The changes of relative position of the thoracic aorta after anterior or posterior instrumentation of type I Lenke curve in adolescent idiopathic thoracic scoliosis

Weijun Wang · Zezhang Zhu · Feng Zhu ·
Bin Wang · Winnie C. W. Chu · Jack C. Y. Cheng ·
Yong Qiu

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Abstract The risk of impingement of the aorta associated with thoracic vertebral screw or pedicle screw instrumentation in the treatment of thoracic scoliosis has been an important concern. To understand this phenomenon more systematically, the relative position of the aorta with reference to the thoracic vertebrae in right thoracic adolescent idiopathic scoliosis (AIS) following anterior and posterior spinal instrumentation was analyzed in detail quantitatively; 34 patients underwent anterior ($n = 14$) or posterior ($n = 20$) spinal instrumentation were recruited in the present study. The relative position of the thoracic aorta, vertebral rotation, apical vertebral translation and thoracic kyphosis were measured from pre- and post-operative CT images from T5 to T12. The aorta was found to shift antero-medially in the anterior instrumentation group but not in the posterior spinal instrumentation group. It is likely that the disc removal, soft tissue release and spontaneous vertebral derotation of the scoliosis could account for the

antero-medial shifting of the aorta. By the shifting, the space for contralateral screw penetration was reduced.

Keywords Adolescent idiopathic scoliosis · Thoracic aorta · Anterior instrumentation · Shift · Computed tomography

Introduction

Anterior spinal instrumentation has been used in the treatment of thoracolumbar curve and lumbar curve for decades with recent extension into thoracic scoliosis by open thoracotomy or through thoracoscopic instrumentation technique [8, 23]. Bi-cortical fixation of vertebral screws was recommended to achieve maximal mechanical stability and pullout strength [9, 19]. The screws placed from right side of thoracic vertebrae, however, have the potential risk of injuring the thoracic aorta or penetrating the spinal canal. In patients with main right thoracic adolescent idiopathic scoliosis (AIS), the thoracic aorta were found to displace more laterally and posteriorly relative to the vertebral body, which could increase the potential risk [21, 26, 28, 30]. In a bovine model, Faro et al. [7] found that screw tip impinging on the aorta could lead to erosion of the aortic wall [3, 10, 15, 31].

In the literature, aortic injury caused by vertebral screws have not been reported in thoracic AIS [3, 4, 6, 15, 31]. With preoperative computed tomography (CT), Kuklo et al. [15] was able to show qualitatively the presence of antero-medial shift of the aorta following surgical curve correction in thoracic AIS. Recently, Bullmann et al. [2] found significant migration of aorta in 25 thoracic AIS treated with dual rod anterior instrumentation system by quantitatively studying the preoperative CT and

W. Wang · Z. Zhu · F. Zhu · B. Wang · Y. Qiu (✉)
Spine surgery, The Affiliated Drum Tower Hospital of Nanjing
University Medical School, Zhongshan Road 321,
Nanjing 210008, China
e-mail: scoliosis2002@sina.com.cn

W. C. W. Chu
Department of Diagnostic Radiology and Organ Imaging,
The Chinese University of Hong Kong, Hong Kong, China

J. C. Y. Cheng
Department of Orthopaedics and Traumatology,
The Chinese University of Hong Kong, Hong Kong, China

W. Wang · W. C. W. Chu · J. C. Y. Cheng · Y. Qiu
The Joint Scoliosis Research Center of Nanjing University
and The Chinese University of Hong Kong, Nanjing, China

postoperative magnetic resonance imaging (MRI). However, the factors that contributed to the aorta shifting were not clearly analyzed.

The thoracic pedicle screw has been used increasingly in posterior instrumentation of AIS in the recent years [12, 25]. Studies on the relative position of the pedicle screw with reference to the pedicle and spinal canal has been made [16, 29]. The relative position of the pedicle screws to the aorta has not been studied systematically.

The aim of the present study was to analyze the changes of relative position of the thoracic aorta with reference to the vertebral body in AIS patients with right thoracic curve treated with anterior or posterior spinal instrumentation.

Materials and methods

From June 2005 to June 2006, patients with main right thoracic AIS Lenke I curve treated by surgical correction and instrumentation were recruited into this study.

Group A included patients treated with mini-incision thoracoscopic anterior fusion with CDH-TSRH instrument (Medtronic Sofamor Danek, Memphis, TN). A 10–12 cm incision was done parallel to the 6th or 7th rib, which ended 2–4 cm anterior to the anterior axillary line and 2–3 cm posterior to the posterior axillary line. Thoracotomy was made by removing a 10–12 cm long rib. Pleurotomy, segmental vessel ligation and disectomy at periapical vertebral were done through the incision. Two portals with 2.0 cm diameter were made on the middle axillary line at the interval of two intercostals spaces above and below the incision, respectively. Procedures at other vertebral levels could be achieved by thoracoscopically through the portals.

Patients operated through posterior approaches were put into group B. All patients were treated with hybrid thoracic hook/pedicle screws plus lumbar pedicle screw constructs with TSRH instrument (Medtronic Sofamor Danek, Memphis, TN). During operation, thoracic and lumbar pedicle screws were placed using free-hand technique described by Kim [11].

All patients were operated on by the same team of surgeons (Y.Q and B.W). Somatosensory evoked potential (SEP) was used for intra-operative neurological monitoring. In both groups, the pre- and post-operative thoracic coronal curves, kyphosis between T5 and T12 and apical vertebral translation (AVT) were measured on standard standing posterior-anterior and lateral X-ray using the Cobb method.

CT measurements

All recruited subjects underwent spiral CT of the spine before and 1 week after operation. Axial images from T5 to

Fig. 1 Illustration of parameters measured on the CT images. α aorta-vertebral angle. γ vertebral rotation angle. a distance between the aorta and the left rib head. b distance from aorta to vertebral body cortex

T12 were obtained with the subjects in supine position. The CT examinations were performed by a spiral CT scanner (LightSpeed GE Healthcare) with the following parameters: 320mAs, 120kVp, and 5 mm thicknesses, with a 5 mm gap between slices. Pre- and post-operative CT images with most similar morphology of vertebrae and bilateral rib heads were selected for analysis. A number of parameters were measured using PacsClient software (PACS) on workstation, which included (1) Angle α , the angle subtended by the line joining left and right rib heads and the line from anterior midpoint of vertebral canal to midpoint of the aorta showing the relative position of aorta to the vertebrae, (2) Vertebral rotation angle γ , similar to the Rasag angle [14], (3) Distance a , defined as the distance from posterior wall of the aorta to anterior edge of the left rib head, and (4) Distance b defined as the distance from aorta to the closest point of the cortex of the vertebral body (Fig. 1). The screw position was analyzed on CT images based on the following criteria. For group A, the vertebral screw had a bi-cortical penetration which did not encroach on the spinal canal and had at least 1 mm a distance from the aorta. This was defined as satisfactory screw position [3, 15, 31]. For group B, the screw should have its central axis within the pedicle with its tips at least 1 mm distant away from the aorta [29]. All the measurements were taken by an independent observer (WJW) Figs. (2, 3).

Statistical analysis

The data were statistically evaluated using SPSS software for Windows (10.0, Chicago). A related two sample test (Wilcoxon signed ranks test) was used to determine the difference between vertebral levels pre- and post-operation and also differences between the two groups. The Pearson correlation analysis was used to evaluate the relationship

Fig. 2 A 12-year-old girl with AIS Lenke Type 1BN was operated by mini-incision thoracotomic anterior approach. **a, d** Pre and Post-operative anteroposterior X-ray; **b, e** Pre and Post-operative lateral X-ray; **c, f** CT images of T8, the aorta shift antero-medially after curve correction compared with the preoperative CT images

between the aorta shifting and curve correction. Significance was defined as a $P < 0.05$.

Results

Thirty-four patients with main thoracic AIS were recruited in the present study; 14 patients were recruited in group A anterior instrumentation group and 20 patients in group B posterior instrumentation group. The average age was 14.3 year in group A and 14.4 year in group B, respectively. No significant difference in age and Risser sign was found between the two groups. The Cobb angle, the curve pattern, thoracic kyphosis and flexibility of main thoracic curve show no significant difference between group A and B, while the AVT was significantly higher in group A (Table 1).

All patients in group A and five patients in group B were treated with selective spinal instrumentation [17]. The average fusion level was 8.2 in Group A and 10.8 in Group B. The average immediate postoperative MT curve magnitude was 9.6° in Group A, and 15.1° in Group B, respectively. The average curve correction rate was 78.6 and 68.6% in group A and group B, respectively. The thoracic kyphosis was restored in group A but without

significant changes in group B. Significant improvement of the apical vertebral translation was achieved in both group A and B (Table 2). No intra-operative SEP monitoring abnormality was found and no neurologic deficits were occurred after operation. All patients were followed up for a minimum of 1 year. No obvious complications were found during the operation and follow up.

The changes in the relative anatomical position of the thoracic aorta with the vertebral body postoperatively

In total, 111 thoracic vertebrae in Group A and 160 thoracic vertebrae in Group B were instrumented and measured. The results in both groups were summarized in Table 3. By curve correction in group A, the angle α increased at T6–T12 with maximum found at T8 and T9 measuring 11.7° and 9.6° , respectively. The increments were 44.8 and 29.4%, respectively. The distance between the left rib head and the thoracic aorta also increased from T6 to T10 with the most significant increase at T9 (31.3%, $P < 0.05$). These increments showed that the aorta had shifted anteriorly relative to the vertebrae after curve correction. Significant derotation was also found in the

Fig. 3 A 18-year-old boy with AIS Lenke Type 1B- treated by posterior approach. **a, d**: Pre and Post-operative anteroposterior X-ray; **b, e**: Pre and Post-operative lateral X-ray; **c, f**: CT images of T8, no significant aorta shift was found when compared with the preoperative CT images

Table 1 The pre-operative general information of patients in both groups

	Group A		Group B		
Age	14.3 ± 1.7 (12–18)		14.4 ± 1.5 (12–18)		
Sex					
Female	13		17		
Male	1		3		
Risser sign	3.4 (2–4)		3.1 (0–4)		
Main thoracic curve					
Cobb angle (°)	44.9 ± 5.8 (40–55)		48.3 ± 8.1 (40–70)		
Flexibility (%)	59.6 ± 13.2 (40.5–69.4)		50.6 ± 18.2 (21.7–100)		
Kyphosis Cobb angle (T5–T12) (°)	12.6 ± 9.5 (–4 to 22)		15.5 ± 12.2 (–4 to 48)		
Apical vertebral translation (mm)	3.50 ± 1.14 (0.70–5.10)		1.78 ± 0.55 (0.96–2.84)††		
Lenke classification	–	N	–	N	+
1A	3	5	4	3	
1B	1	2	3	4	1
1C	1	2	4	1	

periapical vertebrae. Further analysis revealed that the increase of angle α and distance were significantly correlated with the decrease of angle γ ($P < 0.01$). The most significant aortic shifting was found at the periapical

vertebral levels. The increase of angle α and distance were negatively correlated with the decrease of AVT ($P < 0.05$). The distance b decreased post-operatively in Group A with the maximum decrease at T9 (27.0%, $P < 0.05$), which

Table 2 Curve correction in both groups

	Group A	Group B
Fusion level	8.2 ± 0.4 (8–9)	10.8 ± 1.4 (8–12)
Main thoracic curve		
Cobb angle (°)	9.6 ± 3.6 (4–15)	15.1 ± 5.4 (5–25)
Correction rate (%)	78.6 ± 7.2 (69–90)	68.6 ± 9.1 (45.6–85.7)††
Kyphosis Cobb angle (T5–T12) (°)	19.3 ± 11.3 (2–40)*	18.4 ± 6.8 (9–32)
Apical vertebral translation (cm)	0.53 ± 0.55 (0–1.68)**	0.74 ± 0.48 (0–1.51)**

Significant difference was found when compared with pre-operation * $P < 0.05$, ** $P < 0.01$

Significantly higher curve correction rate was achieved in group A: †† $P < 0.01$

meant aorta moved closely to the vertebral body following curve correction. The decrease also correlated significantly with the increase of thoracic kyphosis ($P < 0.05$).

In group B, no significant increase of angle α and distance a was found. For distance b , significant decrease was only found at T12. No significant aorta shifting and vertebral derotation was found in Group B.

The quality and accuracy of vertebral screw placement

One hundred and fifteen vertebral screws were inserted in group A, in which 95 (82.6%) were distant away (>1 mm) from the aorta, 12 (10.4%) were adjacent to the aorta, and 8 (7.0%) were thought to touch or create a contour indentation of the aorta; 92 (80.0%) vertebral screws had a bi-cortical penetration, and none penetrated into the spinal canal. The satisfaction rate was 68.3% (28/41) in proximal area (T5–T7), 67.8% (19/28) in periapical area (T8–T9) and 78.3% (36/46) in distal area (T10–L1) with an average of 72.2%, no significant difference was found during three areas ($P > 0.05$).

A total of 113 pedicle screws and 60 hooks were inserted from T4 to L3 in group B. There were 53 screws in thoracic while 60 in lumbar vertebrae. All screws were at least 1 mm distant from aorta; 102 (90.2%) pedicle screws were inserted in pedicle cortex but two thoracic and one lumbar screw in medial violation, and six thoracic and two lumbar screws in lateral violation.

Discussion

Anterior spinal instrumentation has become one of the standard approaches for idiopathic thoracic scoliosis [13,

18, 22]. Because of the posterior and lateral location of aorta relative to vertebral body [21, 28, 30], the risk of impinging or eroding the thoracic aorta by vertebral screw was increased. Because of this, removing part of rib heads were recommended at the cephalad thoracic spine (T4, T5, T6, and T7) or giving up bi-cortical purchase at periapical vertebrae have been suggested [21, 33]. In the present study, the thoracic aorta was found to have shifted antero-medially after anterior spinal instrumentation thus increased the risk of aortic injury by screw impingement although a relatively more space for ventral excursion of screw was created.

Two studies on aorta shifting following curve correction of thoracic AIS have been reported. By studying the pre- and post-operative CT images, Kuklo et al. [15] found the descending aorta moved antero-medially with curve correction. However, because the main emphasis in this study was given to the accuracy of screw placement, the position of the aorta relative to vertebral body was only recorded using a semi-quantitative clock method, and no further analyses were done on the shifting of the thoracic aorta postoperatively. Recently, in a prospective study taken by Bullmann et al. [2], the position of aorta in 25 consecutive patients with right thoracic AIS treated with anterior spinal fusion were studied. Base on the preoperative MRI and postoperative axial CT scans, the author concluded that the aorta had migrated from postero-lateral to a more antero-medial position after curve correction. This migration is maximal at the apex vertebra. The patients were scanned in supine position during MRI which differs from the lateral position in CT scanning thus making it difficult to calculate the real changes in aortic position postoperatively.

In the present prospective study, the changes of angle α , distance a and b in anterior instrumentation supported the fact that the aorta shifted antero-medially following curve correction. Same as Bullman, most significant shifting were found in periapical vertebrae. In group B, however, no shifting of aorta was found though the curve was equally well corrected as group A. To minimize the variation between pre- and post-operative images, same scanning technique and patients' position were used. Never the less, the metallic artifacts in some post-operative images would make the margin vertebrae and aorta hard to distinguish. In that case the margin of vertebrae and aorta would be determined by exploring on serial CT images. Another weak point in this study is all the images were parallel to transverse plane. The tilt of vertebrae might be changed by curve correction so its ideal do measurement on the pre- and post-operative images made exactly through the same plane of each vertebrae. However, it's unavailable for the CT machine used. The images with similar morphology of vertebrae and aorta were selected for measurement to minimize the variation.

Table 3 The average measurements of CT scans

N		α (°)		γ (°)		a (mm)		b (mm)										
A	B	A	B	A	B	A	B	A	B									
		Preop		Postop		Preop		Postop		Preop		Postop		Preop		Postop		
T5	13	20	40.8 ± 22.3	38.9 ± 11.5	44.6 ± 19.7	35.0 ± 16.5**	1.1 ± 14.0	-1.6 ± 4.1	-5.0 ± 6.0	-2.8 ± 7.8	7.6 ± 8.4	7.4 ± 5.1	7.9 ± 8.9	4.3 ± 7.2*	3.1 ± 1.5	2.9 ± 2.3	6.2 ± 4.8	6.2 ± 6.4
T6	14	20	31.0 ± 25.7	34.4 ± 14.0	27.4 ± 17.2	24.5 ± 13.3	4.2 ± 10.0	1.1 ± 4.3	1.1 ± 5.6	0.7 ± 6.6	5.1 ± 8.2	6.6 ± 6.4	3.1 ± 6.0	0.5 ± 4.9	3.5 ± 2.8	2.7 ± 1.0	4.6 ± 2.5	4.6 ± 3.9
T7	14	20	28.4 ± 21.8	32.5 ± 14.7	21.0 ± 16.4	22.5 ± 13.6	8.1 ± 10.5	4.5 ± 5.4	5.8 ± 4.6	6.7 ± 6.6	5.4 ± 8.2	6.0 ± 6.3	3.2 ± 6.0	1.9 ± 5.5	3.6 ± 2.7	2.8 ± 1.5	4.4 ± 2.4	4.0 ± 2.9
T8	14	20	26.1 ± 22.5	37.8 ± 14.9**	23.5 ± 16.5	26.2 ± 10.2	12.2 ± 7.8	4.7 ± 5.2**	8.9 ± 6.7	9.4 ± 6.2	6.4 ± 8.1	9.2 ± 7.4	4.7 ± 7.1	4.5 ± 5.1	3.8 ± 3.1	3.3 ± 1.1	4.5 ± 1.9	4.2 ± 2.2
T9	14	20	32.7 ± 23.4	42.3 ± 16.0*	29.4 ± 16.7	32.6 ± 10.2	12.1 ± 9.7	6.0 ± 5.9**	10.2 ± 5.7	8.7 ± 6.8	9.6 ± 8.1	12.6 ± 6.6*	8.2 ± 7.5	8.0 ± 6.0	3.7 ± 2.4	2.7 ± 1.7*	4.0 ± 2.3	4.3 ± 1.9
T10	14	20	44.4 ± 22.4	48.5 ± 13.9	39.6 ± 13.4	40.3 ± 10.0	10.9 ± 13.5	7.0 ± 7.1	9.6 ± 6.5	7.8 ± 7.5	14.7 ± 8.1	15.7 ± 7.6	12.1 ± 7.7	12.0 ± 6.5	3.2 ± 1.3	2.9 ± 1.5	3.9 ± 3.1	4.1 ± 3.4
T11	14	20	53.8 ± 24.9	56.5 ± 13.8	54.3 ± 13.1	53.7 ± 9.1	8.3 ± 18.3	4.0 ± 8.9	3.6 ± 8.1	1.2 ± 8.6	19.5 ± 7.4	18.5 ± 9.1	18.7 ± 9.2	17.6 ± 7.7	2.5 ± 1.4	2.0 ± 1.1	3.8 ± 5.9	4.1 ± 5.3
T12	14	20	65.8 ± 23.2	67.8 ± 15.2	70.6 ± 14.6	60.4 ± 17.2**	4.2 ± 20.3	1.4 ± 9.7	-4.5 ± 10.3	-3.8 ± 8.3	26.6 ± 7.0	25.2 ± 8.3	24.5 ± 9.5	24.2 ± 9.3	2.0 ± 1.4	1.3 ± 1.2	4.6 ± 7.5	3.3 ± 7.1*

Significant difference was found compared with the pre-operation * $P < 0.05$, ** $P < 0.01$. Related two sample test: Wilcoxon Signed Ranks Test

A group A, B group B, Preop Pre-operation, Postop Post-operation

Several procedures in anterior spinal instrumentation might be responsible for the antero-medial aorta shifting. Opening and dissecting of the parietal pleura followed by cutting of the right segmental vessels along the periapical vertebrae could mobilize the aorta. Then following dissection, the partially spontaneous vertebral derotation could contribute in part to the anterior shifting of aorta with increased angle α and distance a. By curve correction after instrumentation, much more aorta shifting would be gain. Moreover, the giving up pleura closure following with curve correction were also thought to help in allowing the aorta to transpose anteriorly by Crawford [5]. As the pleura were sutured in all patients in the present study, we would test the hypothesis in further study. In group B, no shifting of aorta was found, which can probably be explained by the absence of soft tissue release and vertebral derotation, and thoracic kyphosis. One of the concerns on the ligation and dissection of the segmental vessels and aorta shifting is the risk of spinal cord ischemia [24]. However, these have not been thought as the potential risk factor of neurological deficits of surgical correction for scoliosis in several previous studies [4, 20, 24, 27]. Our previous study [32] has showed that the occlusion of the segmental vessels could cause a temporary change of SEP monitoring but will return to its normal baseline within 17 min and no neurologic complication was found in all patients. In the present study no abnormality was found by intro-operation SEP monitoring and no neurologic deficit was occurred in all patients after operation.

Since part of vertebral derotation was achieved before screw placement, the maximum ventral excursion angle for screw insertion could be increased slightly. After curve correction, with more anterior shifting of aorta the risk of aorta locating in the axis of screw would be diminished. However, as the distance between aorta and vertebral body was decreased, the bi-cortical inserted screws have higher risk of aorta encroaching if it is located on the screw axis. A feasible way to improve the critical situation is to use screws with shorter increment. Results from previous and present studies have shown that the risk of aorta encroaching by vertebral screws were relatively higher in patients instrumented by screws with 5 mm increment [15, 30] when compared with those treated by screws with 2.5 mm increment [3]. One of the reasons is the increment of vertebral width in thoracic vertebrae was 1.2 mm per level [30]. Moreover, screws with blunt tips would also help to diminish the risk of aorta penetrating.

In summary, significant antero-medial shifting of the thoracic aorta could be achieved in patients with main thoracic AIS by anterior but not posterior spinal instrumentation. Both soft tissue releasing and curve correction are essential conditions. With the shifting, more space would be freed for screw excursion. However, the aorta is

closer to vertebral body with less safe area for contralateral screw penetration; much care should be taken when deciding on the length of screw. For consideration of the variability of relationship between the vertebral body and the thoracic aorta within individual patients, the instrumented vertebrae could be justified by pre-operative CT scan. However, it should be kept in mind that the radiation exposure during CT scans might do harm to patients especially to children i.e. the radiation-induced carcinogenesis [1]. Hence it's recommended to use the magnetic resonance imaging instead of the CT scans in future. Further more, the shifting of the aorta should be considered when planning the virtual passage of the vertebral screws.

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