

Comparison of the aorta impingement risks between thoracolumbar/lumbar curves with different convexities in adolescent idiopathic scoliosis: a computed tomography study

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Abstract

Purpose To compare the positions of the aorta relative to vertebral bodies and the potential risk of the aorta impingement for pedicle screw (PS) placement between right-sided and left-sided thoracolumbar/lumbar curves of adolescent idiopathic scoliosis (AIS).

Methods Thirty-nine AIS patients with a main thoracolumbar or lumbar curve were recruited. The Lenke's classification was type 5C in all patients. According to the convexity of the thoracolumbar or lumbar curves, the patients were divided into either group R or Group L. The patients in Group R had a main right-sided thoracolumbar/lumbar curve, and the patients in Group L had a main left-sided thoracolumbar/lumbar curve. Axial CT images from T12 to L4 at the midvertebral body level were obtained to evaluate Aorta-vertebra angle (α), Vertebral rotation angle (β), Lefty safety distance (LSD), and Right safety distance (RSD). The risks of the aorta impingement from T12 to L4 were calculated and then compared between the two groups.

Results The α increased from T12 through L4 in Group R, increased from T12 through L1, and then decreased from L1 through L4 in Group L. The β decreased from T12 through L4 in both groups. The LSD constantly increased from T12 through L4 in Group R, increased from T12 through L3, and then decreased from L3 through L4 in Group L. The RSD increased from T12 through L3 and

then decreased from L3 through L4 in both groups. With the increment of the lengths of the simulated screws, the aorta impingement risks were constantly elevated at all levels in both groups. The aorta was at a high risk of impingement from left PS regardless of the diameters of the simulated screws in Group R (80–100 % at T12 and 53.3–100 % at L1). In Group L, the aorta was completely safe when using 35 mm (0 at all levels) PS and at high risks of the aorta impingement on the right side from 45 mm PSs (31.8–72.7 %). In all, the risks of the aorta impingement were mainly from left PS in Group R and from right PS in Group L, and the risk of the aorta impingement from PS placement was generally higher in right thoracolumbar or lumbar curves when compared with that of the left.

Conclusions The present study illustrated different changed positions of the aorta relative to vertebrae between thoracolumbar/lumbar curves with different convexities. In right-sided curve, the risks of the aorta impingement were mainly from left PS while in left-sided curves, from right PS. The aorta was more proximal to entry points in right-sided lumbar curve when compared with left-sided curve; thus placing PS carries more risks in right-sided thoracolumbar/lumbar curve. Surgeons should be more cautious when placing PSs on the concave sides of T12 and L1 vertebrae of right-sided thoracolumbar/lumbar curves.

Keywords Aorta impingement · Thoracolumbar/lumbar curve · Convexity · Adolescent idiopathic scoliosis

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Introduction

Pedicle screw (PS) has been widely used in the treatment of thoracolumbar/lumbar scoliosis [1]. However, the risks of neural, vascular, and visceral injuries from malpositioned

pedicle screws have raised some concerns in this region [2–4]. The aorta may be at the risk of impingement and even perforation, if it is located at the trajectory of PS and when the PS perforates the anterior or lateral wall of vertebral body.

Several studies have been conducted regarding the position of the aorta in either normal subjects or scoliotic patients [5–7]. These studies demonstrated that the aorta is always located on the left side of the thoracic spine and stays in front of the lumbar spine in normal subjects [5] while tending to reside on the lateral side of the spine in scoliotic patients, and this change may elevate the risk of the aorta impingement when placing screws on the concave side of the thoracic spine [6–9]. However, the majority of such studies have always paid attention to the relative position of the aorta to thoracic vertebrae, and there was little information concerning the relative position of the aorta to thoracolumbar or lumbar vertebrae [6–10]. Moreover, these studies did not include curve pattern into consideration as most studies were performed on patients with right-sided thoracic curves and did not compare the risk of the aorta impingement among different curve patterns. We postulated that the position of and the impingement risk of the aorta might be different among various curve patterns of AIS. The purpose of this study was to compare the positions of the aorta relative to vertebral bodies and the potential risk of the aorta impingement for PS placement between right- and left-sided thoracolumbar/lumbar curves of AIS.

Materials and methods

A retrospective review of AIS patients from our hospital database who had CT images of the lower thoracic and lumbar spine from January 2009 through October 2011 was

performed. The following inclusion criteria were applied: (1) a single main thoracolumbar or lumbar curve with thoracic curves $<25^\circ$; (2) Cobb angle: $40^\circ \sim 70^\circ$; (3) normal thoracic kyphosis without thoracolumbar junctional kyphosis, and (4) no previous spinal or/and cardiothoracic surgery. Patients with a known congenital vascular abnormality were excluded from the study. Thirty-nine patients were recruited. The Lenke's classification was type 5C in all patients. According to the convexity of the thoracolumbar/lumbar curve, the patients were divided into either Group R or Group L. The patients in Group R had a main right-sided thoracolumbar/lumbar curve, and those in Group L had a main left-sided thoracolumbar/lumbar curve. In both groups, the curves were measured on standard standing posterior-anterior X-ray radiographs according to the Cobb method, and the heights of subjects were measured. The corrected heights were calculated using Bjure formula ($\text{Log } y = 0.011x + 0.177$, where y is the loss of trunk height (cm) caused by the spinal deformity, and x is the Cobb angle of the primary curve) [11].

CT measurements

The CT scans were performed using a spiral CT scanner (LightSpeed, GE Healthcare) with the following parameters: 320 mAs, 120 kVP., and 5-mm thickness with a 5-mm gap between the slices. To quantify the relative positions of the aorta to vertebrae, the following radiographic parameters were measured from the CT imagines of the middle transverse planes of vertebrae from T12 through L4:

1. Aorta-vertebra angle (α) (Fig. 1): subtended by the tangent line of the anterior margin of vertebral canal and the line from the posterior midpoint of the vertebral body to the midpoint of the aorta. The angle was defined as 0° when the aorta was located directly

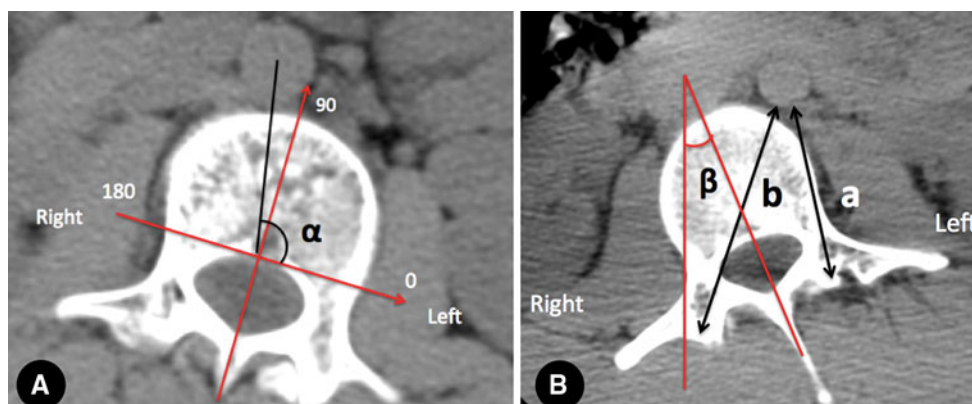


Fig. 1 Illustration of parameters measured on the CT images. **A** A 16-year-old female patient with AIS had a left lumbar curve of 53° . α : Aorta-vertebra angle. **B** A 15-year-old female patient with AIS had a

right lumbar curve of 49° . β : Vertebral rotation angle *a* Left safety distance (LSD) *b* Right safety distance (RSD)

- laterally to the left, 90° when it was located strictly anteriorly, and 180° when it was located directly laterally to the right [8].
2. Vertebral rotation angle (β) (Fig. 1): formed between a perpendicular line starting from the posterior central aspect of the spinal canal and a straight line through the posterior central aspect of the spinal canal and the middle of the vertebral body [12].
 3. Left safety distance (LSD) (Fig. 1): the line connecting the ideal entry point of the left PS (middle of the base of the left superior facets) and the posterior edge of the aorta.
 4. Right safety distance (RSD) (Fig. 1): the line connecting the ideal entry point of the right PS (middle of the base of the right superior facets) and the posterior edge of the aorta.

Potential risk of aorta impingement from PS placement

We simulated placements of the PSs. The lengths of screws were 35, 40, and 45 mm (three scenarios). The aorta was considered at a potential risk of impingement when the safety distance (LSD or RSD) was less than pedicle screw length. The percentages of the vulnerable aorta on right and left sides of the spine at all levels were analyzed.

Statistical analysis

The data were analyzed using SPSS 13.0 for Windows (Chicago, IL). A related two-sample test (the Wilcoxon signed-rank test) was performed to determine the differences between the two groups. Significance was defined as a P value <0.05. The percentages of aorta at a potential risk of impingement were calculated on both sides in AIS patients to analyze the risks of the aorta impingement from PS placemen in three scenarios.

Results

The study cohort consisted of 39 female AIS patients: 17 patients with a right-sided thoracolumbar/lumbar curve

were assigned to Group R, and 22 patients with a left-sided thoracolumbar/lumbar curve were assigned to Group L. The average age of the patients was 15.2 years (range, 12–18 years) in Group R and 14.9 years (range, 12–18 years) in Group L. No difference in either the ages or the Risser signs was found between the two groups ($P > 0.05$). In Group R, the Cobb angles of the thoracolumbar/lumbar curves ranged from 41 to 50, with an average of 43 while in Group L, the Cobb angles of the thoracolumbar/lumbar curves ranged from 42 to 58 with an average of 47.5. The mean corrected height was 162.4 cm (range, 157–168 cm) in Group R, and 161.7 (range, 154–169 cm) in Group L. No significant difference of the corrected heights was noted between two groups ($P > 0.05$).

CT measurement

A total of 85 vertebrae were measured in Groups R and 110 in Group L; the results are summarized in Table 1. The α increased gradually from T12 through L4 in Group R, increased from T12 through L1, and decreased from L1 through L4 in Group L, which suggested that the aorta moved from the left side of the vertebra to a more anterior position from T12 through L4 in patients with right-sided thoracolumbar/lumbar curves while moved from the right anterolateral side of the vertebrae to the front of vertebral body from L1 through L4 in patients with left-sided thoracolumbar/lumbar curves (Fig. 2).

The LSD constantly increased from T12 through L4 in Group R, increased from T12 through L3, and then decreased from L3 through L4 in Group L. The RSD showed a similar tendency in both groups, increased from T12 through L3, and decreased from L3 through L4 (Fig. 2).

Potential risk of the aorta impingement

The percentages of the aorta at a potential risk of the aorta impingement from PS insertion were demonstrated in Table 2. With the increment of the lengths of the simulated screws, the aorta impingement risks were constantly elevated at all levels in both groups.

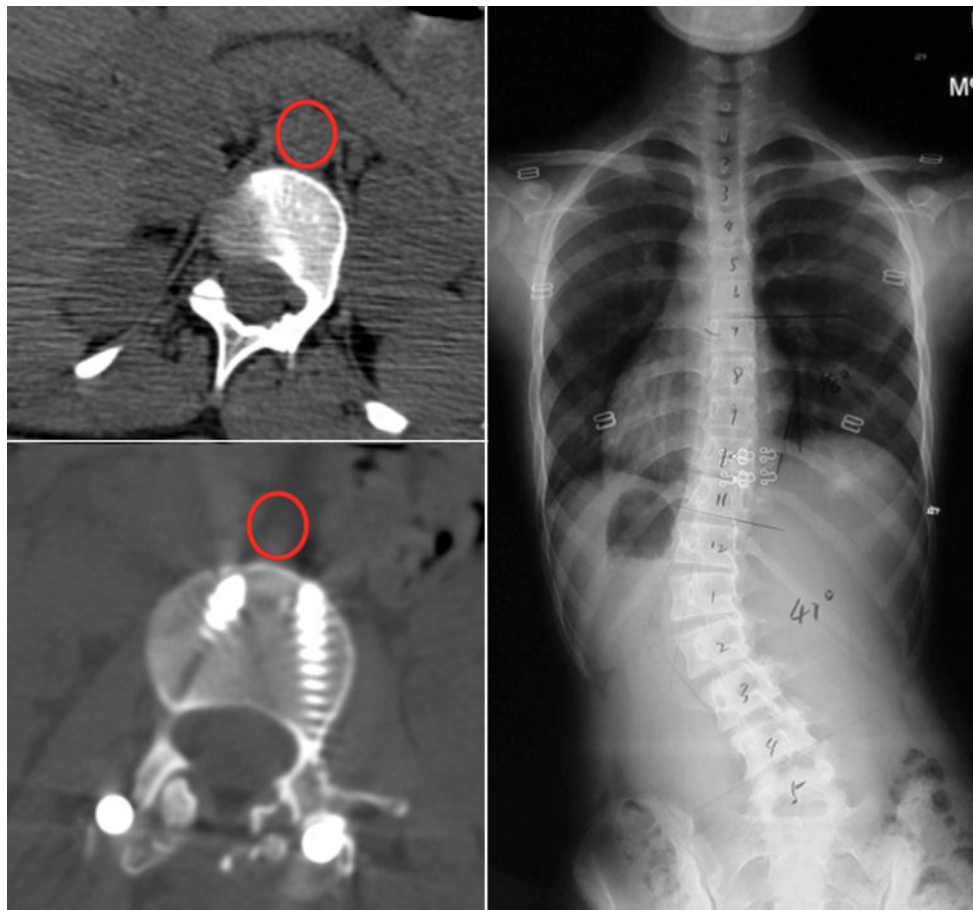
Table 1 Distribution of the parameters from T12 to L4 in Group R and Group L

	T12		L1		L2		L3		L4	
	R	L	R	L	R	L	R	L	R	L
α (°)	41.5	102.5	47.1	112.0	54.8	106.4	65.3	99.1	73.9	89.4
β (°)	24.9	26.6	23.9	24.0	20.4	24.6	20.2	23.3	17.4	18.3
LSD (mm)	31.1	45.7	34.9	44.4	38.8	46.7	42.9	46.8	44.2	46.4
RSD (mm)	45.6	43.3	48.3	44.0	49.7	44.6	50.3	43.3	49.3	48.3

α Aorta-vertebral angle, β Vertebral rotation angle, LSD Left safety distance, RSD safety distance

Table 2 Distribution of the aorta-at-risk cases in three simulated scenarios

	35 (mm)		40 (mm)		45 (mm)	
	Group R	Group L	Group R	Group L	Group R	Group L
T12						
Left side	82.4 % (14)	0	100 % (17)	0	100 % (17)	40.9 % (9)
Right side	0	0	0	13.6 % (3)	40 % (6)	72.7 % (16)
L1						
Left side	52.9 % (9)	0	88.2 % (15)	0	100 % (17)	18.2 % (4)
Right side	0	0	0	4.5 % (1)	13.3 % (2)	72.7 % (16)
L2						
Left side	11.8 % (2)	0	52.9 % (9)	0	94.1 % (16)	9.1 % (2)
Right side	0	0	0	0	26.7 % (4)	45.5 % (10)
L3						
Left side	0	0	17.6 % (3)	0	76.5 % (13)	4.5 % (1)
Right side	0	0	0	0	20 % (3)	31.8 % (7)
L4						
Left side	5.9 % (1)	0	11.8 % (2)	13.6 % (3)	41.2 % (7)	54.5 % (12)
Right side	0	0	0	0	20 % (3)	40.9 % (9)

**Fig. 2** A 16-year-old female patient with AIS had a left lumbar curve. The aorta was located in the front of a L1 vertebral body with a α of 93° . Two 45-mm PSs were placed without the aortic abutment

The aorta was at a high risk of impingement from left PS placement irrespective of the diameters of the simulated screws in Group R (80–100 % at T12 and 53.3–100 % at L1). In Group L, the aorta was safe when using 35 mm (0 at all levels) PS and at risks of impingement from 45 mm PS placement on the right pedicles (31.8–72.7 %). In all, the risks of the aorta impingement were mainly from left PS in Group R and from right PS in Group L, and the risk of the aorta impingement from PS placement were generally higher in right-sided thoracolumbar/lumbar curves when compared with the left-sided curves.

Discussion

The aorta tends to follow the concavity of the curve [6]. For right thoracic curves, the thoracic aorta shifted to the left side of the curves and was positioned more left laterally and posteriorly to the vertebral body, while for left thoracic curves it moved to the right and was positioned anterior to the vertebral body. Milbrandt et al. [7] ascribed the changes of the relative position of the aorta to vertebral body to the tethering effect of diaphragm. The aorta was caught in place by the surrounding crux of the diaphragm and then forced into the concave side of the curves for it is the shortest distance between the top and the bottom of the chest cavity, as is especially true for the lumbar aorta. In a normal subject, the aorta is not located at the middle front of vertebral body, but at a center-left position to vertebral body in thoracolumbar and lumbar region (12 to 1 o'clock position using a clock analogy) (Fig. 3). In left thoracolumbar/lumbar curves, as vertebra rotates towards the left, the aorta relatively shifts towards the right, and stops at the direct front of vertebral body, further from the posterior

entry point. In right curves, as vertebra rotates towards the right, the aorta further shifts towards the left, and goes closer to the left posterior entry point, elevating the risks of the aorta impingement. The subsequent measurement demonstrated that the mean distances between the aorta and the left posterior entry point almost reached 45 mm at all levels in left curves, but less than 35 mm at T12 and L1 levels in left curves. It meant that the aorta had more possibilities of being impinged in right thoracolumbar/lumbar curves than in left curves.

Previous studies set different scenarios that simulated screw placement with different lengths and trajectory error angles to analyze the risks of the aorta impingement from PS [13, 14]. We feel that the safety distance may be more important than the angle of trajectory for risks analysis. From a surgical standpoint, surgeons always want to place PS following an ideal trajectory, and when malposition occurred, the trajectory error angles could not be anticipated. Moreover, as the lumbar aorta is located in front of the vertebral body, the ideal trajectory always directly passes the aorta. Ignoring the length of PS, the aorta was always at impingement risks even when the PSs were precisely placed. Actually, the aorta was at impingement risks only when the screw length was larger than the distance between entry points and the aorta (Fig. 2). Therefore, we simulated three scenarios for screw placement based on the screw length and the distance between entry point and aorta without taking trajectory error angle into consideration. The risk analysis showed that the aorta impingement risks were constantly elevated when the diameters of the simulated screws increased especially in right curves. Obviously, the shorter the screw length, the smaller the risk of aorta impingement, and 35 mm PSs seem to carry smaller risks of the aorta impingement at

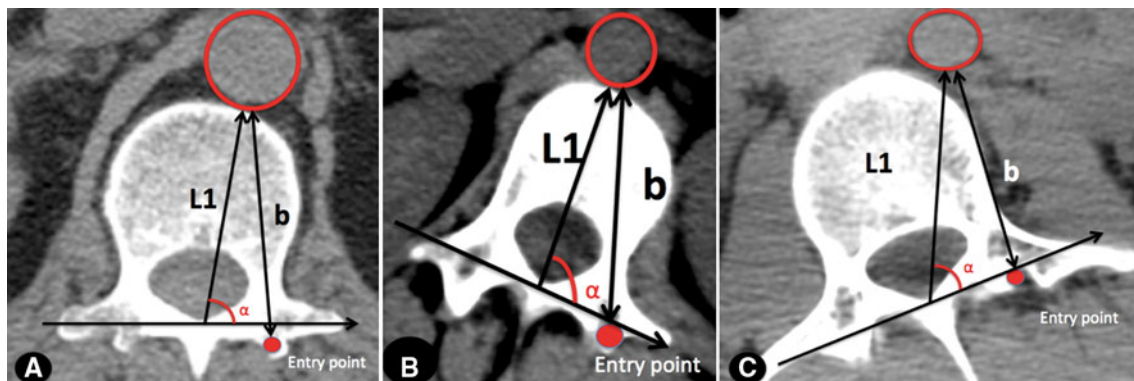


Fig. 3 Different relative positions of the aorta to L1 vertebrae. **A** No spinal deformity. The aorta was at a center-left position to vertebral body. The α angle was 80° , and the distance from the aorta to the left posterior entry point for screw (b) was 41 mm; **B** left lumbar

scoliosis. The aorta was located laterally to the left wall of vertebral body. The α angle was 62° , and the b distance was 36 mm; **C** right lumbar scoliosis. The aorta was at the middle-front of the vertebral body. The α angle was 94° , and the b distance was 46 mm

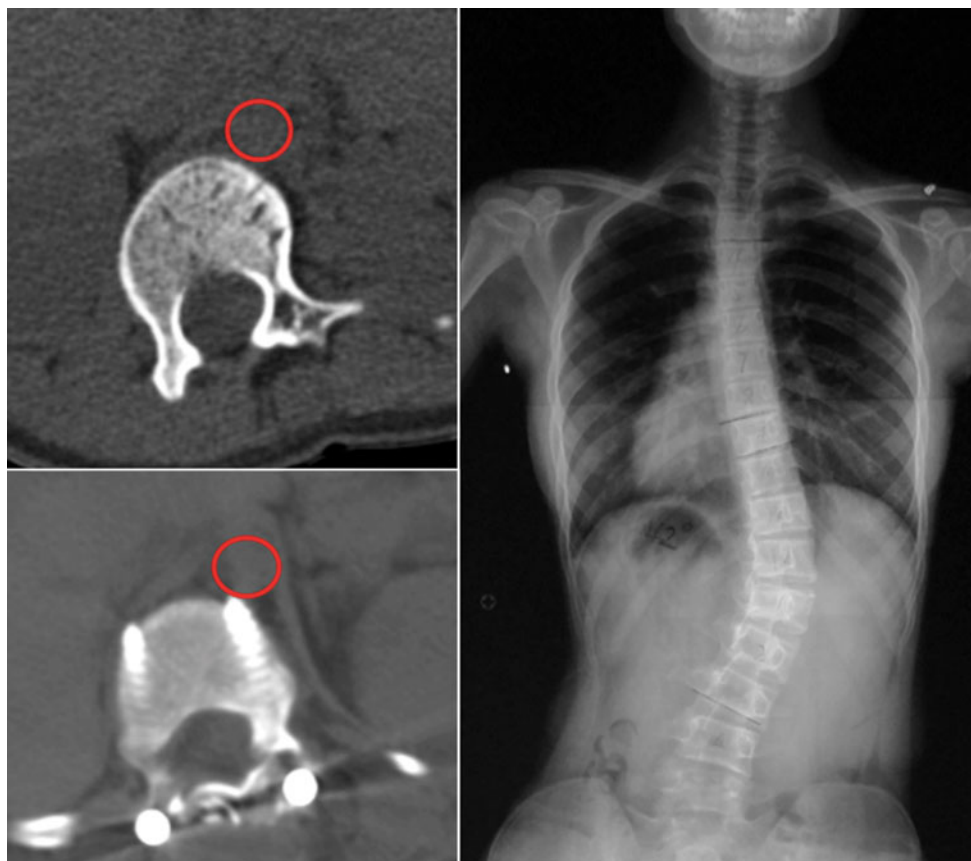


Fig. 4 A 14-year-old female patient with AIS had a right lumbar curve. The aorta was located anterolaterally to the left half of a L1 vertebral body with a α of 49°. Two 40-mm PSs were placed, and the left PS appeared to deform the normal outline of the aorta

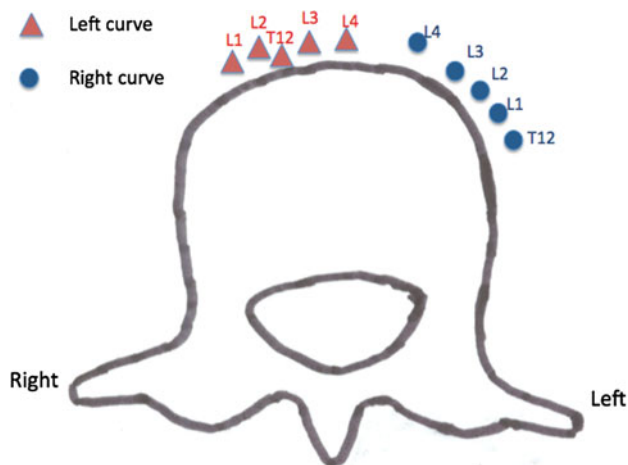


Fig. 5 The average course of the aorta relative to the spine in right and left thoracolumbar/lumbar curves. The point was defined by the mean aorta-vertebra angle and the mean left safety distance at each level. The aorta surrounded the left half of the vertebral bodies in right thoracolumbar/lumbar curves while surrounding the right half of the vertebral bodies in the left, and the relative positions of the aorta to vertebral bodies were more posterolateral in right curves when compared with those in the left

thoracolumbar region when compared with 40 mm PSs. However, the difference of the risks was not significant, and 40 mm PS could provide bigger fixation strength. Moreover, the aorta at thoracolumbar region largely deviated from the ideal trajectory of PS in right curves, and PSs were rarely placed at such a big error angle. Based on these facts, we still recommend using 40 mm at thoracolumbar vertebrae in right curves.

After comparing the risks of impingement between left-sided and right-sided thoracolumbar/lumbar curves, we found that the risks of the aorta impingement were mainly from left PS in right-sided curves and from right PS in left-sided curves. As has been mentioned, with the rotation of vertebrae, the PS entry points at concave side of curves approximate the aorta, thus shortening the safety distance for PS placement (Fig. 4). In addition, the risks of the aorta impingement were generally higher in right-sided curve, especially in T12 and L1 levels (82.4 and 52.9 % using 35 mm PSs while 100 and 88.2 % using 40 mm PSs), which could be ascribed to the more posterior position of the aorta in right-sided curve (Fig. 5). Globally, placing PS carries more risks in right-sided curve than in left-sided

curve. Besides, the spinal cord tends to shift to the concave side, which further elevates the risks of neurovascular complication for left PS placement in right-sided thoracolumbar/lumbar curves.

Conclusion

The present study illustrated the different migration of the aorta relative to vertebrae in thoracolumbar/lumbar curves with different convexities. In right-sided curve, the risks of the aorta impingement were mainly from left-side PS while mainly from right-side PS in left-sided curves. The aorta was more proximal to the left posterior cortical entry point in right-sided thoracolumbar/lumbar curve than in left-sided curve. Surgeons should be particularly cautious when placing PSs on the concave sides of T12 and L1 vertebrae of right thoracolumbar/lumbar curves.

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Conflict of interest None.

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