

The predictor for Preoperative Coronal Imbalance in patients with Degenerative Lumbar Scoliosis—A related analysis on spinopelvic parameters

Zifang ZHANG

Nankai University

Dengbin QI

Chinese PLA General Hospital

Tianhao WANG

Chinese PLA General Hospital

Zheng WANG

Chinese PLA General Hospital

Yan WANG (✉ yanwang301spine@163.com)

Chinese PLA General Hospital

Research Article

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Abstract

Background: The mechanism of coronal imbalance is still unclear. The relationships among CBD and major curve, L4 and L5 tilt have been reported, which were not explicit although. The aim of this retrospective study was to explore and examine the association between spinopelvic parameters and coronal balance distance (CBD) in degenerative lumbar scoliosis (DLS) patients.

Methods Following institutional ethics approval, the radiographs of 161 DLS patients were retrospectively reviewed. The coronal measurements involving CBD, L4 coronal tilt, L5 coronal tilt, fractional curve, pelvic coronal tilt, the Cobb angle and included vertebrae of major curve were documented. All of those participants were divided into group A ($CBD \geq 30\text{mm}$) and group B ($CBD < 30\text{mm}$). Statistical analysis was performed to compare the difference of continuous and categorical variables. Pearson-Correlation, and Multiple-Regression Analysis were performed to explore the related parameter with CBD.

Results The CBD in 31 (19.25%) DLS patients at pre-operation was over 30mm. With similar major Cobb angle, main curve of patients in the group A had less involving vertebrae ($P=0.009$), but more rotation of the apical vertebra ($P<0.001$) compared with that in the group B respectively. Additionally, the L4 coronal tilt in group A was much larger ($P=0.02$). Pearson-correlation analysis showed that CBD had significant relationship with L4/L5 coronal tilt ($P<0.001$), weak relationship with fractional curve ($P=0.027$), but linearly independent with pelvic tilt and major Cobb. Stepwise Multiple-regression analysis revealed that only L4 tilt was the independent predictor for major Cobb and CBD.

Conclusions The prevalence of coronal imbalance at pre-operation in DLS patients is about 20%. With similar major Cobb, the less the number of involving vertebrae, the higher the incidence of coronal imbalance in DLS patients. L4 coronal tilt would be the predictive variable for progression of scoliosis and global coronal malalignment. Pelvis, the foundation of spine, had less effect on full-spine coronal balance.

Key Points

1. The prevalence of coronal imbalance in patients with degenerative lumbar scoliosis is common.
2. DLS patients with similar Cobb angle but less involving vertebrae would be at the greatest risk for coronal imbalance at pre-operation.
3. L4 coronal tilt is an independent effective predictor for coronal imbalance, however, the foundation of spine, including fractional curve and pelvis, has less correlation with full-spine balance.

Background

Coronal imbalance is one of the major pathological symptom in patients with degenerative lumbar scoliosis (DLS)^[1], which decreases health related quality of life (HRQOL) significantly^[2, 3], and increases incidence of implant failure in patients performed long-fusion surgery^[4]. According to the results of

previous studies^[5, 6], the incidence of coronal imbalance in those patients ranged from 19.3% to 34.8%. The prevalence of this disorder is common, however, the pathophysiological mechanism of coronal imbalance is still unclear. There has been hypothesis that coronal imbalance might be brought by spinal stenosis, degeneration of discs and facet joints, or atrophy of paraspinal muscles, however, the hypothesis was short of solid evidence^[5]. Pelvis plays an essential role on keeping full-body balance^[7]. Additionally, previous study proposed that the ability to level the coronal tilt of L4 and L5 had greatest impact on the ability to achieve coronal balance^[8], but there was paucity of literature paying attention to analyze the relationship among coronal tilt of L4/L5, major curve, fractional curve, pelvic coronal tilt, and coronal balance distance(CBD).

The measurement of distance between C7 plumb line(C7PL) and central sacral vertical line(CSVL), namely coronal balance distance(CBD) in this current study, has been widely used to reflect global coronal alignment. We performed this retrospective radiographic study in order to investigate the prevalence of coronal imbalance in DLS patients at pre-operation, and explore the relationships between radiological parameters and the coronal imbalance.

Methods

Patients

Approval by the Clinical Research Ethics Committee of our hospital was obtained before this research. We retrospectively documented radiographic data of DLS patients with preoperative standing full-spine X-rays in our single institution from May 2015 to December 2018. General inclusion criteria for this study included any DLS patient(≥ 45 years old), diagnosed at our orthopedic department, who had integrated radiographic materials at baseline visit. Patients with prior spine surgery, spinal neoplasms, spinal tuberculosis, spinal or pelvic trauma, non-structural curvature, prior hip or knee surgery, or the discrepancy in leg length more than 2cm were excluded from this study.

Radiographic Evaluation

Radiographic data collection consisted of full-length standing coronal and sagittal radiographs obtained in free-standing posture with the upper limbs resting on a support, the shoulders at 30° forward flexion, and the elbows slightly flexed^[9]. All of the radiographic parameters were measured with accurate and reliable spine measurement software (Surgimap version: 2.3.2.1; Spine Software, New York, NY)^[10].

On coronal radiographs 8 parameters were measured: 1) major Cobb angle, defined as the angle between the superior endplate of the most tilted vertebra cranially and the inferior endplate of the most tilted vertebra caudally (left scoliosis was recorded as negative[-], right scoliosis as positive[+]). 2) Lumbosacral fractional curve^[11], defined as the angle between the superior endplate of L4 and the line formed by pedicles of S1(left fractional curve was recorded as negative[-], right fractional curve as positive[+]). 3) Coronal balance distance(CBD) was defined as the horizontal distance between the C7PL and the center

of the S1 on coronal plane, C7PL on the left side of CSVL was recorded as negative(-), right side as positive(+).^[12] 4) L4 coronal tilt, defined as the angle between superior endplate of L4 and the horizontal line(left side was recorded as negative[-], right side as positive[+]).^[5] 5) L5 coronal tilt, defined as the angle between superior endplate of L5 and the horizontal line(left side was recorded as negative[-], right side as positive[+]).^[5] 6) the number of involved vertebra in the structure curve. 7) the coronal pelvic tilt(C-PT), the angle between the line formed by iliac crests and the horizontal line(left side was recorded as negative[-], right side as positive[+]). 8) apical vertebra rotation by the Nash–Moe method(left side was recorded as negative[-], right side as positive[+])^[13]. The detailed measured methods were shown in **Figure 1 A-B** and **Figure 2**.

Statistical analysis

Continuous variables with normal distribution are expressed as the Mean \pm standard deviation(SD) and abnormal data as the median. Categorical variables are expressed as counts and percentages. All of those radiographic data were measured with Surgimap by two independent researchers. Intra- and inter-rater reliabilities were excellent with kappa values ranging from 0.889 to 0.938. Pearson correlation coefficient(r) was calculated to test for associations between CBD and regional coronal parameters. Then, parameters having statistical relationship($P < 0.05$) were further investigated using stepwise multiple regression analysis and the coefficient of determination(R^2) was calculated. According to the recent criterion^[14], 161 patients were assigned into the coronal imbalance group($\text{CBD} \geq 30.00\text{mm}$, group A) and the coronal balance group($\text{CBD} < 30.00\text{mm}$, group B). Those normal distributed variables were analyzed using independent-sample t test, and analysis of abnormal distributed variables performed with Mann-Whitney U-test. Statistics were performed with SPSS 26.0 package software (version for Mac IBM® SPSS® Statistics) with statistical significance set at $P < 0.05$ (two-sided).

Results

Group description

A total of 161 patients including 132 men and 29 women met inclusion criteria with mean age: 63.88 years(SD 8.42). 106 patients had left side curve and right side curve appeared in the rest of 55 patients. There were no difference($P > 0.05$) involving age, ratio of gender and types of curves between group A and B.

Radiographic results

In this study, there were 31 patients with CBD over 30mm, and the incidence of coronal imbalance was 19.25%(31/161). Although major Cobb and the fractional curve had no differences respectively($P > 0.05$) in two groups, the number of involving vertebra in major curve was less in group A than that in group B($t = 2.639$, $P = 0.009$), and the rotation of apical vertebra was much more($t = -3.796$, $P < 0.001$). Moreover, the

L4 coronal tilt was much more in group A than that in group B($t=1.992$, $P=0.02$). The details were shown in **table 1**.

The mean coronal balance distance(CBD) was $0.14\text{mm} \pm 20.5\text{mm}$ (from -57.6mm to 68.2mm), the mean major Cobb was $-2.83^\circ \pm 26.83^\circ$ (from -48.8° to 61.7°), the mean fractional curve was $3.18^\circ \pm 10.84^\circ$ (from -33° to 24.5°), the mean L4 coronal tilt was $3.77^\circ \pm 14.52^\circ$ (from -22.9° to 28.7°), the mean L5 coronal tilt was $1.91^\circ \pm 8.3^\circ$ (from -16.2° to 19.6°), and the mean pelvic tilt was $-0.19^\circ \pm 2.89^\circ$ (from -6.7° to 8.7°). The details were shown in **table 2**.

Relationship between CBD, the number of vertebra in major curve, major Cobb, fractional curve, L4/L5 coronal tilt, and pelvic tilt.

Simple Line chart showed that the number of vertebra in major curve decreased with CBD increasing(**Figure 3**). Pearson correlation analysis showed CBD was significantly correlated with L4 ($r=-0.471$, $P<0.001$) or L5 ($r=-0.468$, $P<0.001$) coronal tilt, and weakly correlated with fractional curve ($r=-0.255$, $P=0.017$). Although there were significant correlation between pelvic coronal tilt and regional parameters including major curve ($r=-0.366$, $P<0.001$), L4 coronal tilt ($r=0.348$, $P<0.001$), L5 coronal tilt ($r=0.351$, $P<0.001$), and fractional curve ($r=0.552$, $P<0.001$), neither major Cobb ($r=0.036$, $P=0.741$) nor pelvic tilt ($r=0.206$, $P=0.056$) had relationship with CBD. The details were shown in **table 3**.

Regression Analysis

On the basis of the results above, entry of regional parameters involving L4 coronal tilt, L5 coronal tilt, and fractional Cobb into stepwise multiple regression analysis showed that only L4 coronal tilt was the independent predictor of CBD ($R^2=0.221$, $P<0.001$), and the linear regression equation was obtained, $\text{CBD} = 0.583 - 0.742 * \text{L4 tilt}$. Additionally, entry of major curve-related four variables including fractional curve, L4 coronal tilt, L5 coronal tilt, and coronal pelvic tilt into stepwise multiple regression analysis revealed that only L4 coronal tilt was an independent predictor of structure curve ($R^2=0.549$, $P<0.001$), and the linear regression equation was as follows: $\text{Major Cobb} = 2.42 - 1.355 * \text{L4 tilt}$. The scatter diagrams were shown in **Figure 4 A-B**.

Discussion

Spinal imbalance, involving the sagittal and/or coronal planes, is an essential index to the severity of spine deformity^[15, 16]. The increasing imbalance on the coronal plane in patients with degenerative lumbar scoliosis (DLS) has become one of main underlying factor that leads them to abnormal appearance, functional decline, and back pain^[17]. The distance between C7 plumb line (C7PL) and central sacral vertical line (CSVL), named coronal balance difference^[5], coronal balance distance^[12], global coronal malalignment^[14], and C7 migration^[11], has been used to reflect coronal alignment. In this current study, we defined the global coronal parameter as coronal balance distance (CBD). The latest study demonstrated the threshold of CBD was 30mm, after analyzing those related-variables involving the

health-related quality of life (HRQOL), radiographic data, and complications in adult spinal deformity (ASD) patients^[14].

In our study, the prevalence rate of coronal imbalance was 19.25% (31/161) by the criterion of 30mm. According to previous studies^[8, 11], structure curve had no influence on coronal imbalance in ASD patients. Comparisons in this current study revealed that although the degree of the main curvatures of patients in the two groups had no difference, the involving vertebrae were less in patients with coronal imbalance (group A) than those with coronal balance (group B) ($t=2.639$, $P=0.009$). Additionally, Line Chart shows the number of vertebrae in the major curve decreases gradually with the mean value of CBD increasing. According to compensatory mechanism of spine^[18], the more the involved vertebrae and the rotation degrees of apical vertebra, the larger the degrees of the structural curvatures, which can keep the global spinal balance. Contrarily, spine would be imbalance if the compensatory mechanism were broken. Therefore, according to the results in our study we deduce that DLS patients, with similar major Cobb angle, but less vertebrae and more rotation degrees of those apical vertebrae, would be at greater risk for coronal imbalance because of spinal decompensation.

Lewis et al.^[8] proposed that the coronal tilt of L4 and L5 were larger in ASD patients with CBD over 40mm, and the correction of coronal tilt of L4 and L5 had the greatest impact on restoration of global coronal balance, further prospective study involving larger number of participants is needed to verify that although. What's more, the threshold of CBD being as 30mm would be more reasonable^[14]. Bao et al.^[19] proposed that the horizontalization of L5 was the foundation of coronal spinal alignment, in terms of addressing lumbosacral fractional curve. A population of 161 patients with DLS were absorbed in our study. Comparisons of regional radiographic data between coronal balance and imbalance patients showed significant difference only in L4 coronal tilt. Pearson correlation analysis showed that there were significant relationship between CBD and coronal tilt of L4 and L5, and weak relationship with fractional curve, however, only L4 coronal tilt was an independent predictor for CBD after multiple regression analysis. In other words, reconstruction of L4 coronal tilt would restore effectively the coronal imbalance in DLS patients.

Additionally, considering correction of main curve during long-fusion surgery in ASD patients, Zhang et al.^[12] suggested that there is significant correlation among pre-operative CBD, rectified Cobb angle of main curves, and post-operative CBD. Unfortunately, they did not explore the relationship between major curve and CBD further. The current study explore the relationships between major Cobb and those regional parameters involving L4/L5 coronal tilt, fractional curve, and coronal pelvic tilt, and the results showed significant relationship between each other. Moreover, L4 coronal tilt was independent predictor of major Cobb following stepwise multiple regression analysis. Therefore, the correction of L4 tilt would play the essential role on rectification of scoliosis and restoration of coronal balance for degenerative lumbar scoliosis patients.

Regarding to sagittal full-body balance in patients with spinal deformity, Ferrero et al.^[7] illustrated the key role of pelvis. Then, pelvis should be one of compensatory factor in global coronal balance. The results of

this study revealed moderate relationship between coronal pelvic tilt and regional radiographic variables involving coronal tilt of L4/L5, major Cobb, and fractional curve, however, there was no relationship between pelvic tilt and CBD. Moreover, comparisons between balance and imbalance patients showed no difference of coronal pelvic tilt. In other words, pelvis would play less compensation on global coronal balance.

The limitation of this study should be mentioned. Although the number of patients was sufficient in this study, when all patients were divided into two groups, the patients in coronal imbalance group were much less(31 patients), and these may lead to bias. Furthermore, exploring the relationship between coronal balance distance and clinical findings, this current study did not consider those functional scores such as SRS-22 and ODI, and did not explore the role of those regional parameters on reconstruction surgery. Despite those limitations, we insist that the results from this study can be as the foundation for those purpose.

Conclusion

The prevalence of coronal imbalance in degenerative lumbar scoliosis(DLS) patients is about 20% at pre-operation time. With similar major Cobb, the less the number of involving vertebra, the larger the CBD on DLS patients who would be at greater risk for coronal imbalance due to spinal decompensation. L4 coronal tilt would be an independent predictor on progression of structure curve and global coronal malalignment. Pelvis, the foundation of spine, had less effect on full-spine coronal balance.

Abbreviations

DLS, degenerative lumbar scoliosis; CBD, coronal balance distance; HRQOL, health related quality of life; C7PL, C7 plumb line; CSVL, central sacral vertical line; MC, major Cobb; FC, fractional Cobb; CPT, coronal pelvic tilt; M, male; F, female; SD, standard deviation.

Declarations

1. Acknowledgements: Each author of this article certifies that the Chinese PLA general hospital approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research. This work was performed at the Chinese PLA general hospital, Fuxing Road, Beijing, China.
2. There was no data published previously.
3. All data generated during this study are available from the corresponding author on reasonable request.
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6. Authors' contributions: ZHANG Z F wrote this article completely; ZHANG Z F & QI D B measured and recorded all of the data for this article. WANG T H analyzed and interpreted the data. WANG Y & WANG Z designed and supervised this study. WANG Z is the co-correspondence author for this article; QI D B is the co-first author for this article. All authors read and approved this final manuscript.
 7. This study was conducted with approval from the Ethics Committee of Chinese PLA General Hospital and was performed in accordance with the Declaration of Helsinki. Written informed consent to participate was obtained from all participants.
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Tables

Table 1. The parameters of the patients in group A and B.(Mean±SD)

	group A n=31	group B n=130	t/c 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±10.64	63.96±7.84	0.219	0.828
Major Cobb(°)	28.28±11.4	26.66±9.84	-0.798	0.426
Apical rotation	2.81±0.60	2.32±0.77	-3.796	<0.001*
Fractional Curve(°)	17.08±10.0	14.4±6.25	-1.402	0.17
Vertebras	3.87±0.85	4.36±0.95	2.639	0.009*
CBD(mm)	41.03±11.83	8.92±6.7	14.532	<0.001*
L4 tilt(°)	16.29±5.59	12.01±8.41	1.992	0.02*
L5 tilt(°)	7.99±3.95	6.59±5.24	0.982	0.329
Pelvic tilt(°)	2.52±2.15	2.25±1.68	0.554	0.581

* $P < 0.05$ M, male; F, female; CBD, coronal balance distance; SD, standard deviation.

Table 2. Mean Value and Range of parameters			
Parameter	Mean Value	SD	Range
CBD(mm)	0.14	20.49	-57.6 – 68.2
Major Cobb(°)	-2.83	26.82	-48.8 – 61.7
Fractional Cobb(°)	3.18	10.83	-33 – 24.5
L4 tilt(°)	3.77	14.51	-22.9 – 28.7
L5 tilt(°)	1.91	8.3	-16.2 – 19.6
Pelvic tilt(°)	-0.18	2.89	-6.7 – 8.7
CBD, indicates coronal balance distance.			

Table 3. Pearson Correlation and <i>r</i> Value of the parameters						
Variables	CBD(mm)	MC (°)	FC (°)	L4 tilt(°)	L5 tilt(°)	CPT(°)
CBD(mm)	X	0.036	-0.255*	-0.471 ^D	-0.468 ^D	0.206
MC (°)		X	-0.638 ^D	-0.741 ^D	-0.661 ^D	-0.366 ^D
FC (°)			X	0.838 ^D	0.625 ^D	0.552 ^D
L4 tilt(°)				X	0.837 ^D	0.348 ^D
L5 tilt(°)					X	0.351 ^D
CPT(°)						X
Note: CBD, indicate coronal balance distance; MC, major Cobb; FC, fractional Cobb; CPT, coronal pelvic tilt. *, <i>P</i> <0.05(two-tailed); D, <i>P</i> <0.001(two-tailed).						

Figures

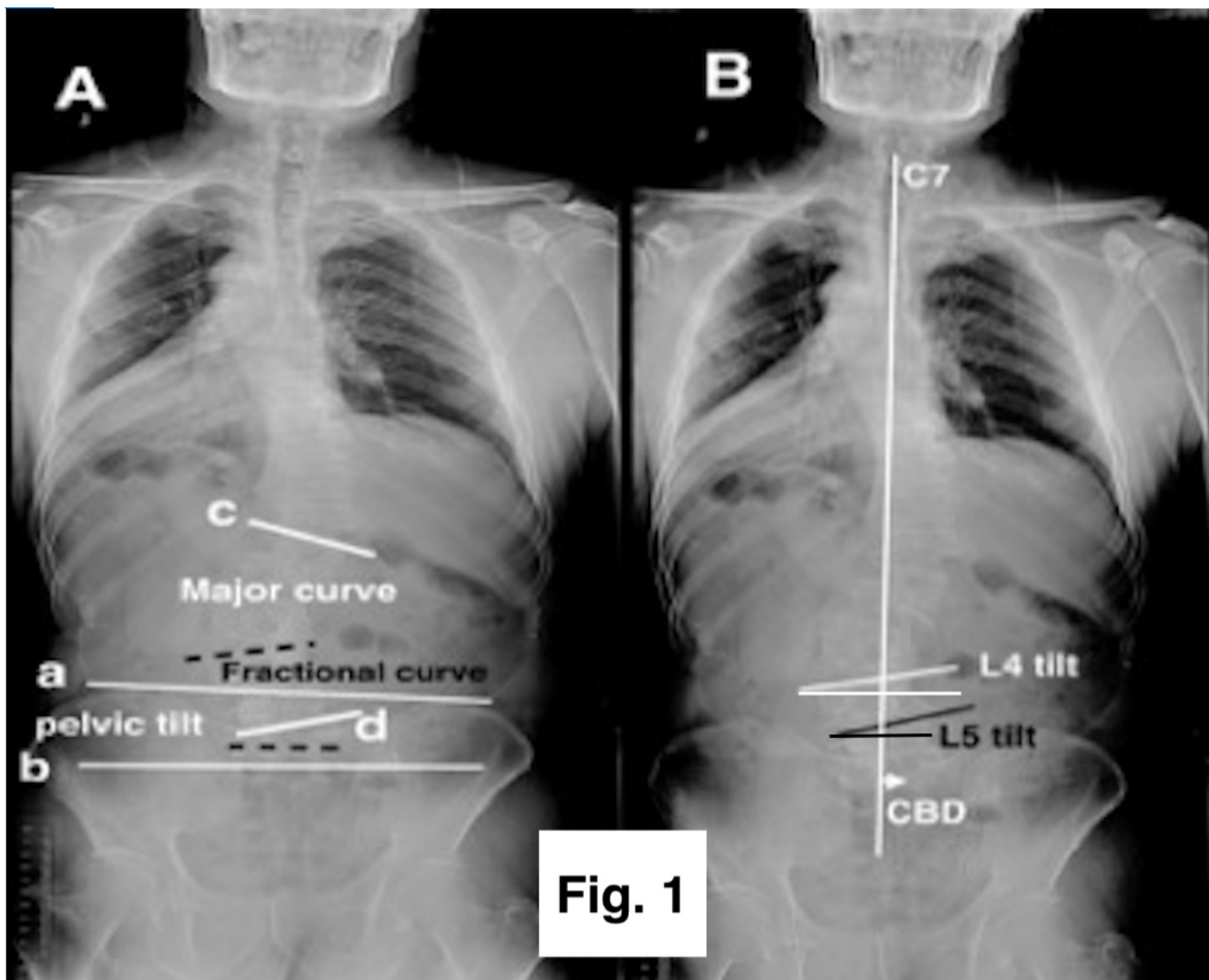


Figure 1

Schematic drawing of each parameter. Major curve, Coronal pelvic tilt, Fractional curve, (A). Coronal balance distance(CBD), L4 coronal tilt, and L5 coronal tilt.(B)

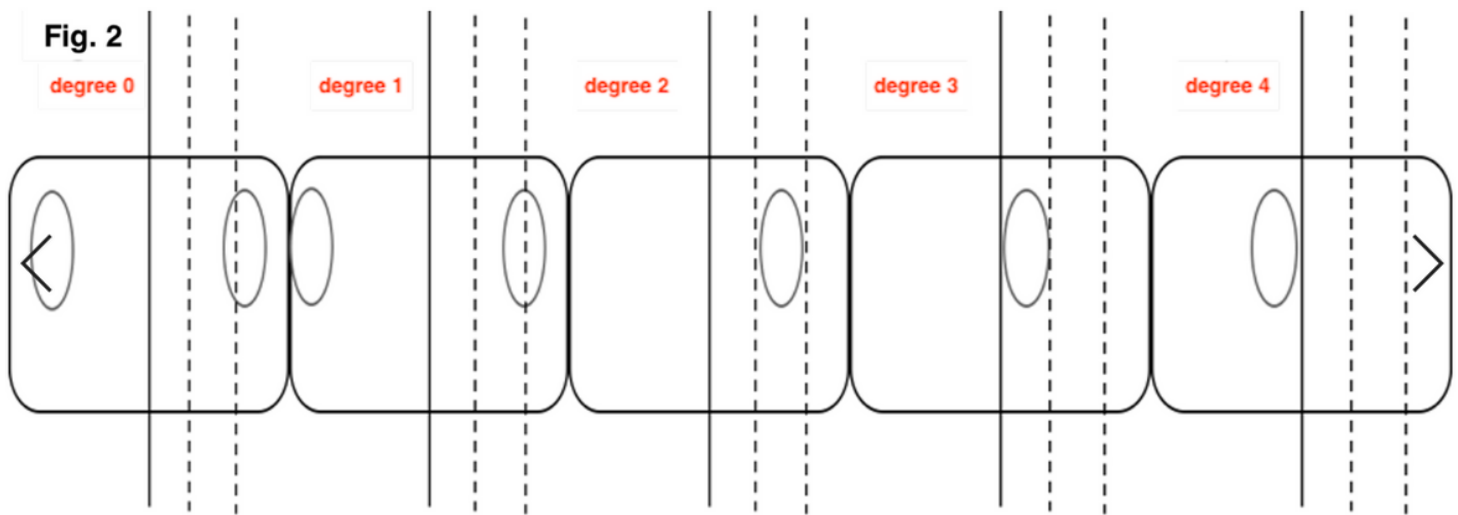


Figure 2

Nash–Moe method categorizes vertebral rotation into five degree. According to this method, the vertebra is first bisected longitudinally and then each half is further divided into 3 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 the one-third of the edge portion; grade 2 is defined when it is within the one-third of the central portion; grade 3 is refined when it is within to one-third portion close to the midline; grade 4 is defined when it exceeds the midline.

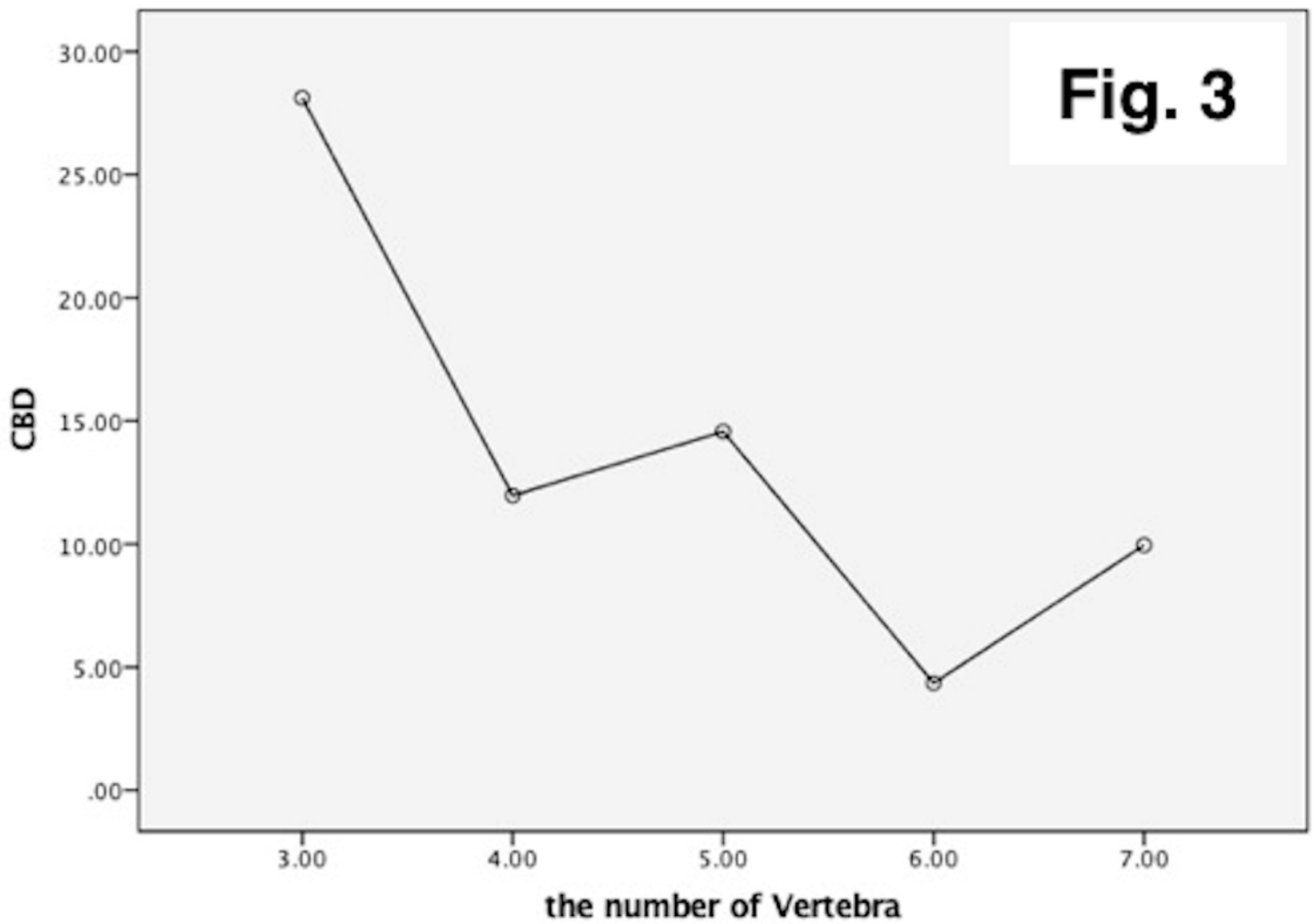


Figure 3

Association trend between coronal balance distance(CBD) and the number involving in Major curve.

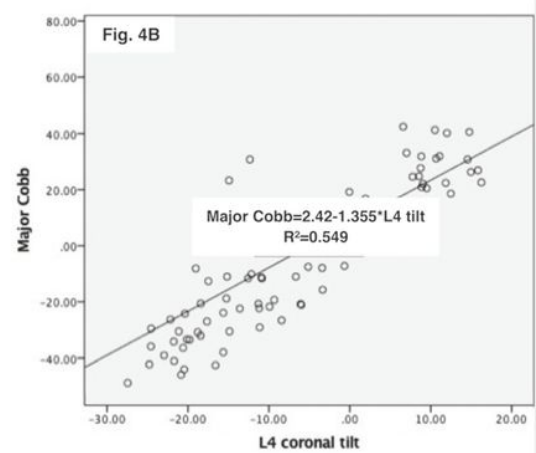
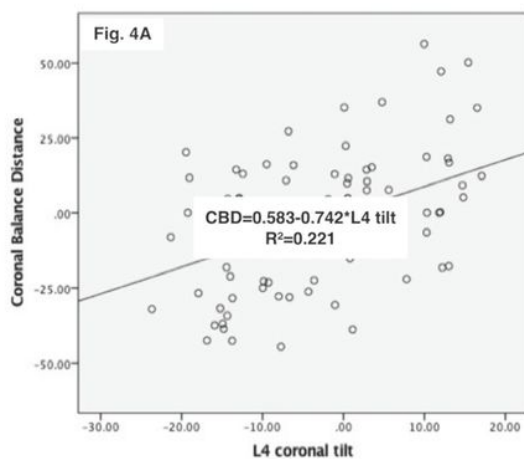


Figure 4

Association between coronal balance distance(CBD) and L4 coronal tilt (A), and that between major curve and L4 coronal tilt (B).