The position of the aorta relative to the spine in patients with adult degenerative scoliosis

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Abstract

Study design: A retrospective analysis was conducted to analyze the position of the aorta by MRI in patients with adult degenerative scoliosis.

Objective: This study aimed to investigate the relative anatomic positions of the aorta and spine in patients with adult degenerative scoliosis (ADS).

Summary of background data: Aorta injury is a rare complication of spinal surgeries. However, there would be a disastrous consequence once it happened. Therefore, knowing about the position of aorta is of great importance.

Methods: A retrospective analysis was performed in 90 patients with ADS and 132 participants without spine deformity. ADS patients were divided into several groups such as left scoliosis, left scoliosis with thoracolumbar kyphosis, right scoliosis, and right scoliosis with thoracolumbar kyphosis. The aorta-vertebrae angle (α) and aorta-vertebrae distance (d) in each level of T12–L4 were measured by using a Cartesian coordinate system. t test of independent samples was performed, α and d were compared, and Pearson correlation analysis was employed for α, d, and X-ray radiographic measurements.

Result: The changes of α were not statistically significant (P > 0.05) in LS and LKS groups but d (P < 0.05) was longer in LKS group compared with the control group. In the right malformed group, there was no significant change in the angle (P > 0.05) in the abdominal aorta but longer d (P < 0.05) than the normal group. There was longer d in the RKS group compared with the RS group (P < 0.05). Pearson correlation analysis showed that there was a positive correlation between d and TLK (r = 0.439, P < 0.05).

Conclusion: In patients with ADS, a relative normal position is maintained between the aorta and vertebrae. While the aorta is slightly away from the left pedicle in RS patients and farther away in patients with kyphosis, the angle of kyphosis would become bigger and d becomes longer. Therefore, the surgeons should be aware of the changes of the aorta position to avoid the disastrous vessel injuries.

Keywords: Adult degenerative scoliosis, Aorta, Aorta-vertebrae angle, Aorta-vertebrae distance, Rotation angle

Introduction

ADS (adult degenerative scoliosis) was defined as a curve > 10° due to asymmetrical degeneration of the facets and discs which apply an asymmetric load on the spine leading to degenerative scoliosis [1–3]. In ADS, there is a major curve on the lumbar spine complicated by lateral and rotatory subluxation. Therefore, deformity correction surgery was necessary and osteotomy was required to achieve a good balance. Due to the complexity in the posterior tissue, the insertion of pedicle screws appeared to be difficult and risky. Besides, ADS patients were usually accompanied by advanced age and atherosclerosis; thus, the vascular elasticity was reduced. All these factors could lead to aorta injury during the surgeries. Although aorta injury is rare among the complications, the consequence would be disastrous once it occurred.
Previous studies reported that the manifestation of aorta injury is mainly bleeding and pseudoaneurysm [4, 5]. Several studies have evaluated the relative position of the aorta and the spine in adolescent patients with idiopathic scoliosis and kyphosis deformity [6–10]. Nonetheless, there was no study investigating the relative anatomic position of aorta and spine in patients with ADS. Therefore, our research was conducted to explore the relative anatomic position of the aorta and spine in patients with ADS.

Materials and methods

Participants

This retrospective single-center study was approved by the medical ethic committee of our hospital. A total of 132 subjects without spine deformity (control group) and 90 patients with DLS in our hospital were recruited from January 2014 to June 2018. Twenty-six patients with DLS were assigned into the left lumbar scoliosis group (LS group), 30 patients into the left kyphoscoliosis group (LKS group), 20 patients into the right scoliosis group (RS group), and 14 patients into the right kyphoscoliosis group (RKS group). Scoliosis was defined as no sagittal local malformation while LKS or RKS was defined as a thoracolumbar kyphosis (TLK) > 15° without any other deformities. The inclusion criteria are as follows: (1) the apical vertebrae were located within thoracolumbar or lumbar spine (T12–L4), (2) magnetic resonance images (MRI) of the thoracolumbar and lumbosacral spines were available, and (3) posteroanterior and lateral radiographs containing lumbar and the whole spine were available. The exclusion criteria are follows: (1) congenital vascular abnormalities, (2) previous spinal surgeries, or (3) previous cardiovascular surgeries. Informed consents were obtained from all subjects.

There was no significant difference in sex distribution among the LS, LKS, and control groups (P = 0.775) and between the RS and RKS groups (P = 0.394). The age (P = 0.109 and P = 0.785, respectively) and the body mass index (BMI) (P = 0.555 and P = 0.058, respectively) were well-matched in the LS and LKS groups and RS and RKS groups compared with the control group (Table 1).

Measurements

Measurements on X-ray radiograph

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

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 slices (4 mm) with 1-mm overlap were acquired using a three-dimensional thick T2-weighted spin-echo axial scan through the vertebral bodies (TR, 5000 ms; TE, 120 ms; FOV, 250 mm; matrix size, 250 × 360). The same MR scans and image acquisition protocol were applied for supine position. 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 in 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 perpendicular to the x-axis starting from the dorsal edge of the right superior facet. The two axes intersect at the origin O.

Left pedicle-aorta angle (α) The left pedicle-aorta angle (α) was formed by the y-axis and a line connecting the origin and the center of the aorta. The angle was 90° when the aorta was located on the left side and ~90° when it was on the right side of the origin.

Table 1 Demographic characteristics of deformity and control participants

|                      | Control | LS      | LKS     | P     | Control | RS      | RKS     | P    |
|----------------------|---------|---------|---------|-------|---------|---------|---------|------|
| Sex                   |         |         |         |       |         |         |         |      |
| Male                  | 20      | 2       | 4       | 20    | 6       | 4       |         |      |
| Female                | 112     | 24      | 26      | 112   | 14      | 10      |         |      |
| Age, year             | 63.30 ± 8.42 | 66.08 ± 7.18 | 67.87 ± 7.08 | 0.098 | 63.30 ± 8.42 | 65.90 ± 6.47 | 63.43 ± 8.83 | 0.785 |
| Height, m             | 1.61 ± 0.06 | 1.59 ± 0.05 | 1.60 ± 0.07 | 0.567 | 1.61 ± 0.06 | 1.62 ± 0.08 | 1.63 ± 0.09 | 0.549 |
| Weight, kg            | 67.85 ± 10.36 | 72.81 ± 9.92 | 68.93 ± 9.09 | 0.275 | 67.85 ± 10.36 | 61.30 ± 7.79 | 72.57 ± 13.95 | 0.078 |
| BMI, kg/m²            | 26.29 ± 3.66 | 28.89 ± 3.40 | 26.80 ± 2.76 | 0.555 | 26.29 ± 3.66 | 23.46 ± 2.29 | 27.20 ± 5.29 | 0.058 |

LS left scoliosis group, LKS left kyphoscoliosis group, RS right scoliosis group, RKS right kyphoscoliosis group, BMI body mass index
**Left pedicle-aorta distance (d)** This distance was defined as a line connecting the origin O and the nearest edge of the aorta (Fig. 1).

**Statistical analysis**
The values of each parameter at each vertebral level were presented as mean ± standard deviation. Independent samples t test was performed to compare \( \alpha \), \( \gamma \), and \( d \) respectively between the four DLS groups and control group, between the LS and LKS groups, and between the RS and RKS groups. Pearson correlation analysis was employed for Cobb angle, the horizontal displacement distance, and \( \alpha \), \( \gamma \), and \( d \) in the four deformity groups. The data were analyzed using SPSS 22.0 software. If \( P < 0.05 \), the data were considered significantly different.

**Results**
**Measurements on X-ray radiograph**
In the whole left group, L1 to L4 was distributed as apical vertebrae, of which L3 (53.8%) was the most in LS group while L2 (40.0%) and L3 (33.3%) were the majority in LKS group. There was no statistical difference in apical vertebrae distribution between the LS and LKS groups. Moreover, there was no significant difference in the average Cobb angle and coronal horizontal displacement distance between the LS and LKS groups (\( P = 0.088 \) and \( P = 0.195 \), respectively). Apical vertebrae could be identified from T12 to L4 which were mainly located on L2 (50.0%) in the RS group and L3 in the RKS group. However, there was no difference between the two groups in apical vertebrae distribution (\( P = 0.163 \)). The average Cobb angle and coronal horizontal displacement distance were also of no statistical difference between the RS and RKS groups (\( P = 0.743 \) and \( P = 0.353 \), respectively) (Table 2).

**Measurements on MRI**
**Comparisons of \( \alpha \) and \( d \) among LS, LKS, and control groups**
There were no significant differences in \( \alpha \) between the LS (\( -5.27 \pm 7.15^\circ \)) and control groups (\( -3.56 \pm 6.40^\circ \)) (\( P = 0.063 \)), LKS (\( -3.43 \pm 7.75^\circ \)) and control groups (\( P = 0.876 \)), or LS and LKS groups (\( P = 0.107 \)). In the control group, \( d \) (\( 4.45 \pm 0.43 \) cm) gradually increased from T12 to L4, indicating that abdominal aorta moved ventrally away from the left vertebral pedicel along the descending trace, and similar results could be obtained in the LS group (\( 4.51 \pm 0.49 \) cm) and LKS group (\( 4.70 \pm 0.79 \) cm). There were significant differences between the LKS and control groups (\( P < 0.001 \)) or LS and LKS groups (\( P = 0.035 \)), but no significant differences between the LS and control groups (\( P = 0.327 \)) (Table 3) (Fig. 2).

**Comparisons of \( \alpha \) and \( d \) among RS, RKS, and control groups**
There were no significant differences in \( \alpha \) between the RS (\( -5.74 \pm 9.03^\circ \)) and control groups (\( -3.56 \pm 6.40^\circ \)) (\( P = 0.051 \)), RKS (\( -2.87 \pm 10.79^\circ \)) and control groups (\( P = 0.591 \)), or RS and RKS groups (\( P = 0.072 \)). There were significant differences in \( d \) when the RS (\( 4.85 \pm 0.46 \) cm) and RKS (\( 5.11 \pm 0.65 \)) groups were compared with the control group (\( P < 0.001 \), \( P < 0.001 \), and \( P = 0.008 \), respectively) (Table 4, Fig. 3).

**Correlation analysis**
The Pearson correlation analysis demonstrated a positive correlation between \( d \) and TLK (\( r = 0.439 \), \( P = 0.012 \)), while \( \alpha \) or \( d \) was not significantly correlated with Cobb angle (\( P > 0.05 \)) and coronal horizontal displacement distance (\( P > 0.05 \)). The results demonstrated that a severe thoracolumbar column kyphosis may lead to a farther distance away from the aorta (Table 5).

**Discussion**
ADS usually resulted from asymmetric disc space collapse and facet degeneration with subsequent lateral and rotatory listhesis. Such degeneration commonly leads to a large curve in the lumbar spine and malalignment of the sagittal plane [12, 13]. Due to the lumbar curve, vertebrae rotatory, and lateral listhesis, the relative position of the aorta and the spine may be changed. Studies on the relative position of the aorta and the spine in AIS patients demonstrated that the position of the aorta changed at different curves [6–8, 14]. In patients with AS [9] and Pott’s diseases [10], the aorta is prone to
move anteriorly and medially to the vertebrae. However, the relative position of the aorta in ADS patients remains unclear. Since ADS patients are usually accompanied by advanced age and reduced vascular elasticity, most patients suffered from atherosclerosis [15, 16]. Therefore, it is important to have a clear understanding on the anatomy of aorta to guide the physician in intraoperative manipulation and reduce the vascular-related complications.

The thoracic aorta begins at the aortic arch and runs anterior to the middle axis of the vertebral body. The position of the aorta changes with the arrangement of spine. According to the theory of tethering effect, the aorta is constraint by the surrounding crux in the diaphragm and forced into the concave side of the curves as it is the shortest distance between the top and the bottom of the chest cavity. The relative position of the aorta and the spine in AIS patients could be explained by this theory in multiple studies. Milbrandt and Sucato [6] proved that the thoracic aorta shifted to the left side of the curves and moved left laterally and posteriorly to the vertebral body in right thoracic curves in AIS patients. On the contrary, the thoracic aorta moved to the right and anterior to the vertebral body in left thoracic curves. Liljenqvist et al. and Sevastik et al. [17, 18] investigated the relative position of the aorta in AIS patients. It was found that the lateral displacement is larger but the vertical displacement is shorter in AIS patients. However, the relative position of the aorta in ADS patients is totally different. In our study, 132 patients without spine deformity and 90 patients with ADS were recruited. There was no significant difference in the left pedicle-aorta angle between normal people and ADS patients. AIS is commonly featured as a regular and smooth curve with a larger Cobb angle, and the typical characteristic is the axis rotation contributing to three-dimensional

Table 2: Comparisons on α and d from T12 to L4 among LS, LKS, and control groups

|       | Ap-V in LS | Ap-V in LKS | P   | Ap-V in RS | Ap-V in RKS | P   |
|-------|------------|------------|-----|------------|------------|-----|
| T12   | 0          | 0          | 0.301 | 1          | 0          | 0.163 |
| L1    | 2          | 2          | 0.301 | 2          | 1          |       |
| L2    | 1          | 6          | 0.301 | 5          | 2          |       |
| L3    | 7          | 5          | 0.301 | 2          | 4          |       |
| L4    | 3          | 2          | 0.301 | 0          | 0          |       |
| Cobb angle, ° | 19.78 ± 8.86 | 28.44 ± 16.74 | 0.088 | 22.36 ± 10.28 | 24.20 ± 12.46 | 0.743 |
| Coronal movement, mm | 42.21 ± 9.79 | 47.90 ± 12.41 | 0.195 | 52.18 ± 12.00 | 58.02 ± 12.95 | 0.335 |
| TLK, ° | 10.26 ± 8.37 | 19.50 ± 12.12 | 0.001 | 11.85 ± 11.72 | 33.53 ± 18.89 | < 0.001 |

Ap-V apical vertebrae distribution, LS left scoliosis group, LKS left kyphoscoliosis group, RS right scoliosis group, RKS right kyphoscoliosis group, TLK thoracolumbar kyphosis

Table 3: Comparisons on α and d from T12 to L4 among LS, LKS, and control groups

|       | LS vs control | LKS vs control | LS vs LKS |
|-------|---------------|----------------|-----------|
| a, °  |               |                |           |
| T12   | −1.96 ± 10.08 | −1.94 ± 10.04  | −1.96 ± 10.06 | −2.90 ± 10.04  |
| L1    | −3.93 ± 10.12 | 0.30 ± 1.20     | 0.30 ± 1.20 | −3.93 ± 1.20     |
| L2    | −7.30 ± 4.06**| −3.17 ± 4.81    | −3.17 ± 4.81 | −3.17 ± 4.81    |
| L3    | −3.69 ± 7.67  | −5.41 ± 8.52    | −3.69 ± 7.67 | −5.41 ± 8.52    |
| L4    | −9.48 ± 4.35  | −7.63 ± 6.13    | −7.63 ± 6.13 | −7.63 ± 6.13    |
| Mean  | −5.27 ± 7.15  | −3.56 ± 6.40    | −3.56 ± 6.40 | −3.56 ± 6.40    |
| d, cm |               |                |           |
| T12   | 4.03 ± 0.58   | 4.02 ± 0.39     | 4.02 ± 0.39 | 4.02 ± 0.39     |
| L1    | 4.33 ± 0.42   | 4.26 ± 0.29     | 4.58 ± 0.45**| 4.26 ± 0.29     |
| L2    | 4.61 ± 0.31   | 4.50 ± 0.30     | 4.91 ± 0.36**| 4.50 ± 0.30     |
| L3    | 4.76 ± 0.29   | 4.70 ± 0.34     | 4.70 ± 0.34 | 4.70 ± 0.34     |
| L4    | 4.85 ± 0.33   | 4.71 ± 0.38     | 5.05 ± 0.36**| 4.71 ± 0.38     |
| Mean  | 4.51 ± 0.49   | 4.45 ± 0.43     | 4.70 ± 0.79**| 4.45 ± 0.43     |

LS left scoliosis group, LKS left kyphoscoliosis group
*Significance with P < 0.05
**Significance with P < 0.01
malformation. The rotation of the vertebrae plays an important role in changing the relative position of the aorta in AIS patients. On the contrary, ADS is mainly caused by the degeneration of intervertebral discs, facets, and paravertebral muscles, in which the curve is irregular and the Cobb angle is usually less than 40°. In ADS, the typical characteristics are moderate rotation of the vertebrae and lateral listhesis, while the rotation is limited in the apical levels [19, 20]. Besides, most ADS patients have advanced age, the vascular elasticity is reduced, and the tethering
ability of connective tissues is weakened, which is beneficial in maintaining a normal anatomical vertebrae-aorta position. Therefore, the degree of malformation is ameliorated and the relative position of the aorta is not obviously changed in ADS patients.

The left pedicle-aorta distance in ADS patients with kyphosis is increased compared with the control group and the group of ADS without kyphosis. The results indicated that kyphosis plays an important role in the changes of the distance, which was consistent with the previous studies [9, 10]. The Pearson correlation analysis demonstrated a positive correlation between the left pedicle-aorta distance and TLK, indicating that kyphosis is increased compared with the control group and the group of ADS without kyphosis. The results in-  

dicated that kyphosis plays an important role in the  

distance between the aorta and the left pedicle was  

reduced and commonly complicated by atherosclerosis. Ayca et al. [24] reported the correlation between ADS and the diameter of aorta, and it was found that the  
aorta in ADS patients was more vulnerable to be injured. Besides, the insertion of pedicle screws was tricky and risky, and the misplaced screws in ADS patients would result in aorta injury. Moreover, in patients with severe or rigid ADS, the deformity correction surgery was necessary and sometimes osteotomy was performed to restore a good balance. Previous reports have proved that aorta injury would occur in osteotomy surgery [22, 23]. Furthermore, ADS patients are usually in an advanced age, so the vascular elasticity is reduced and commonly complicated by atherosclerosis.

There are some limitations in this study. First, patients usually take supine position during MR 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. Second, kyphosis deformities in ADS patients are not always located in thoracolumbar regions but sometimes in lumbar column; thus, the conclusion may not be applicable for all ADS cases. Last, the sample number in our study is relatively small, so more cases are needed in further research.

### Table 4

|        | RS vs control | RKS vs control | RS vs RKS |
|--------|---------------|----------------|-----------|
| a, °   | 4.33 ± 12.73  | 1.94 ± 7.02    | 1.94 ± 7.02 |
| L1     | 3.02 ± 9.35   | 0.30 ± 5.20    | 0.30 ± 5.20 |
| L2     | 2.39 ± 4.59   | 3.17 ± 4.81    | 3.17 ± 4.81 |
| L3     | 8.55 ± 8.31   | 5.41 ± 5.82    | 5.41 ± 5.82 |
| L4     | 10.41 ± 6.98  | 7.63 ± 6.13    | 7.63 ± 6.13 |
| Mean   | 5.54 ± 9.03   | 3.86 ± 6.40    | 3.86 ± 6.40 |
| d, cm  | 4.41 ± 0.46** | 4.02 ± 0.39    | 4.02 ± 0.39 |
| L1     | 4.66 ± 0.30** | 4.26 ± 0.29    | 4.26 ± 0.29 |
| L2     | 4.90 ± 0.32** | 4.50 ± 0.30    | 4.50 ± 0.30 |
| L3     | 5.12 ± 0.40** | 4.70 ± 0.34    | 4.70 ± 0.34 |
| L4     | 5.15 ± 0.39** | 4.71 ± 0.38    | 4.71 ± 0.38 |
| Mean   | 4.85 ± 0.46** | 4.45 ± 0.43    | 4.45 ± 0.43 |

RS: right scoliosis group, RKS: right kyphoscoliosis group

*Significance with $P < 0.05$

**Significance with $P < 0.01$

in normal structure, the anatomic position would change. ADS patients were commonly complicated by osteoporosis which may lead to the destruction of the anterior vertebrae. The surgery is usually performed in prone position. Whether the position of the aorta changes from supine to prone position is not clear. Second, kyphosis deformities in ADS patients are not always located in thoracolumbar regions but sometimes in lumbar column; thus, the conclusion may not be applicable for all ADS cases. Last, the sample number in our study is relatively small, so more cases are needed in further research.

### Conclusion

In conclusion, the left pedicle-aorta angle maintained relatively normal in ADS patients. The aorta shifted
slightly away from the left pedicle in ADS patients with RS and kyphosis, especially in those with kyphosis. However, the shift was not obvious in ADS patients with LS. Moreover, the aorta-vertebrae distance was significantly correlated with TLK. The surgeon should evaluate the position of the aorta before operations to avoid vessel injuries. Besides, the vertebral rotation angle is an important parameter to evaluate the severity of the deformity in ADS patients.

Table 5 Pearson correlation analysis between Cobb angle, the horizontal displacement, TLK, and $\alpha$ and $d$

|                  | $\alpha$ r | $\alpha$ p | $d$ r | $d$ p |
|------------------|------------|------------|-------|-------|
| Cobb angle       | 0.019      | 0.899      | 0.052 | 0.733 |
| Coronal movement | 0.050      | 0.740      | 0.779 | 0.060 |
| TLK              | 0.029      | 0.871      | 0.439 | 0.012 |

TLK thoracolumbar kyphosis
Abbreviations

ADS: Adult degenerative scoliosis; LKS: Left scoliosis with thoracolumbar kyphosis; LS: Left scoliosis; RKS: Right scoliosis with thoracolumbar kyphosis; RS: Right scoliosis; TLK: The sagittal angle between superior endplate of T10 and inferior endplate of L2

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Authors’ contributions

YL and XT carried out the molecular genetic studies, participated in the sequence alignment, and drafted the manuscript. YZ participated in the design of the study and performed the statistical analysis. KM, HL, and ZW conceived of the study, participated in its design and coordination, and helped to draft the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Please contact the author for data requests.

Ethics approval and consent to participate

This retrospective study was approved by the Institutional Review Board (IRB) Ethics approval and consent to participate. Please contact the author for data requests.

Consent for publication

All individual person consented for their data to be published.

Competing interests

The authors declare that they have no competing interests.

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