The anatomical relationship between the aorta and the thoracic vertebral bodies and its importance in the placement of the screw in thoracoscopic correction of Scoliosis

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Abstract Thoracoscopically-assisted anterior spinal instrumentation is being used widely to treat adolescent idiopathic scoliosis (AIS). Recent studies have showed that screws placed thoracoscopically could counter the aorta or entrance into the spinal canal. There are a few studies defining the anatomic landmarks to identify the relationship between the aorta and the thoracic vertebral body using quantitative measurement for the sake of safe placement of thoracoscopic vertebral screw in anterior correction for AIS. The CT scanning from T4 to T12 in 64 control subjects and 30 AIS patients from mainland China were analyzed manually. Parameters to be measured included the angle for safety screw placement (α), the angle of the aorta relative to the vertebral body (β), the distance from the line between the left and the right rib heads to the anterior wall of the vertebral canal (a), the distance from the left rib head to posterior wall of the aorta (b), the vertebral body transverse diameter (c) and vertebral rotation (γ). No significant differences were found between the groups with respect to age or sex. Compared with the control group, α angle from T7 to T10, β angle from T5 to T10 and b value at T9, T10 were significantly lower in the scoliotic group. The a value was significantly lower in the scoliotic group. The c value showed no significant difference between the two groups. In conclusion, to place the thoracoscopic vertebral screw safely, at the cephalad thoracic spine (T4–T6), the maximum ventral excursion angle should decrease gradually from 20° to 5°, the entry-point of the screw should be close to the rib head. For apical ver-

tebrae (T7–T9), the maximum ventral excursion angle increased gradually from 5° to 12°. At the caudal thoracic spine (T10–T12), the maximum ventral excursion angle increased, the entry-point should shift 3–5 mm ventrally.

Keywords Aorta · Thoracic vertebrae · Anatomy · Thoracoscopy · Scoliosis

Introduction

Comparing with the control subjects, the thoracic aorta in patients with right main thoracic adolescent idiopathic scoliosis (AIS) was found to shift more posteriorly and closely to the vertebra because of the vertebral rotation and morphological anomaly at the vertical plane [13, 22, 23]. For this reason, the placement of the screws in these patients thoracoscopically was subject to the complication of aorta injury and the penetration of the spinal canal [4, 6, 8, 11, 18, 19]. At present, only a few studies quantitatively mentioned the anatomic relationship between thoracic aorta and thoracic vertebrae [13, 22, 23]. Through morphometric comparison of the spatial relationship between thoracic aorta and thoracic vertebrae in right thoracic scoliosis patients and that in control subjects, the present study aims to find the safe entry point, trajectory, and length of screw for Chinese AIS as well as providing the anatomic reference data for correct screw placement under thoracoscopy.

Methods

Sixty-four patients without any spinal deformity who had axial thoracic CT because of non-vertebral pathology were

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chosen as the control group. Patients with any congenital malformation or other diseases which may affect the normal anatomy of thoracic vertebrae and aorta were excluded. There were 28 males and 36 females with an average age of 13.3 years (range 15–20 years) in the control group. The scoliosis group was composed of 30 cases of right main thoracic idiopathic scoliosis including 8 males and 22 females, with an average age of 15.7 years (range 13–20 years), posteroanterior and lateral radiographs and pan spinal cord MRI have been performed to ensure that the scoliosis was idiopathic. Patients with proven or suspected congenital, muscular or neurological scoliosis was excluded. The patients in both groups were from mainland China.

Spiral scans were obtained on a 16-multidetector-spiral CT (MDCT) scanner (LightSpeed, GE Healthcare) with the following parameters: 320 mAs, 120 kVp, 10 mm slice thickness. Images showing bilateral rib heads and costovertebral joints were selected for measurement. The transverse CT images from T4 to T12 in both groups were measured with conimeter, vernier caliper and compasses with respect to the following parameters (Fig. 1): (1) The angle formed by the line that passed the anterior edge of the bilateral rib heads (Line RR) and the line from the anterior edge of the right rib head to the posterior wall of the aorta (α), (2) the angle composed by Line RR and another line from the anterior midpoint of the spinal canal to the center of the aorta (β), (3) the vertical distance from the line RR to the anterior wall of the spinal canal (a), (4) the distance from the anterior edge of the left rib head to the posterior wall of the aorta (b), (5) the vertebral body transverse diameter (c), (6) vertebral rotation (γ) i.e. RASag angle [10].

Statistical analysis was performed with the use of SPSS software (version 11.5, America). Mean values $\pm$ standard deviations were calculated for all variables at each level. Comparisons were made between the two groups with the use of the student t test. Significance was defined as a $P < 0.05$.

Table 1 Measurements of T4–T12 in normal subject

	<i>n</i>	α (°)	β (°)	<i>a</i> (mm)	<i>b</i> (mm)	<i>c</i> (mm)
T4	44	28 ± 9	61 ± 8	6 ± 3	18 ± 6	26 ± 2
T5	44	13 ± 9	47 ± 10	6 ± 2	8 ± 6	27 ± 2
T6	45	9 ± 8	43 ± 9	5 ± 2	6 ± 5	28 ± 2
T7	44	12 ± 9	45 ± 11	5 ± 2	7 ± 5	29 ± 2
T8	46	18 ± 9	50 ± 10	4 ± 2	12 ± 6	30 ± 2
T9	48	22 ± 10	55 ± 13	3 ± 2	14 ± 6	32 ± 3
T10	49	27 ± 9	59 ± 16	3 ± 2	18 ± 6	33 ± 3
T11	42	32 ± 7	67 ± 9	2 ± 2	22 ± 6	35 ± 2
T12	39	36 ± 6	71 ± 8	0 ± 3	26 ± 5	38 ± 2

Results

No significant differences were found between the two groups with respect to age or gender distribution. In the scoliosis group, Cobb angles ranged from 40° to 70° with an average of 54° . No anomaly of thoracic vertebrae and aorta were found except scoliosis, and the most common apical vertebra was eighth thoracic vertebra. A total of 403 vertebrae in the control group and 266 vertebrae in the scoliosis group were measured. The measurement results in the control group and the scoliosis group were summarized in Tables 1 and 2. The α angle, β angle and b value had a tendency to decrease and then increased from T4 to T12, and values were generally lower in the scoliosis group than that in the control group (Fig. 2). The α angle from T7 to T10, β angle from T5 to T10 and b values at T9, T10 were significantly lower in the scoliosis group. The a value decreased steadily from the cephalic to the caudal aspect of the spine in both groups and became negative at T11 and T12 in the scoliosis group, while the values were significantly lower in the scoliosis group from T4 to T11 (Fig. 3). The c value of both groups increased gradually from T4 to T12, however, no significant difference was found at any segment level other than T7. The γ angle in the scoliosis

Fig. 1 Measurement of index in control group and scoliotic group. **a** The vertebra of normal subject; **b** the vertebra of AIS patient

Table 2 Measurements of T4–T12 in scoliotic group

	<i>n</i>	α (°)	β (°)	<i>a</i> (mm)	<i>b</i> (mm)	<i>c</i> (mm)	γ (°)
T4	30	29 ± 13	61 ± 19	4 ± 2*	17 ± 8	26 ± 2	-13 ± 6
T5	30	10 ± 11	39 ± 18	2 ± 2	7 ± 7	28 ± 3	-10 ± 8
T6	30	6 ± 10	33 ± 15	2 ± 2	4 ± 6	29 ± 4	-3 ± 9
T7	30	5 ± 8	27 ± 12	1 ± 2	5 ± 6	30 ± 4	7 ± 7
T8	30	11 ± 9	32 ± 14	1 ± 1	9 ± 8	31 ± 3	13 ± 5
T9	30	13 ± 9	38 ± 12	1 ± 2	8 ± 6	32 ± 4	13 ± 7
T10	30	18 ± 12	44 ± 15	1 ± 3	13 ± 8	33 ± 3	12 ± 9
T11	29	27 ± 12	69 ± 55	-1 ± 2	21 ± 8	35 ± 4	4 ± 12
T12	27	35 ± 12	69 ± 19	-2 ± 3	27 ± 8	37 ± 4	-3 ± 15

Each group is normal distribution

Asterisk indicates $P < 0.05$ (compared with the contrast group)

group also had a tendency to increase and then decrease from T4 to T12, while the value was larger at the periapical levels. At the periapical levels, there were significant negative corrections between the vertebral rotation and the β angle ($R = -0.765$, $P < 0.05$).

Discussion

At present, the correction of scoliosis under thoracoscopy has been performed on some thoracic AIS patients, especially those with the Cobb angle less than 70° or relatively flexible curve [21]. The thoroscopic technique features

Fig. 3 The change of *a* value. The *a* value decreased steadily from T4 to T12 in both groups and became negative at T11 and T12 in the scoliosis group, while it was significantly smaller in the scoliosis group from T4 to T11

minimal injury, fewer complications, faster recovery, reduced pain, fewer respiratory compromises and cosmetically a less prominent surgical scar when compared with the traditional anterior thoracotomy approach [2, 9, 15–17, 20]. With the increasing popularity of this technique, there has also been an increasing concern over the proximity of the descending aorta to the tips of screws and the possibility of vessel wall erosion over time [3, 8, 13, 24, 26]. Due to the rotation and distortion of vertebra, the deflected aorta and the deformed morphology of the spinal canal in patients with scoliosis [13, 22, 23], the insertion of vertebral screws during scoliosis correction may place the

Fig. 2 The change of α angle, β angle and *b* value. The α angle, β angle and *b* value had a tendency to decrease and then increase from T4 to T12, and values were generally lower in the scoliosis group than in the control group, significant differences of the α angle were found from T7 to T10, the β angle from T5 to T10, *b* values at T9 and T10

patient at risk for aorta injury and violation of the spinal canal (Fig. 4). Although no thoracic aorta complication caused by the placement of vertebral screw through thoracoscopic technique in AIS patients has been reported, some aortic complications such as screw penetration [14], aortic laceration [25], false aneurysm of the thoracic aorta [1, 5] have been found in anterior spinal instrumentation for other diseases.

Proper placement of the screws during anterior corrective surgery of scoliosis showed great importance and challenge to spine surgeons. Picetti et al. [21] suggested usage of capitulum costae and vertebra segment vessel as the position landmark of screw placement. Ebara et al. [7] recommended a new thoracoscopic instrument to measure the transverse diameter of vertebra after removing the intervertebral discs. Despite these studies, there was little information documenting the relationship of the aorta to the thoracic scoliotic spine and little anatomic data based on the pathological morphology of scoliosis. Through analyzing the CT images of the apical vertebra T8 or T9, Sevastik et al. [22] found that the mean lateral translation distance from the aorta to the mid axis of the vertebral body in the scoliosis group increased, while the vertical distance from the aorta to the mid axis of the vertebral body reduced compared with the adult control group. Liljenqvist et al. [12] got the same result by measuring the distance from the aorta to the vertebra, without comparing with the normal spine. By analyzing the magnetic resonance images from the fourth thoracic vertebra to the third lumbar vertebra, Sucato et al. [23] found that the aorta was located more laterally and posteriorly relative to the vertebral body in patients with right thoracic idiopathic scoliosis compared with that in patients without scoliosis.

Fig. 4 Display the spacial relationship of screw and vertebrae

In the present study, the vertebrae from T4 to T12 in patients with scoliosis and age-matched controls were analyzed. A total of 401 vertebrae in the control group and 266 vertebrae in the scoliosis group were measured in the present study, and the parameters of α angle, a value and b value were taken to ensure the safety of the placement of the screws. The α angle and b value could reflect the safe margin of screw insertion, and the a value could predict the possibility of spinal cord injury during placement of the screw, then the β angle along with γ angle would show the extent of aortic displacement. The c value provided a reference index in screw length selection.

The displacement of the aorta in patients with scoliosis was expressed as the aorta-vertebral angle or β angle in the present study. Both Sucato et al. [23] and Sevastik et al. [22] found that the aorta was positioned more posteriorly in patients with AIS than in patients with a normal spine. The present study showed that β angle was smaller in the scoliosis group than that in the age matched control group at every vertebra, and the differences were significant from T5 to T10 ($P < 0.01$) particularly close to the apex of the curve (T7 to T9), with an angle of 45.2° and 26.9° , respectively, at the seventh thoracic vertebrae in control and scoliosis group; 50.3° and 31.5° , respectively, at the eighth thoracic vertebrae; and 54.8° and 37.6° , respectively, at the ninth thoracic vertebrae. As the rotational deformity increased in the scoliosis group, the β angle relative to the vertebral body decreased, and this negative correlation was significant in the periapical levels. The vertebral rotation was significant in the apex and the γ angle was 13.4° , which was similar with the report of Sucato [23]. But at proximal and distal thoracic levels, the vertebrae rotated to the convex side and γ angle turned out to be negative.

The safe margin for screw insertion was affected by the displacement of the aorta. The aorta arch was located more anterior to the vertebra at T4 level (α angle was 29.1° , b was 17.3 mm), which indicated that the screw placement in T4 was safe and unlikely to injure the aorta unless the insertion angle exceeded 29° . From T5 to T12, compared with that in the control group, α angle and b values in scoliosis group were relatively lower, the difference in α angle at T7–T10 levels and b value at T9, T10 levels are significant (Fig. 2). It showed that the aorta was positioned more posteriorly to vertebrae and a safe margin for screw insertion decreased especially at the apex of the curve (T7–T10), where the vertebra rotation angel (γ) was increased. Sucato et al. [24] analyzed the accuracy of the vertebral screw placed following thoracoscopic anterior instrumentation. Fifteen (14.2%) of 106 screw tips were adjacent to the aorta, and there were 13 (12.3%) screws that were thought to create a contour deformity of the aorta. During Maruyama's [13] study, the aorta was found to be

located posteriorly between T6 and T9 in patients with AIS, at these levels the aorta was found to be crossed by a line that passed the anterior edge of the bilateral rib heads in 33 of 40 vertebrae, so giving up the bicortical screw position at these levels were suggested. In the present study, the *b* value was minimum (4–8 mm) and from T5 to T9 in the scoliosis group the aorta was very close to the lateral wall of the vertebra. According to α angle, the safe ventral excursion angle couldn't exceed 5° at T6 and T7, 10° at T5 and T8 and 12° at T9, respectively. To get the bicortical fixation without violating the aorta, the screw could run nearly parallel to the posterior wall of the vertebral body directed to the rib head of the opposite side. In addition, the safe ventral excursion angle couldn't exceed 17° at T10 and 20° at T4, T11 and T12 while bicortical fixation was also recommended.

In the study of Sucato et al. [24], four screws at proximal and distal thoracic levels (T5, T6, and two at T12) were found to be violating the posterior cortex of the vertebral body. Zhang and Sucato [26] have studied the position of the rib head with respect to the spinal canal and vertebral body in both normal patients and those with right thoracic AIS using MRI. They have found that the percent of the vertebra obscured by the rib head significantly decreased from T4 to T12 in both groups and no significant difference was found at the same thoracic levels between the two groups. They concluded that when placing anterior thoracic screws at the caudal thoracic spine (T10–T12), staying anterior to the rib head was important to avoid penetration into the spinal canal. In the present study, the vertical distance from Line RR to the anterior wall of the spinal canal (*a*) decreased steadily from T4 to T12 in both groups, while it turned out to be negative from T10 to T12 with the minimum negative value, –6 mm in the scoliosis group. The *a* value was significantly lower in the scoliosis group at all segment levels but T12, which was opposite to Zhang et al. [26]. In the scoliosis group, the *a* value was 0.5 ± 3.0 mm at the tenth thoracic vertebrae, -1.4 ± 1.9 mm at the 11th thoracic vertebrae and -1.6 ± 3.3 mm at the 12th thoracic vertebrae. Because the *a* value (the vertical distance from the line RR to the anterior wall of the spinal canal) decreased steadily from the cephalic to the caudal levels of the spine in both groups and became negative at T11 and T12 in the scoliosis group, the risk of screw violating into spinal canal would increase when the screw entry-point was still close to the rib head. Considering the screw was usually 6.5 or 5.5 mm in diameter, we recommend 3–5 mm ventral shift to the rib head at T10–T12 and be parallel to the rib head at T4–T9.

The screw length, which could be estimated by measuring the transverse diameter of vertebra on the CT scanning, was generally longer than that of the reported results [12]. The *c* value at the fourth to the 12th thoracic

vertebra increased from 26.2 to 37.1 mm in the scoliosis group and from 26.2 to 37.9 mm in the control group, for an average increase of 1.2 and 1.3 mm per level, respectively, which was similar to Sucato's [23] finding. Stefan et al. [21] have reported the vertebral deformation of scoliosis, but in the present study the transverse diameter of the vertebral body showed no significant difference at any of the segment levels except for T7 between the two groups. It posed problems with present instrumentation systems that the incremental changes in screw length was 5 mm. Large increments would increase the risk of vascular injuries to the thoracic vertebrae. According to the present results, we suggested that the optimal screw length be 25 mm from T4 to T6 and 30 mm from T7 to T9, 35 mm from T10 to T12.

In conclusion, to place the thoracoscopic vertebral screw safely, at the cephalad thoracic spine (T4–T6), the maximum ventral excursion angle should decrease gradually from 20° to 5°, the entry-point of the screw should be close to the rib head and the optimal screw length was 25 mm. At apical area (T7–T9), the maximum ventral excursion angle should increase gradually from 5° to 12°, and the optimal screw length was 30 mm. At the caudal thoracic spine (T10–T12), the maximum ventral excursion angle increased, the entry-point should shift 3–5 mm ventrally and the optimal screw length was 35 mm. In addition, the variation of the vertebral rotation and morphology in different patients should also be taken into consideration, and preoperative measurement of CT scanning may be helpful in determining the precise screw selection. Another important thing was that patient should be placed in straight lateral position.

References

1. Ahat E, Tuzun H, Bozkurt AK, Kaynak K, Erolcay HA (1996) False aneurysm of the descending aorta due to penetrating injury. *Injury* 27:225–226
2. Arlet V (2000) Anterior thoracoscopic spine release in deformity surgery: a meta-analysis and review. *Eur Spine J* 9S:S17–S23
3. Baker JK, Reardon PR, Reardon MJ, Heggeness MH (1993) Vascular injury in anterior lumbar surgery. *Spine* 18:2227–2230
4. Bullmann V, Fallenberg EM, Meier N, Fischbach R, Schulte TL, Heindel WL, Liljenqvist UR (2005) Anterior dual rod instrumentation in idiopathic thoracic scoliosis: a computed tomography analysis of screw placement relative to the aorta and the spinal canal. *Spine* 30:2078–2083
5. Choi JB, Han JO, Jeong JW (2000) False aneurysm of the thoracic aorta associated with an aorto-chest wall fistula after spinal instrumentation. *J Trauma* 50:140–143
6. Dunn HK (1986) Anterior spine stabilization and decompression for thoracolumbar injuries. *Orthop Clin North Am* 17:113–119
7. Ebara S, Kamimura M, Itoh H, Kinoshita T, Takahashi J, Takaoka K, Ohtsuka K (2000) A new system for the anterior restoration and fixation of thoracic spinal deformities using an endoscopic approach. *Spine* 25:876–883

8. Huitema GC, van Rhijn LW, van Ooij A (2006) Screw position after double-rod anterior spinal fusion in idiopathic scoliosis: an evaluation using computerized tomography. *Spine* 31:1734–1739
9. Husted DS, Yue JJ, Fairchild TA, Haims AH (2003) An extrapedicular approach to the placement of screws in the thoracic spine: an anatomic and radiographic assessment. *Spine* 28:2324–2330
10. Krismer M, Bauer R, Sterzinger W (1992) Scoliosis correction by Cotrel-Dubousset instrumentation. The effect of derotation and three dimensional correction. *Spine* 17:S263–S269
11. Kuklo TR, Lehman RA Jr, Lenke LG (2005) Structures at risk following anterior instrumented spinal fusion for thoracic adolescent idiopathic scoliosis. *J Spinal Disord Tech* 18:S58–64
12. Liljenqvist UR, Allkemper T, Hackenberg L, Link TM, Steinbeck J, Halm HF (2002) Analysis of vertebral morphology in idiopathic scoliosis with use of magnetic resonance imaging and multiplanar reconstruction. *J Bone Joint Surg Am* 84:359–368
13. Maruyama T, Takeshita K, Nakamura K, Kitagawa T (2004) Spatial relations between the vertebral body and the thoracic aorta in adolescent idiopathic scoliosis. *Spine* 29:2067–2069
14. Matsuzaki H, Tokuhashi Y, Wakabayashi K, Kitamura S (1993) Penetration of a screw into the thoracic aorta in anterior spinal instrumentation. A case report. *Spine* 18:2327–2331
15. Newton P, Shea K, Granlund K (2000) Defining the pediatric spinal thoracoscopy learning curve: sixty-five consecutive cases. *Spine* 25:1028–1035
16. Newton PO, White KK, Faro F, Gaynor T (2005) The success of thoracoscopic anterior fusion in a consecutive series of 112 pediatric spinal deformity cases. *Spine* 30(4):392–398
17. Niemeyer T, Freeman BJ, Grevitt MP, Webb JK (2000) Anterior thoracoscopic surgery followed by posterior instrumentation and fusion in spinal deformity. *Eur Spine J* 9:499–504
18. Ohnishi T, Neo M, Matsushita M, Komeda M, Koyama T, Nakamura T (2001) Delayed aortic rupture caused by an implanted anterior spinal device. Case report. *J Neurosurg* 95(Suppl 2):253–256
19. Parent S, Labelle H, Mitulescu A, Latimer B, Skalli W, Lavaste F, de Guise J (2002) Morphometric analysis of anatomic scoliotic specimens. *Spine* 27:2305–2311
20. Picetti G 3rd, Blackman RG, O'Neal K, Luque E (1998) Anterior endoscopic correction and fusion of scoliosis. *Orthopedics* 21:1285–1287
21. Picetti GD 3rd, Pang D, Ulrich BH (2002) Thoracoscopic techniques for the treatment of scoliosis: early results in procedure development. *Neurosurgery* 51:978–984
22. Sevastik B, Xiong B, Hedlund R, Sevastik J (1996) The position of the aorta in relation to the vertebra in patients with idiopathic thoracic scoliosis. *Surg Radiol Anat* 18:51–56
23. Sucato DJ, Duchene C (2003) The position of the aorta relative to the spine: a comparison of patients with and without idiopathic scoliosis. *J Bone Joint Surg (Am)* 85:1461–1469
24. Sucato DJ, Kassab F, Dempsey M (2004) Analysis of screw placement relative to the aorta and spinal canal following anterior instrumentation for thoracic idiopathic scoliosis. *Spine* 29:554–559
25. Woolsey RM (1986) Aortic laceration after anterior spinal fusion. *Surg Neurol* 25:267–268
26. Zhang H, Sucato DJ (2006) Regional differences in anatomical landmarks for placing anterior instrumentation of the thoracic spine in both normal patients and patients with adolescent idiopathic scoliosis. *Spine* 31:183–189