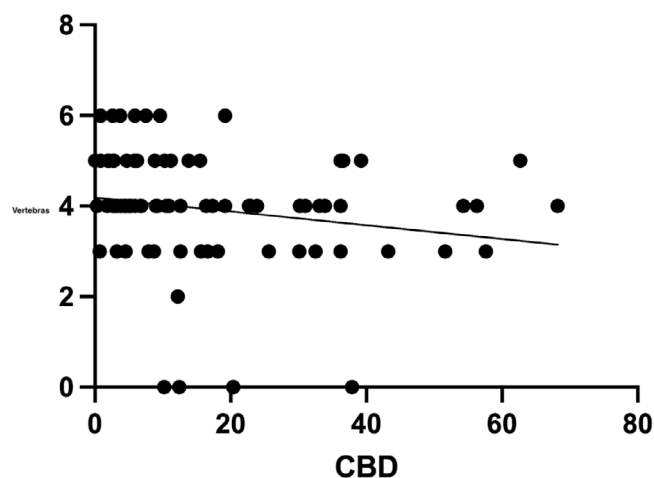


Fig. 3 The correlated trend between the coronal balance distance and the vertebrae in the major curve

thoracolumbar/lumbar curves, with the apical vertebrae of the structural curve located between the T12 and L4.

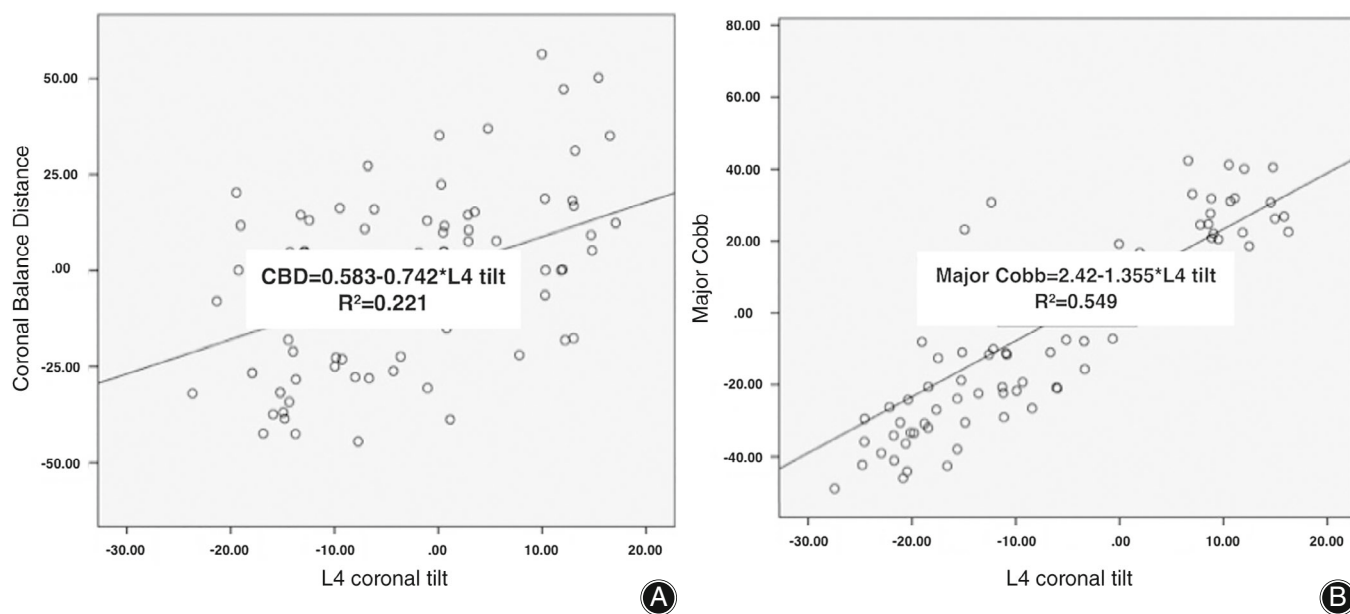
Radiographic Results

The reliability of those measurements between the intra- and inter-observers were excellent, ranging from 0.889 to 0.938 (Table 1). In this study, there were 31 patients with CBD over 30 mm, and the incidence of CM was 19.25% (31/161). Although the MC had no difference ($p > 0.05$) between the two groups, the vertebrae in major curve were less ($p = 0.009$), the apex rotation ($p < 0.001$) and the L4 coronal tilt ($p = 0.007$) were much more in group A. Although the FC and MC had no difference between the two groups ($p > 0.05$), the match was smaller ($p = 0.021$) in group A. Those details were shown in Table 2.

TABLE 4 Pearson correlation and *r* value of the parameters

Variables	CBD (mm)	MC (°)	FC (°)	L4 tilt (°)	L5 tilt (°)	CPT (°)
CBD (mm)	X	0.036	-0.255*	-0.471 ^Δ	-0.468 ^Δ	0.206
MC (°)		X	-0.638 ^Δ	-0.741 ^Δ	-0.661 ^Δ	-0.366 ^Δ
FC (°)			X	0.838 ^Δ	0.625 ^Δ	0.552 ^Δ
L4 tilt (°)				X	0.837 ^Δ	0.348 ^Δ
L5 tilt (°)					X	0.351 ^Δ
CPT (°)						X

* *p* < 0.05(two-tailed); Δ, *p* < 0.001(two-tailed); Note: CBD indicate coronal balance distance; MC, major Cobb; FC, fractional Cobb; CPT, coronal pelvic tilt.

**Fig. 4** Associations of the L4 coronal tilt with the coronal balance distance (A), and major Cobb (B), respectively

The details of those coronal parameters including CBD, MC, FC, L4 coronal tilt, L5 coronal tilt, and CPT were listed in the Table 3.

Relationships between the Vertebrae in Major Curve, MC, FC, L4 Coronal Tilt, L5 Coronal Tilt, CPT, and CBD

Simple line chart showed that the vertebrae in major curve decreased gradually with the CBD increasing (Figure 3). CBD correlated significantly to the L4 coronal tilt ($r = -0.471$, $p < 0.001$) and L5 coronal tilt ($r = -0.468$, $p < 0.001$), respectively, but weakly to FC ($r = -0.255$, $p = 0.017$). Although there were significant correlations between MC and CPT ($r = -0.366$, $p < 0.001$), L4 coronal tilt ($r = 0.348$, $p < 0.001$), L5 coronal tilt ($r = 0.351$, $p < 0.001$), and FC ($r = 0.552$, $p < 0.001$), respectively, neither MC ($r = 0.036$, $p = 0.741$) nor CPT ($r = 0.206$, $p = 0.056$) had relationships with CBD. The details are listed in Table 4.

Regression Analysis

Multiple regression analysis in stepwise method showed that only L4 coronal tilt was the independent predictor for CBD ($R^2 = 0.221$, $p < 0.001$) and MC ($R^2 = 0.549$, $p < 0.001$), respectively, and the linear regression equations were as follows:

$$\text{CBD} = 0.583 - 0.742 * \text{L4 coronal tilt}$$

$$\text{MC} = 2.42 - 1.355 * \text{L4 coronal tilt}$$

The scatter diagrams are shown in Figure 4A,B.

Discussion

In our current study, 31 degenerative lumbar scoliosis (DLS) patients showed coronal mal-alignment (CM), and the incidence was about 19.25% (31/161). Similar results, ranging from 20% to about 35%, were reported in previous studies^{1,10}. Moreover, we deduced the predictor of

L4 coronal tilt for CM happening at pre-operation and determined the associations of coronal pelvic obliquity with full-spine alignment, which were unclear in previous studies.

Coronal Parameters for CM in DLS

The fractional curve, recognized as one compensatory mechanism, was described in previous studies^{20,21}. Liu *et al.*²² concluded that mismatch between the correction rates of the main curve and compensation curves is a critical cause of immediate CM postoperatively. In order to achieve postoperative coronal balance, the correction rates of the main curve and compensation curves in type A, B, and C should be equal, higher, and smaller, respectively. In this current study, those patients with and without CM had similar major Cobb (MC) and fractional Cobb (FC) preoperatively, but the match between MC and FC was much smaller in those with CM. Then the mismatch between MC and FC may be one of the risk factors for CM developing at pre-operation. For those patients suffering from CM, smaller correction rates of the MC and the FC should be considered to restore the coronal balance in correction surgery.

With the similar MC, the vertebrae in the major curve were much less and the apical rotation of the structural curve was more serious in patients with CM compared to those without CM. Additionally, the linear trend chart (Figure 3) showed that the less vertebrae in the major curve, the larger the coronal balance distance (CBD) in DLS patients. We concluded that those patients with similar MC, the fewer vertebrae but the more serious apex rotation in the structural curve would result in coronal full-spine decompensation, and CM developing subsequently.

It is essential for spinal surgeons to diminish the rotation of vertebrae in structural curves during scoliosis surgery. As illustrated in previous studies, the spinal lateral bending was always accompanied by co-rotation of the L5 above the sacrum, but inverse rotation of the lumbar spinal vertebrae^{23–25}. This can explain why patients with such consistent types of coronal alignments are prone to CM after correction surgery^{1,11}.

Lewis *et al.*¹¹ concluded that the correction in L4 and L5 coronal tilt correlated strongly with the full-spine coronal imbalance ($r = 0.75$ and 0.61). In our current study, L4 coronal tilt in the patients suffering from CM was much larger than those without CM. Pearson correlation analysis showed that the CBD correlated significantly with the L4 and L5 coronal tilt ($r = -0.471$ and -0.468), respectively, and moderately with the FC, however, only the L4 coronal tilt was an independent predictor for CBD after further multiple regression analysis ($r^2 = 0.221$). Therefore, we insist that L4 coronal tilt may have significant effect on the scoliosis deformity and CM happening at pre-operation in DLS patients, which can explain why the correction in L4 coronal tilt is so important in restoration of full-spinal balance.

Relationships between the CPT and the Full-Spine Alignment

Transverse plane pelvic tilt was considered to be as the primary or compensatory factor for the main curves in previous studies^{26–29}. Up until now, there has been a paucity of studies about the effect of pelvis on the coronal imbalance in DLS patients. The results of this study revealed that the coronal pelvic tilt (CPT) correlated moderately to the L4 coronal tilt, L5 coronal tilt, the MC and FC respectively, however, there was no direct relationship between the CPT and the CBD. Moreover, comparisons between the patients with and without CM showed no difference in CPT. Therefore, we conclude that the CPT may be a compensatory factor for the thoracolumbar/lumbar scoliosis, rather than a direct determinant for the full-spinal balance. Additionally, as the patient shown in Figure 5, a female DLS patient had the left major curve, and the pelvic obliquity was in the same direction with a tilt of about 10° (B). Although the absolute length of both lower extremities was similar, the left lower limb was relatively long, showing flexion deformity in the standing position.

Limitations

The limitations of this current study were as follows. Firstly, the subjects in the subgroup were much less, only 31 patients in the CM group, which may lead to bias in the results. Furthermore, the retrospective design and the subjects being from the single institution may undermine the reliable evidence of

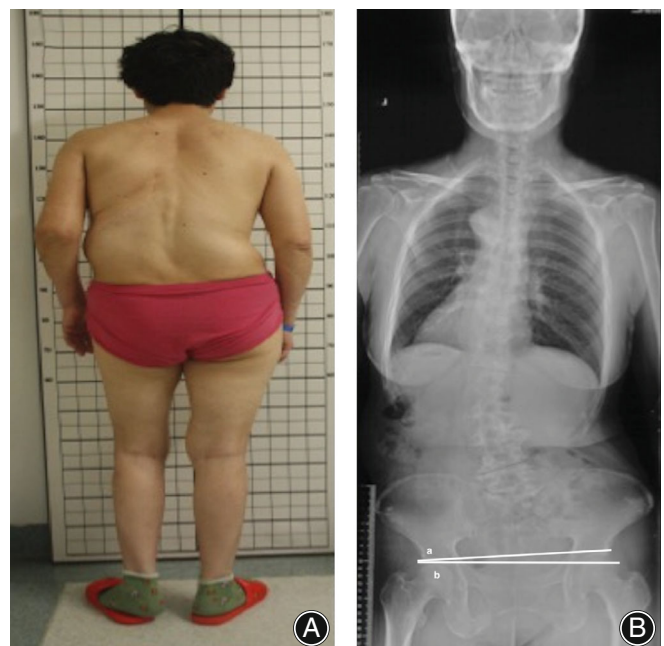


Fig. 5 The standing image and posteroanterior full-spinal radiograph of a female DLS patient illustrate the compensation of spine-pelvis-lower extremities on coronal plane.

this current study. Lastly, according to the results, it's hard to figure out the cause and effect between the scoliosis, CBD, and those related radiographic parameters.

Despite those limitations, we explored the significant associations of the CBD and MC with the L4 coronal tilt, L5 coronal tilt, the fractional Cobb, and the CPT, respectively. Moreover, we determined that L4 coronal tilt may correlate to both scoliosis and coronal alignment directly. Additionally, we concluded the associations of CPT with the full-spinal alignments.

Conclusions

The incidence of coronal malalignment in degenerative lumbar scoliosis (DLS) patients is about 19% at pre-operation. DLS patients with the mismatch of the major and fractional curve may be at the greatest risk to CM developing. Coronal pelvic tilt had less effect directly on the full-spine coronal balance and may be recognized as one of compensatory factor in accordance with scoliosis. L4 coronal tilt may correlate to both scoliosis and coronal balance distance directly. However, longitudinal cohort investigations would be needed to further verify whether the L4 coronal tilt is associated with progression of scoliosis and changes in full-spinal coronal balance.

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Competing Interest

The authors of this manuscript declare no competing interests.

Authors' contribution

Zhang Z F wrote this article completely; Zhang Z F and LIU T measured and recorded all of the data for this article. Prof. Zheng G Q, Wang Z and Wang Y designed and supervised this study. All authors approved this final manuscript.

Ethics Approval

This study was conducted with approval from the Ethics Committee of the Chinese PLA General Hospital (No. 20190602113) and was performed in accordance with the Declaration of Helsinki.

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