The effect of vertebrae rotation on the position of the aorta relative to the spine in patients with adult degenerative scoliosis

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Research article

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Abstract

Purpose : Few study has been published for quantitative relation of the vertebrae rotation on the position of the aorta relative to spine in adult degenerative scoliosis (ADS). Thus, this study was to explore the effect of the vertebrae rotation on the position of the aorta relative to spine in patients with ADS and identify the risk factor of vertebrae rotation.

Methods : A retrospective analysis was performed for 71 patients with ADS divided into left scoliosis (LS group, 40cases) and right scoliosis (RS group, 31cases). The two group were well-matched in demographics. Apical vertebrae, Cobb angle (°), coronal displacement and thoracolumbar kyphosis (TLK) were measured on X-ray. Aorta-vertebrae angle (α), aorta-vertebrae distance (d) and rotation angle (γ) for each level of T12-L4 on MRI were obtained within a Cartesian coordinate system.

Results : There was no significant difference in apical vertebrae distribution between the LS and RS group, so were Cobb angle and coronal horizontal displacement distance (P□0.05). There was no significance on mean γ of of apical vertebrae among different levels in LS group (P=0.337) and RS group (P=0.253). Pearson correlation analysis showed γ was a positively correlated to Cobb angle and coronal horizontal displacement distance (P<0.001) in both groups. There was no significant correlation between the γ and α, d, whichever the group (P□0.05). Coronal movement was the independent risk factor of γ (P=0.003) in LS group while Cobb angle (P=0.001) and coronal horizontal movement (P=0.006) were risk factors in RS group.

Conclusion : Vertebral rotation could be calculated by Cobb angle or coronal movement without MRI in ADS. Aorta maintained a relatively normal position in patients with ADS. The surgeons should aware of this to avoid the injury of the aorta.

Introduction

The adult degenerative scoliosis (ADS) are a condition that a major curve at the lumbar commonly develop in the elder age [1, 2]. The vertebrae rotation is a typical characteristic and play an important role in the development of ADS. Due to the vertebrae rotation, the structure of the vertebrate is complex and blur, ensuing the insertion of pedicle screw was difficult and may injury the aorta at a higher risk. So, knowing about the effect of the vertebrae rotation in the position of the aorta relative to the spine in patients with ADS is of great importance.

Previous studies had purely described the influence of vertebrae rotation on the pedicle screw placement or focused on adolescent idiopathic scoliosis (AIS) as well as other spine deformity[3, 4]. But no study has been published for quantitative relation of the vertebrae rotation on the position of the aorta relative to spine in patients with ADS, a highly prevalent disease of thoracolumbar or lumbar spine. Therefore, the purpose of this paper is to explore the effect of the vertebrae rotation on the position of the aorta relative to thoracolumbar or lumbar spine in patients with ADS and identify the risk factor of vertebrae rotation.

1 Materials And Methods

1.1 Participants

This retrospective single-center study was approved by the medical ethics committee of our hospital. A total of 71 patients with ADS in our hospital were recruited from January 2014 to June 2018. 40 cases were in left lumbar scoliosis (LS group) and 31 were of right lumbar scoliosis (RS group).

The inclusion criteria were: (1) the apical vertebrae were located within thoracolumbar or lumbar spine (T12-L4); (2) magnetic resonance image (MRI) of the thoracolumbar and lumbosacral spines were available and (3) posteroanterior and lateral radiograph containing lumbar and the whole spine were also available. The exclusion criteria were: (1) congenital vascular abnormality; (2) previous spinal surgery or (3) previous cardiovascular surgery. Informed consents were obtained from all subjects.

1.2 Measurements

1.2.1 Measurements on X-ray radiograph

The standard standing posterior-anterior and lateral X-ray films of the lumbar and whole spine were obtained to identify (1) LS, RS scoliosis, (2) coronal Cobb angle (°), (3) apical vertebrae distribution, (4) coronal horizontal displacement distance (mm) (the vertical distance from curvature apex to the sacral vertical line) and (5) the angle of thoracolumbar kyphosis (TLK) (the sagittal angle between superior endplate of T10 and inferior endplate of L2, of which the kyphosis was a positive value). Two investigators acquired parameters above independently.

1.2.2 Measurements on MRI

All subjects were required to lie in a neutral supine position. MRI was obtained using a 1.5-T scanner (Gyroscan Intera; Philips Medical Systems, NL). Axial 4-mm slices with 1-mm overlap were acquired using a three-dimensional thick T2-weighted spin-echo axial scans through the vertebral bodies (time of repetition: 5000 ms; time of echo: 120 ms; field of view: 250 mm; Matrix size: 250 × 360). The same MR scans and image acquisition protocol were applied as for the supine position and images were analyzed using PACS client software (Easy Vision IDS5, version 11.4; Philips, Hamburg, Germany). To clarify the relative positions of the abdominal aorta and the vertebrae, the following parameters were measured from the MR images from the T12 vertebrae to the L5 vertebrae with a Cartesian coordinate system [11].

Cartesian coordinate system: A line connecting both medial edges of the superior facets was defined as the X-axis. The Y-axis was drawn perpendicular to the X-axis starting from the dorsal edge of the right superior facet and the two lines intersect at the origin O.

Left pedicle-aorta angle (α): The angle formed by the Y-axis and a line connecting the origin and the center of the aorta was defined as the left pedicle-aorta angle (α). The angle was defined as 90 ° when the aorta was located directly to the left, and – 90 ° when it was located directly to the right of the original point.

Left pedicle-aorta distance (d): This distance was defined as a line connecting the origin O and the nearest edge of the aorta.

vertebrae rotation angle (γ): It was defined as the angle subtended by a straight line through the posterior central aspect of the vertebral foramen and the middle of the vertebral body and the sagittal plane. (Fig. 1)

1.3 Statistical analysis

The values of each parameter at each vertebral level were presented as mean ± standard deviation. Independent sample t test or Mann-Whitney U-test was performed on respective comparisons of sex distribution, age, BMI, apical vertebrae distribution, Cobb angle and coronal horizontal displacement distance between LS groups and RS group. One-way analysis of variance and Kruskal-Wallis test were used to compare variables on different apical vertebrae in the same group. Pearson correlation analysis were operated among Cobb angle, the horizontal displacement distance, α, γ and d of the two deformity groups. Multiple linear regression analysis was then performed to identified the risk factors for γ in the two groups. The data were analyzed using SPSS 22.0 (International Business Machines Corporation, Armonk, New York, USA) and significance was defined as a $P < 0.05$.

2 Results

There was no significant difference in sex distribution in among LS and RS group ($P = 0.413$). The age was well-matched in LS and RS group ($P = 0.126$), as well as the body mass index (BMI) ($P = 0.232$). (Table 1)

Table 1 Demographic characteristics of deformity and control participants

	LS	RS	P
Sex	40	31	0.413
Male	6	7	
Female	34	24	
Age, y	67.2±7.3	70.1±8.5	0.126
Height, m	1.6±0.1	1.6±0.1	0.708
Weight, kg	68.7±10.5	66.4±10.4	0.351
BMI, kg/m^2	27.1±3.3	26.0±4.0	0.232

Footnote: LS: left scoliosis group; LRS: right scoliosis group; BMI: body mass index

2.1 Result of measurements on X-ray radiograph

In the two group, L1 to L4 are distributed as apical vertebrae, of which L3 is most in LS group while L2 is the most in RS group. There is no statistical difference in apical vertebrae distribution between LS and RS group. The average Cobb angle and coronal horizontal displacement distance are also of no significance between the two groups (P = 0.311 and P = 0.394, respectively). (Table 2)

Table 2
Cobb angle, apical vertebrae distribution and coronal horizontal displacement distance in 2 malformed groups

	Ap-V in LS/(γ, °)	**Ap-V in RS/(γ, °)**	**P**
T12	0	2 (-5.9 ± 5.7)	0.311
L1	4 (5.4 ± 2.4)	4 (-13.8 ± 13.2)	
L2	14 (10.0 ± 6.1)	11 (-12.4 ± 6.6)	
L3	16 (9.0 ± 5.0)	10 (-12.5 ± 8.6)	
L4	6 (6.7 ± 3.4)	4 (-4.2 ± 3.4)	
Cobb angle, °	23.7 ± 12.7	20.8 ± 10.4	0.311
Coronal movement, mm	45.2 ± 10.7	47.8 ± 15.1	0.394
TLK, °	8.8 ± 12.6	13.2 ± 14.7	0.253

Footnote: Ap-V: apical vertebrae distribution; LS: left scoliosis group; RS: right scoliosis group; TLK: thoracolumbar kyphosis

2.2 Result of measurements on MRI and the correlation analysis

When comparing inner-group mean γ of apical vertebrae, there was no significance on γ among different levels in LS group ($F = 1.165$, $P = 0.337$), neither was that of RS group ($F = 1.427$, $P = 0.253$) (Table 2)

The Pearson correlation analysis demonstrated a significant correlation between the γ and Cobb angle, coronal horizontal displacement distance in the LS group ($P < 0.001$). And there was a significant correlation between the γ and Cobb angle, coronal horizontal displacement distance in the RS group ($P < 0.001$). While there was no significant correlation between the γ and α, d in the LS group ($P = 0.908$, $P = 0.661$ respectively), and there was no significant correlation between the γ and α, d in the RS group ($P = 0.738$, $P = 0.289$ respectively)(Table 3). Figure 2 and Fig. 3 showed when there was a larger Cobb angle and coronal horizontal movement, there was a larger γ in LS group and a lower γ (a larger absolute value of γ) in RS group.(Fig. 2 and Fig. 3)

Table 3
Pearson correlation analysis between Cobb angle, the horizontal displacement, TLK, α, d and γ

Groups	Parameters	γ	
		r	P
LS	Cobb angle	0.569	< 0.001
	coronal movement	0.674	< 0.001
	TLK	-0.061	0.738
	α	0.019	0.908
	d	-0.072	0.661
RS	Cobb angle	-0.767	< 0.001
	coronal movement	-0.728	< 0.001
	TLK	-0.399	0.081
	α	-0.051	0.783
	d	-0.197	0.289

Footnote: LS: left scoliosis group; RS: right scoliosis group; TLK: thoracolumbar kyphosis; r: correlation coefficient

2.3 Multiple linear regression analysis of γ in two malformed groups

A multiple linear regression analysis was performed based on the correlation analysis. In LS group, coronal horizontal movement was the risk factor of γ ($P = 0.003$) and the regression equation was γ (°) = -4.502 + 0.542 × Coronal movement (mm); In RS group, γ was effected by Cobb angle ($P = 0.001$) and coronal horizontal movement (P = 0.006) and the regression equation was γ (°) = 2.953 − 0.512 × Cobb angle (°)-0.406 × Coronal movement (mm).(Table 4)

Table 4
Multiple linear regression analysis of γ in LS and RS group

Groups	Coefficient	Unstandardized		Standardized	t	P value	Multicollinearity	
		B	SE	Beta			Tolerance	VIF
LS group	(constant)	-4.502	2.097		-2.147	0.038		
	Cobb angle	0.055	0.05	0.186	1.102	0.278	0.502	1.994
	Coronal movement	0.193	0.06	0.542	3.213	0.003	0.502	1.994
RS group	(constant)	2.953	1.809		1.633	0.114		
	Cobb angle	-0.254	0.067	-0.512	-3.767	0.001	0.604	1.655
	Coronal movement	-0.139	0.046	-0.406	-2.987	0.006	0.604	1.655

Footnote: LS: left scoliosis group; RS: right scoliosis group; SE: standard error; VIF: Variance Inflation Factor

3 Discussion

The ADS commonly developed in a skeletally mature spine due to the degenerative change without preexisting spinal deformity [5]. The progressive degenerative mainly occurs in the lumbar spine, which result in load-sharing changes that involve the entire spine, eventually lead to loss of lumbar lordosis and resultant sagittal plane malalignment. Multiple degenerative pathology which included the disc collapse, facet hypertrophy, capsule degeneration, and ligamentous hypertrophy, affecting the load-sharing of both the anterior and posterior columns, ultimately leading to degenerative curves. Two factors have been found in associated with the severity of the ADS which were the magnitude of the curvature and the vertebrae rotation. [6–8].

Previous studies have indicated that there was an obvious correlation between the vertebrae rotation and the clinical symptoms irrespective of the degree of scoliosis [9]. Although the exact mechanism of the vertebrae rotation in ADS was yet to be defined, it was assumed that asymmetry degeneration of facet joint may play an important role. [10–12]. Due to the asymmetry in the orientation of facet joint, the facet position was abnormal and the distribution of mechanical loads and stress in the spine changed which may be a potential cause of spinal degeneration [13–15] and instability [16–20]. Faraj [21] described that the vertebrae rotation was a risk factor for curve progression. It also has been shown that the vertebrae rotation can lead to the pain which caused by the degenerative facet joint or the decreased foraminal width [22, 23]. Therefore, the vertebrae rotation was an important index for the severity of the ADS. In our study, there are positive correlation between the vertebrae rotation and Cobb angle, coronal horizontal displacement distance, which was accordance with the previous studies. So, we can use the γ to evaluate the severity of ADS in the clinical.

As we all know, the vertebrae rotation in the patients with AIS have a great effect on the position of aorta. Milbrandt [24] showed that the thoracic aorta shifted to the left side of the curves and was positioned more left laterally and posteriorly to the vertebral body in right thoracic curves in patients with AIS. On the contrary, it moved to the right and was positioned anterior to the vertebral body in left thoracic curves. Liljenqvist and Sevastik [25, 26] studied the relative position of the aorta in patients with AIS, and found that the lateral displacement is larger and the vertical displacement is shorter. Studies on the position of the aorta in patients with AIS showed that the position of the aorta changed at different vertebrae rotation [24, 27–28]. While the effect of vertebrae rotation on the position of aorta in patients with ADS remains unclear. In our series, a quantitative relation between vertebrae rotation and radiological parameters on X-ray was firstly established. On the one hand, the regression equation indicated that vertebrae rotation in segments with scoliosis could be influenced by Cobb angle and coronal movement, which was a key information in bridging parameters on X-ray and MRI. On the other hand, when there was a lack of MRI with money constraints or other cases, vertebrae rotation could still be predicted by cheaper X-ray and thus the direction of pedicle screws implanting could then be identified. However, it was somewhat different on risk factors between LS and RS group. May be there was asymmetric anatomy construction distributing besides lumbar spine such as vessel and tissue, as well as bilateral discrepancy of muscularity in left- or right-side advantage of the body[4, 13]; Or it was just because of a little sample in this study and larger sample and multi-center studies could be developed.

Due to the vertebrae rotation, the structure of the vertebrate is complex and blur, so the insertion of pedicle screw was difficulty and may injury the aorta at a higher risk. Besides the patients of ADS usually complicated with advanced age, so the vascular elasticity was reduced and commonly combined with atherosclerosis [29]. Therefore, it is important to make a clear understanding of the effect of vertebrae rotation on the position of aorta in patients with ADS to guide the spine physician on intraoperative manipulation and reduce the vascular-related complications. In our study, the effect of vertebrae rotation on the position of aorta in patients with ADS is different from the patients with AIS. The reason are as follows. AIS commonly manifested a regularly and smooth curve with a larger Cobb angle. While the ADS are mainly caused by the degeneration of intervertebral discs, facets and paravertebral muscles. The curve is irregularly and the Cobb angle is usually less than 40°, and the vertebrae rotation is of a moderate size and is limited to the apical levels [30, 31]. Besides, the ADS are commonly elderly patients, the vascular elasticity was reduced and the tethering ability of connective tissues were weakened, which lessen the effect of the vertebrae rotation. So, the vertebrae rotation has no significant effect on the position of aorta in patients with ADS.

In the spine surgery, the vascular injury is a rare but well recognized complication. Once happened, it would be catastrophic [32, 33]. Liu studied that due to the vertebrate rotatory and aliment changed, the risk of aorta injury caused by the misplace of screw would be increased [34]. Due to the vertebrae rotation, the misplaced screw will be at a high potential. During the process of screw insertion, we usually determine the angle according to the rotation of the vertebral body to make sure the accurate of the screw insertion. For the patients with ADS, the effect of the vertebrae rotation on the screw insertion have been studied a lot, and the effect of the vertebrae rotation on the position of the aorta was also important to avoid the aorta injury. In our study, the outcome indicated that the vertebrae rotation has no significant effect on the position of aorta in patients with ADS. So, the position of the aorta in patients with ADS were not changed with the vertebrate rotation. In other words, the aorta maintained a relatively normal positon in patients with ADS. Therefore, we can evaluate the angle of screw and the position of the aorta simultaneously according to the vertebrate rotation. Not only ensuring the safety of screw insertion, but also avoiding the injury of the aorta.

There are some limitations in this study. Firstly, patients usually take the supine position during MRI examinations, but the surgery is usually performed in prone position. Whether the position of the aorta changes from supine to prone position is not clear. Secondly, the vertebrae rotation mainly affect the coronal balance, the sagittal balance was not clearly, so the conclusion may not be applicable for all ADS cases. Besides, the number of the cases in our study is relatively small, so the larger cases of research should be future studied.

4 Conclusion

In summary, there was a positive correlation between the vertebrae rotation and Cobb angle, coronal horizontal displacement distance and vertebrae rotation could be calculated by Cobb angle or coronal movement without MRI. Surgeons can use this to evaluate the severity of the deformity for the patient with ADS. There was no significant correlation between the vertebrae rotation and the position of the aorta, which indicated that the aorta maintained a relatively normal position in patients with ADS. The surgeons should aware of this to avoid the injury of the aorta.

Abbreviations

adult degenerative scoliosis
ADS
adolescent idiopathic scoliosis
AIS
magnetic resonance image
MRI
the angle of thoracolumbar kyphosis
TLK
Left pedicle-aorta angle
α
Left pedicle-aorta distance
d

vertebrae rotation angle
γ

Declarations

Ethics approval and consent to participate: This study has obtained ethics approval and consent of the ethics committee in our hospital.

Consent for publication: Not applicable

Availability of data and material: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: Conceptualization: LHY, XS; Data Curation: LHY, XS, ZZQ; Formal Analysis: LY, XS; Investigation: LY, ZZQ; Methodology: XS; LY, MFQ; Project Administration: LHY; Resources: XS; MFQ; Software: XS, LY; Validation: LY; Visualization: LHY; Writing & Editing: LHY, XS, Yan Liang. All authors read and approved the final manuscript.

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Figures

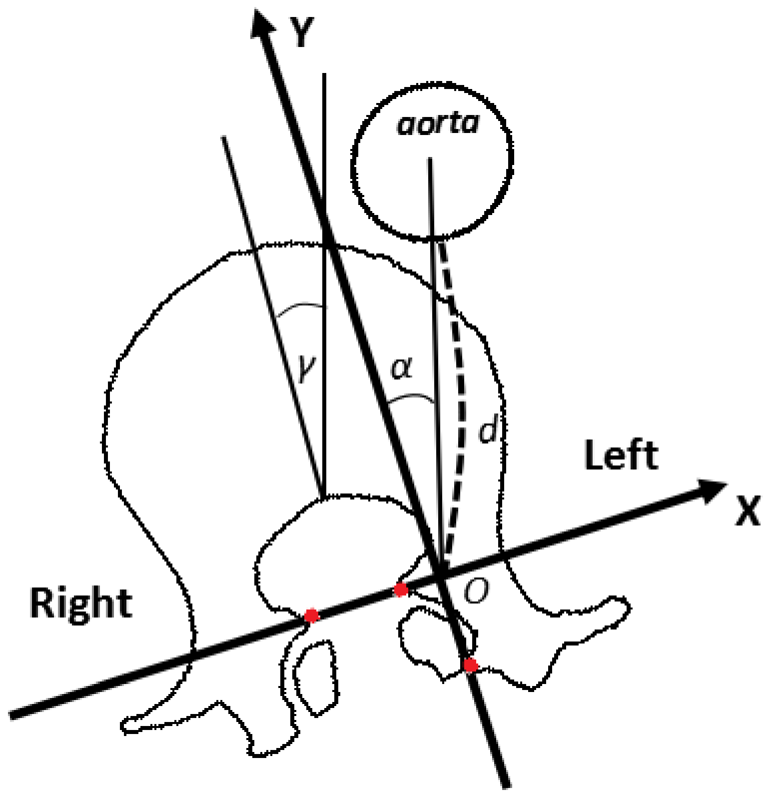

Figure 1

The position of Cartesian coordinate system and instructions for α, γ and d

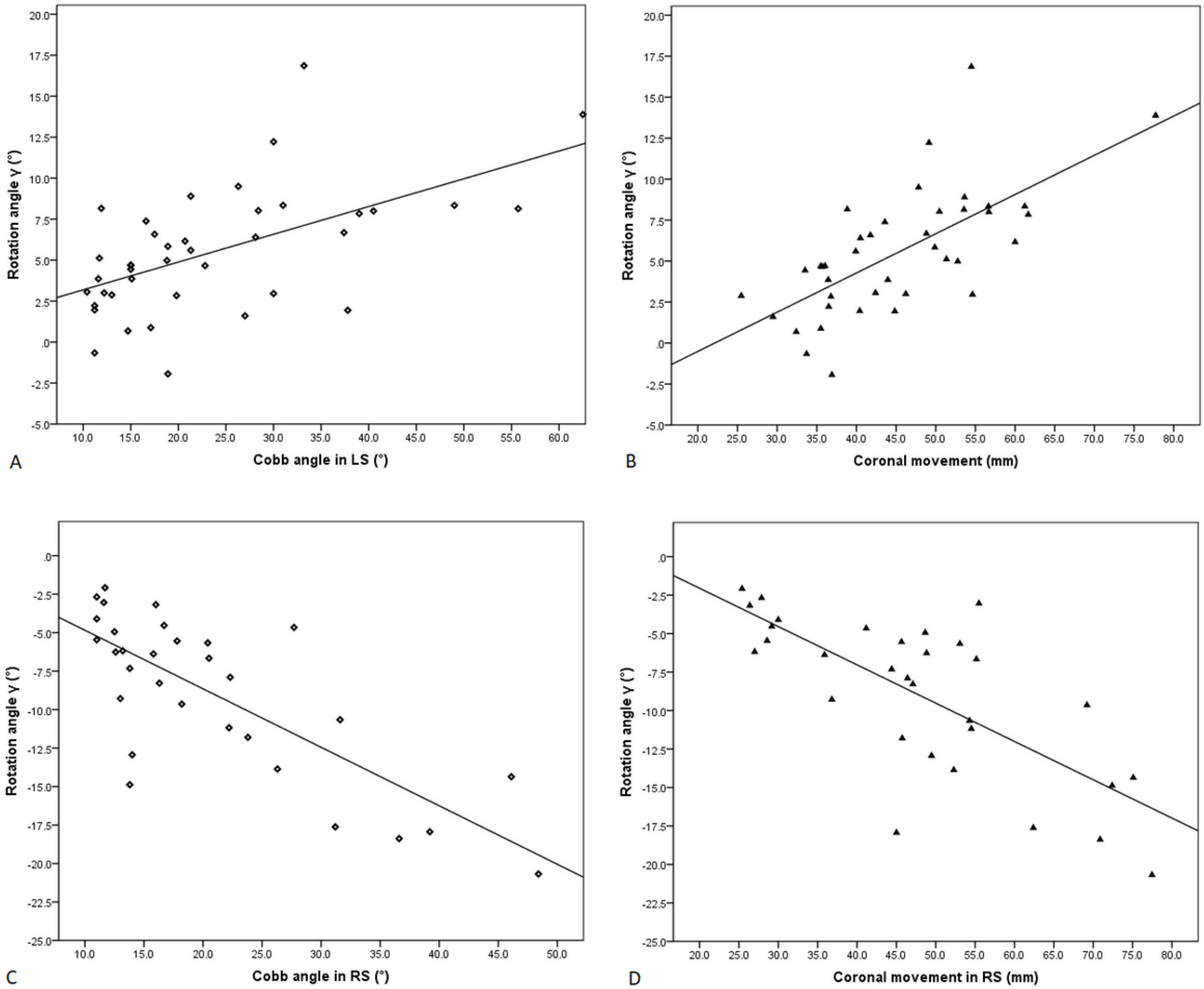

Figure 2

Scatter diagram between mean γ and cobb angle or coronal movement. (A) Correlation between mean γ and Cobb angle in LS group, R2=0.324; (B) Correlation between mean γ and coronal movement in LS group, R2=0.454; (C) Correlation between mean γ and Cobb angle in RS group, R2=0.588; (D) Correlation between mean γ and coronal movement in RS group, R2=0.529. LS: left scoliosis; RS: right scoliosis; γ: vertebrae rotation; R2: coefficient of determination

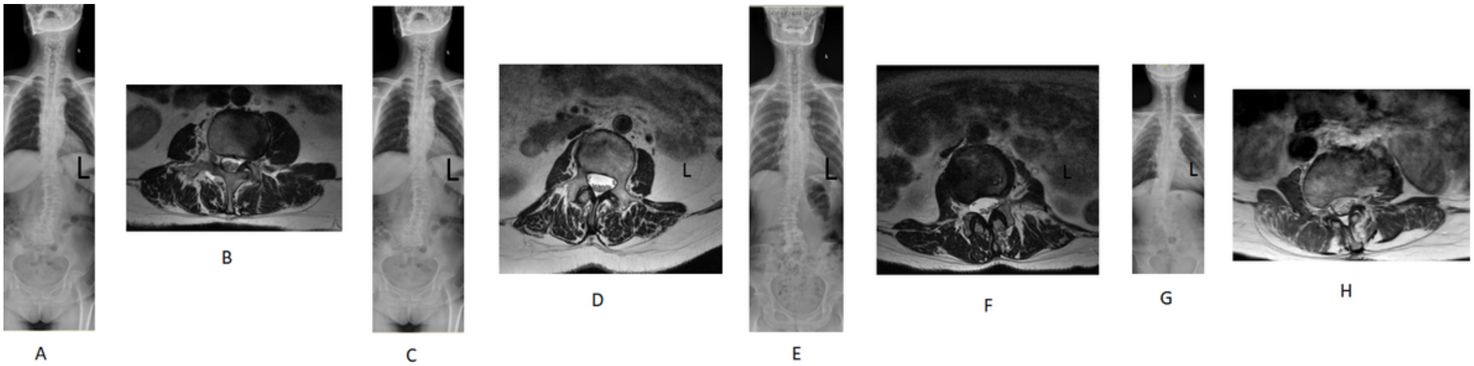

Figure 3

The standard standing whole spine X-ray and lumbar spine MRI T2-weighted axis-image of LS and RS groups. (A-B) The whole spine X-ray and L3 level MRI of a 61 year-old women in LS group. The γ is 6.3°; the apical vertebrae is L3, Cobb angle is 16.7° and coronal movement is 32.4mm; α is -4.8° and d is 5.22 cm. (C-D) The whole spine X-ray and L3 level MRI of a 67 year-old women in LS group. The γ is 13.6°; the apical vertebrae is L3, Cobb angle is 22.3° and coronal movement is 43.6mm; α is -4.8° and d of 5.33 cm. (E-F) The whole spine X-ray and L3 level MRI of a 63 year-old women in RS group. The γ is -10.8°; the apical vertebrae is L3, Cobb angle is 19.2° and coronal movement is 36.4 mm; α is 5.9° and d of 5.73cm. (G-H) The whole spine X-ray and L3 level MRI of a 68 year-old women in RS group. The γ is -16°; the apical vertebrae is L3, Cobb angle is 25.2° and coronal movement is 45.7 mm; α is 6.6° and d of 5.75cm.