New parameters to represent the position of the aorta relative to the spine for pedicle screw placement

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Abstract Parameters of the position of the aorta in previous reports were determined for anterior surgery. This study evaluated the relative position of the aorta to the spine by new parameters, which could enhance the safety of pedicle screw placement. Three parameters were defined in a new Cartesian coordinate system. We selected an entry point of a left pedicle screw as the origin. The transverse plane was determined to include both the bases of the superior facet and to be parallel to the upper endplate of the vertebral body. A line connecting the entry points of both sides was defined as the *X*-axis. 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. The length of a line connecting the origin and the aorta edge was defined as the left pedicle–aorta distance. Distance from the edge of the aorta to the *X*-axis was defined as the pedicular line–aorta distance. These parameters were measured preoperatively in 293 vertebral bodies of 24 patients with a right thoracic curve. We simulated the placement of the pedicle screw with variable length and with some direction error. We defined a warning pedicle as that when the aorta enters the expected area of the screw.

Sensitivity analysis was performed to find the warning pedicle ratio in 12 scenarios. The left pedicle–aorta angle averaged 29.7° at the thoracic spine and -16.3° at the lumbar spine; the left pedicle–aorta distance averaged 23.7 and 55.2 mm; the pedicular line–aorta distance averaged 18.3 and 51.0 mm, respectively. The ratio of warning pedicles was consistently high at T4–5 and T10–12. When a left pedicle screw perforates an anterior/lateral wall of the vertebral body, the aorta may be at risk. These new parameters enable surgeons to intuitively understand the position of the aorta in surgical planning or in placement of a pedicle screw.

Keywords Scoliosis · Pedicle screw · Aorta · Computed tomography

Introduction

Several authors have reported serious injuries of the aorta due to inappropriate placement of screws or plates in anterior surgery [8, 9]. Sucato et al. [10] reported that 12% (13/106) of vertebral screws in right thoracic scoliosis created some contour defect in the aorta on the contralateral side of the vertebral body, although patients had no sequela. They subsequently analyzed the position of the aorta in patients with scoliosis compared to those with non-scoliotic spine and found that the aorta often resides on the lateral side of the vertebral body and concluded that a potential risk of the aorta by a vertebral screw increases in the scoliotic spine. Maruyama et al. [7] studied the spatial relations between the spine and the aorta in adolescent idiopathic scoliosis and concluded that the aorta can be located in the direction of the screw passage in 33 of 40 vertebrae (83%) between T6 and T9. These studies,

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however, paid less attention to the relationship between the aorta and a pedicle screw. Accordingly, parameters describing the position of the aorta in these reports were not intuitive and surgeons have had difficulty utilizing these values in posterior surgery. The purpose of the present study was to evaluate the relative position of the aorta to the spine by new parameters, which can enhance the safety of pedicle screw placement.

Materials and methods

Thirty-seven patients with scoliosis underwent posterior instrumentation and fusion at the University Hospital from 2005 to 2007. Patients with congenital scoliosis were excluded. A total of 24 patients with a right thoracic curve were included in this study. Scoliosis was idiopathic in 17 patients, Chiari-syrinx in 2, Marfan syndrome in 2, multiple epiphyseal dysplasia in 1, Noonan syndrome in 1, and tuberous sclerosis in 1. Age at surgery was 10–29 (mean 17.1) years; 19 patients were women and 5 were men. Lenke's classification of scoliosis [4] was type 1 in eight patients, type 2 in five, type 3 in two, type 4 in four, type 5 in one, and type 6 in four. Preoperative Cobb angle averaged 66.4° (50° – 103°). The apex vertebra ranged from T5 to T10 (median T10). All patients were treated by posterior correction and fusion by pedicle screw instrumentation. One patient with a curve of 103° had undergone anterior release before posterior spinal fusion. Computed tomography was taken before surgery and pedicle screws were placed with guidance of the CT-based navigation system. Postoperative Cobb angle averaged 20.3° (11° – 39°).

A computer tomography was taken from the upper thoracic to the lower lumbar spine with a width of 1.25 mm for navigation. All DICOM data were transferred to a personal computer and analyzed by DICOM software (ExaView LITE: ©Ziosoft, Tokyo, Japan). We defined three parameters in a new Cartesian coordinate system and those parameters from T4 to L4 were measured in 293 vertebral bodies of 24 patients. We selected the middle of the base of the left superior facet as the origin of this coordinate system (Fig. 1), because the most probable threat to the aorta by a pedicle screw is on the left side at the thoracic spine. The transverse plane was determined to include both the bases of the superior facet and to be parallel to the upper endplate of the vertebral body. A line connecting the middle points of both bases of the superior facets is defined as the pedicular line (PL) (X-axis). The Y-axis perpendicular to the X-axis is drawn ventrally from the origin. The angle formed by the Y-axis and a line connecting the origin and the center of the aorta is defined as the left pedicle–aorta angle length of a line connecting the origin and the edge of the aorta as the left pedicle–aorta

distance, and distance from the edge of the aorta to the X-axis as the pedicular line–aorta distance. Moreover, we break down the left pedicle–aorta distance into the X- and Y-unit. The X-unit is the rectangular component of the left pedicle–aorta distance to the X-axis and the Y-unit is that to the Y-axis.

We simulated placement of the pedicle screw with a direction different from the ideal trajectory. Sensitivity analysis was performed by changing the direction error and the length of the screw independently. The direction error started from 10° up to 30° with 10° increments (three scenarios). The length of the screw started from 25 to 40 mm with increments of 5 mm (four scenarios). We set up a total of 12 scenarios (three by four). We defined a warning pedicle as that when the aorta enters the expected area of the screw. The ratio of warning pedicles was calculated from T4 to L4 in the 12 scenarios (Fig. 2). From the repeatability test from our previous study, interclass correlation coefficients were 0.922–0.957 in the intraobserver measurement and 0.896–0.929 (0.864–0.961) in the interobserver measurement [12].

To determine the relationship of the location of the aorta and the characteristics of scoliosis, the Cobb angle of the main thoracic curve, apical vertebral translations of the main thoracic curve, and the angle at T5–T12 in the sagittal plane were measured, and correlations between these

Fig. 1 Measurement of new parameters. The origin is set at the middle of the base of the left superior facet. A line joining the middle points of both bases of the superior facets is defined as the X-axis (the pedicular line). The Y-axis, perpendicular to the X-axis, is drawn ventrally from the origin. A The left pedicle–aorta angle. B The left pedicle–aorta distance. B-x the X-unit of the left pedicle–aorta distance. B-y the Y-unit of the left pedicle–aorta distance. C the pedicular line–aorta distance

Fig. 2 The expected area of the pedicle screw. We simulated the pedicle screw placement with some direction error ($\pm\theta$) and the variable length (length of the screw) with sensitivity analysis. We defined a warning pedicle as that when the aorta enters this zone

parameters and the X-and Y-unit of the left pedicle–aorta line at the apex were calculated.

Results

The relative position of the aorta to the spine changed dramatically at the thoracic spine (Table 1; Fig. 3). The left pedicle–aorta angle spanned from -46° to 78° (average 29.7°) at the thoracic spine and from -38° to 13° (average -16.3°) at the lumbar spine; the left pedicle–

Fig. 3 The average course of the aorta relative to the spine. The origin is set at the middle of the base of the left superior facet. A line joining the middle points of both bases of the superior facets is defined as X-axis. The aorta begins to be seen from T4. It descends laterally and posteriorly and turns back at T7. At T12, the aorta is in front of the left pedicle and moves to the right side at the lumbar level. Attention should be paid to the spine drawn in the figure, because the size of the spine changed considerably at the level of the spine

Table 1 Distribution of the left pedicle–aorta angle, the left pedicle–aorta distance, and the pedicular line–aorta distance

	Left pedicle–aorta angle ($^\circ$)	Left pedicle–aorta distance (mm)	The pedicular line–aorta distance (mm)
T4	20.1 ± 22.7	24.5 ± 6.2	20.9 ± 9.7
T5	32.1 ± 20.3	19.4 ± 4.4	14.1 ± 8.5
T6	39.5 ± 17.3	17.8 ± 3.5	10.9 ± 7.2
T7	43.8 ± 13.6	17.6 ± 3.6	10.1 ± 6.3
T8	42.8 ± 11.9	19.0 ± 4.2	11.4 ± 6.5
T9	40.0 ± 12.8	20.6 ± 4.9	13.6 ± 7.2
T10	30.2 ± 15.1	24.0 ± 6.4	19.2 ± 8.6
T11	13.0 ± 19.9	31.5 ± 8.1	29.1 ± 11.0
T12	0.3 ± 15.6	39.3 ± 8.3	36.9 ± 8.4
L1	-12.9 ± 13.3	52.4 ± 7.1	48.3 ± 7.0
L2	-17.7 ± 10.3	56.2 ± 6.2	51.2 ± 5.2
L3	-16.9 ± 6.8	56.7 ± 5.4	52.9 ± 4.2
L4	-19.4 ± 5.0	56.0 ± 5.0	52.4 ± 7.4

aorta distance ranged from 11 to 52 mm with an average of 23.7 mm and from 36 to 72 mm with an average of 55.2 mm, respectively; the pedicular line–aorta distance ranged from –4 to 59 mm (average 18.3 mm) and from 33 to 75 mm (average 51.0 mm), respectively. From the cephalad to the caudal direction, the aorta was seen at the antero-lateral position of the vertebral body of T4 or T5. The aorta moved to the left side laterally and posteriorly as it descended, changing its course at T7 and moving medially and anteriorly. It located in front of the vertebral

body at the left T12 pedicle. At the lumbar spine, the aorta moved to the right side.

The ratio of warning pedicles increased as the direction error or the screw length increased (Fig. 4). When the direction error was within 30° and the screw length was 40 mm, the ratio was highest at T4 with 69%, followed by T11 (67%), T5 (54%), T10 (46%) and T12 (39%), and this trend was consistent in any scenario.

No parameter of the main thoracic curve correlated with the X-unit of the left pedicle–aorta distance at the apex.

Fig. 4 Distribution of warning pedicle ratios from T4 to L4 in 12 scenario. In any scenario, there was a high percentage of warning pedicles at the thoracic spine except at T7 and T8. **a** The warning pedicle ratio when the direction error is within 10° and the screw length changes from 25 to 40 mm. **b** The warning pedicle ratio when the direction error is within 20° and the screw length changes from 25 to 40 mm. **c** The warning pedicle ratio when the direction error is within 30° and the screw length changes from 25 to 40 mm

Sagittal angle at T5–T12 in the sagittal plane significantly correlated with the *Y*-unit (“anterior–posterior” direction for the spine) of the left pedicle–aorta distance at the apex (-0.44 ; $p = 0.03$).

Discussion

Liljenqvist et al. [5] measured the distance from the aorta to the vertebral body, and reported that the closest distance averaged 6–7 mm between T4 and T9 and <5 mm between T10 and L4. Sucato and Duchene [11] analyzed the position of the aorta in patients with idiopathic scoliosis in magnetic resonance scans and found that the thoracic aorta in idiopathic scoliosis is positioned more posteriorly and laterally compared with straight spines. From their analysis, the aorta begins to be seen as the aortic arch in front of the T4 vertebral body and changes its position posteriorly and laterally as it descends. The aorta turns back anteriorly and medially at the apical region and passes in front of the T12 through the hiatus of the diaphragm. The present study supports their analyses.

Vaccaro et al. [13] analyzed a non-scoliotic thoracic spine and found that the aorta and the esophagus are at greatest risk of injury when a pedicle screw penetrates an anterior cortex of the vertebral body. Liljenqvist et al. [6] analyzed 22 patients with idiopathic scoliosis by computed tomography postoperatively. They found that 3 of 120 pedicle screws penetrated the anterior vertebral cortex and 1 of these three screws was replaced because of its direct proximity to the thoracic aorta.

When a pedicle screw is placed by a free-hand technique [3] or with a fluoroscope, the direction of placement largely depends on several landmarks of the explored surface of the spine: facet joints, transverse processes and laminae. Our new parameters defined by both sides of superior facet are easy to comprehend in posterior surgery. Additionally, we could compare the relative risk of pedicle screw placement between spine levels in various settings by the sensitivity analysis.

The present study elucidated that the aorta usually stays on the anterior or left-lateral side of the vertebral body at T4, T5 and at T10–T12, and a small breach of a pedicle screw outside the vertebral body at these levels may result in indentation of the aorta. Faro et al. [1] studied the influence of indentation of the aorta by a screw in their bovine model and found that the major impingement of vertebral screws on the aorta caused acute and chronic histopathologic and biomechanical changes in the vessel wall. Though sequelae of moderate to mild indentation of the aorta have not yet been known, screws will stay inside the body for over tens of years in

Fig. 5 A case with a typical position of the aorta around the apex level. Though a distance to the left base of the superior facet (an insertion point of a pedicle screw) is closer than other levels, the aorta often resides in the most lateral position from the spine and allows wider maldirection of the pedicle screw

this young population. It is recommended that any screw either in anterior or in posterior surgery be placed away from the aorta.

The present study shows that the aorta at the middle thoracic spine is often located away from the spine and resides in front of a left rib (Fig. 5), which leads to a low percentage of dangerous pedicles at T7 and T8. However, in turn, the spinal cord deviates to the left concave pedicles at the apical area at the right thoracic spine [5]. Moreover, the aorta may not stay in the same position. Huitema et al. [2] examined 50 patients by computed tomography or magnetic resonance scans before surgery, and reported that the aorta moves more anteromedially in a prone position than in a supine position especially at levels T5–T10. Their study indicates that the aorta is fairly mobile at the mid-thoracic level when a subject changes his position. Though the present study showed a relative safety of the aorta at T6–T9, the aorta might reside closer to the spine when a subject is at another position. Admittedly, segmental pedicle screw instrumentation is a most powerful construct for correction and maintenance in spinal deformity. Surgeons, however, must be vigilant about the positions of the aorta and the spinal cord in placement of pedicle screws, especially on the left side, and screw breach may necessitate reoperation for replacement.

In summary, new parameters enable surgeons to intuitively understand the position of the aorta in their preoperative planning or during placement of a pedicle screw. When a left pedicle screw perforates an anterior/lateral wall of the vertebral body, the aorta may be at risk, especially at T4, T5 and T10–T12.

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