Wien Klin Wochenschr (2016) 128:131–136
DOI 10.1007/s00508-015-0850-3

Wiener klinische Wochenschrift
The Central European Journal of Medicine

Aortic issues in scoliosis and scoliotic operations

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Received: 23 December 2014 / Accepted: 11 August 2015 / Published online: 15 September 2015

Summary The spatial relations between the aorta and vertebrae are changing with posture, surgical techniques, and operative maneuvers. "Risky screws" (within 1–3 mm proximity to the aorta or other adjacent tissues) were found in 5.8–15.2 % screws. In order to avoid early and later aortic complications secondary to scoliotic operations, careful preoperative metrology of aorto-vertebrae relations is of crucial importance. Compared with patients with idiopathic scoliosis, Marfan-related scoliosis is characterized by faster progression and it is more bracing-resistant due to the particular developmental anomalies in Marfan syndrome, implying the refractory nature of the latter. The present study aims to highlight the clinical impact of preoperative aorto-vertebra metrology in the scoliotic operations.

Keywords Aorta · Marfan syndrome · Orthopedic procedures · Scoliosis · Spine

Introduction

Scoliosis can be divided into six types according to various etiologies: idiopathic, congenital, neuromuscular, metabolic, traumatic, and dysmorphic (Marfan syndrome) [1]. Idiopathic scoliosis has previously been well documented [2, 3]. A scoliosis affects 1.5–3 % of individuals, most common during late childhood [4]. The prevalence of adolescent idiopathic scoliosis with a spinal column curve of 10° or less is 2–3 %, while the prevalence of curves greater than 30° is only 0.1–0.3 % [2]. Larger curves are more common in girls and most curves are on thoracic or right thoracolumbar convex. The risk of progression depends on curve size and remaining skeleton growth. Patients with Marfan syndrome have a high prevalence of developmental anomalies, such as increased flexibility of the scoliotic curve, increased transverse process distance, significantly smaller pedicle widths and laminar thickness, and widened interpedicular distances in the lumbar vertebrae [5]. Scoliosis associated with Marfan syndrome is characterized by faster progression, it is more bracing-resistant with more and severer surgical complications including more blood loss, pseudarthrosis, and additional curvature, and more frequent dural ectasia compared with patients with idiopathic scoliosis [6]. Marfan patients are prone to develop ascending aortic dilation or aortic dissection during the progression of the disorder [7]. For this reason, Marfan patients receiving a scoliotic operation are more frequently complicated by aortic lesions [8]. A 40-year-old woman with Marfan syndrome developed a saccular aneurysm of the descending thoracic aorta 20 years after anterior spinal instrumentation of a thoracolumbar scoliosis. Computed tomography revealed that the most proximal screw had perforated the aortic wall forming a pseudoaneurysm. An endovascular graft was successfully implanted [9]. Moreover, a crankshaft phenomenon is possible in Marfan-related scoliosis and it may have negative impact on later development after fusion and may cause aorta migration [10]. In idiopathic scoliosis, spatial relations between the aorta and vertebrae are changing with patient's position and scoliotic operation. Aorto-vertebrae metrology is crucial no matter what the pathogenesis of scoliosis. In order to avoid early and later aortic morbidities, preoperative aorto-vertebrae metrol-

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ogy is of crucial importance. The present article aims to highlight the impact of preoperative aorto-vertebra metrology on early and late aortic complications.

Metrology

Cobb angle is widely used to measure the severity of curvature of spinal deformities, especially in scoliosis. It is the "gold standard" of scoliosis evaluation. Intersecting perpendicular lines from the two parallel lines of the most tilted vertebrae at the top and bottom of the curve forming an angle is called a Cobb angle. A Cobb angle of 10° is regarded as a minimum angulation to define scoliosis [11].

The aorto-vertebral angel and aorto-vertebral distance are the two main parameters indicating the spatial position of the aorta in scoliosis patients. In addition to the Cobb angle, Sucato et al. [12] detected in idiopathic scoliosis patients the apex of the curve, apical vertebral rotation, the distance from the aorta to the closest point of the vertebral body cortex, the distance from the posterior edge of the aorta to the spinal canal, and the aorto-vertebral angle. In the measurement on computed tomographic scan, Sevastik et al. [13] stresses the position of the aorta in the medial-lateral plane, where the aorto-vertebral angle was defined as one between the sagittal midvertebral body line and the line from the posterior midpoint of the spinal canal through the middle of the aorta.

Liu et al. [14] studied the spatial relationship between the aorta and the neighboring thoracic vertebral body in idiopathic scoliosis on the axial views of computed tomography at levels T_4-T_{12}. They measured an angle α formed by a bilateral rib heads line and a posterior aortic tangential line through the intersection of the right edge of the vertebral body. When $\alpha > 0$, the spatial relationship between the vertebra and aorta was defined as "safe", representing 74.6%; when $\alpha < 0$ and the aorto-vertebral distance along the rib head line > 2 mm, it was defined as "suspicious", accounting for 15.9%; and when $\alpha < 0$, the aorto-vertebral distance < 2 mm, it was defined as "dangerous", accounting for 9.5% (Fig. 1). Zhu et al. [15] adopted a modified measurement where the aorto-vertebral angle was formed by a rib head line and an aorto-vertebral central line (Fig. 2). When the aorto-vertebral distance was < 2 mm or the aorto-vertebral angle < 45° (the aorta was closer to the pathway of vertebral screws) on preoperative computed tomography, the pleura should be left open so as to increase the safe distance between the aorta and vertebra, which may lessen the risk of screw tip impingement on the aorta. In patients whose aorta was away from the trajectory of vertebral screws (angle α > 45°), the pleural should be closed. For patients receiving anterior release surgery, a posterolateral positioned aorta with the parietal pleura open could decrease the risk of pedicle screw impingement on the aorta during pedicle screw insertion on the concave side of the thoracic curve. Liu et al. [16] applied the left pedicle-aorta angle (angle α) and the left aorta angle (angle β) in their measurement. The measurements facilitated the judgments of the aorto-vertebra relations (Fig. 3). Qiu et al. [17] used a combination of three angles in the metrology, and indicated that γ angle in the scoliosis had a tendency to increase and then decrease at levels T_4–T_{12}, and

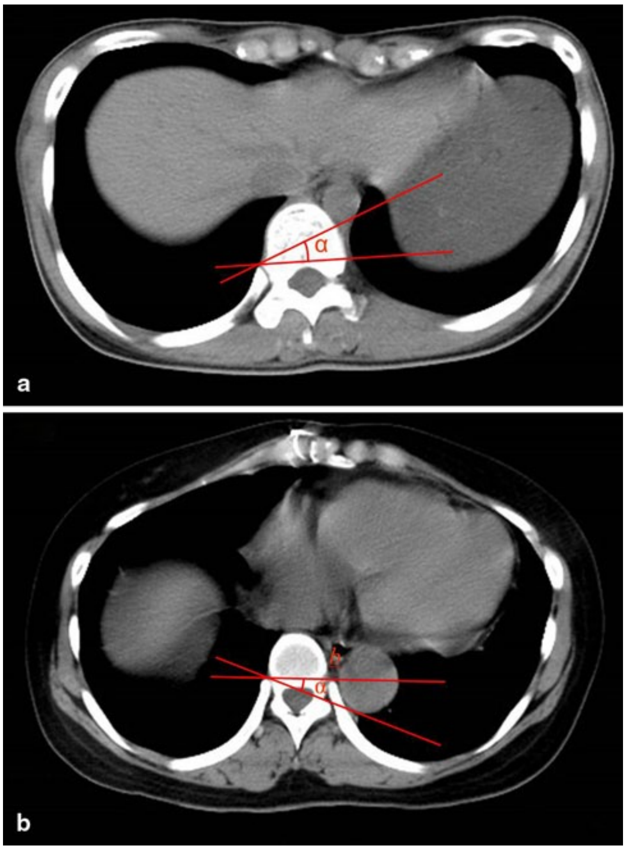

Fig. 1 Measurement of aorto-vertebral relation by Liu et al. [14]: (**a**) when the aortic posterior tangential line was anterior to the rib head line, the angle *α* was positive; and (**b**) when the aortic posterior tangential line was posterolateral to the rib head line, the angle *α* was negative

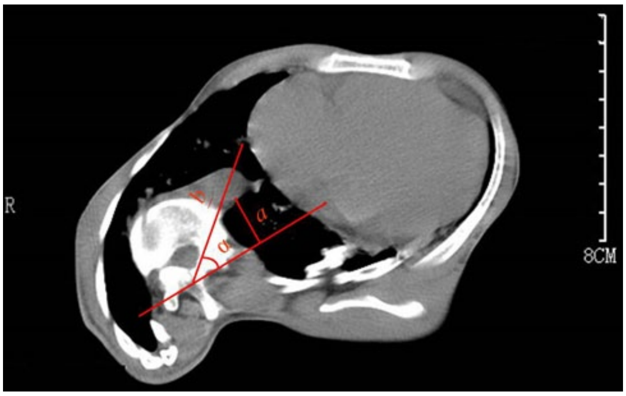

Fig. 2 Measurement of aorto-vertebral relation by Zhu et al. [15]: The aorto-vertebral angle was formed by a rib head line and a mid-aorta line. Distance *b* was drawn from the aorta to the vertebral body cortex

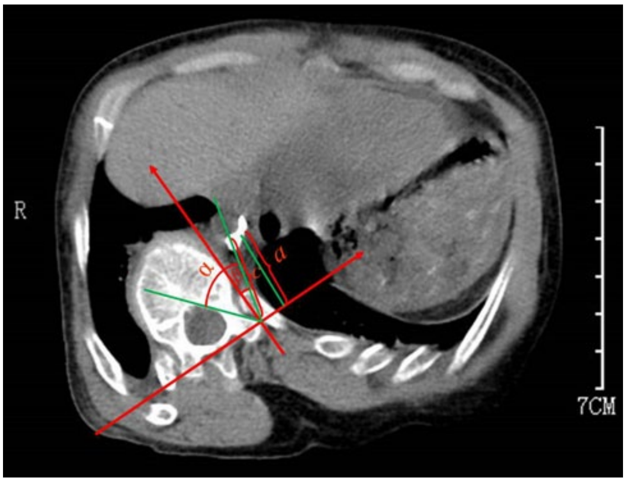

Fig. 3 Measurement of aorto-vertebral relation by Liu et al. [16]: A coordinate system was formed by a left pedicle axial line and the base of the left transverse process. Distance *c* was the length from the aorta to the vertebral body cortex (left pedicle-aorta distance), and distance *a* was the distance from the edge of the aorta to *X*-axis (aorta-*X*-axis distance)

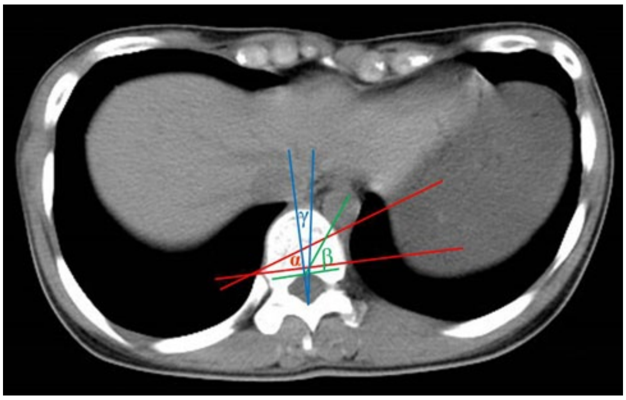

Fig. 4 Measurement of aorto-vertebral angles [17]: Angle α is formed by the bilateral rib head line and the posterior tangential line of the aorta; angle β is formed by the bilateral rib head line and the central line of the aorta; and angle γ is vertebral rotation

angle β along with angle γ would show the extent of aortic displacement (Fig. 4).

Spatial relationship between the aorta and spine

For idiopathic scoliosis, the most common apical vertebra was T_8 vertebra, the average coronal curve measurement was 55.2° and the average apical rotation was 17.3°. The average distance from the aortic wall to the vertebral body cortex at the apex of the curve was greater in the patients with scoliosis (4.0 mm) than at similar levels in the normal group (2.5 mm). The distance from the posterior aspect of the aorta to the anterior aspect of the spinal canal was less in the scoliosis group (11.1 mm) than in the normal group (19.2 mm) at levels T_5–T_{12} [12]. In idiopathic scoliosis patients, the aorto-vertebral angle was significantly larger than that of the normal subjects (41.4 ± 8.4° *vs.* 24.4 ± 6.9°, $p = 0.0001$). They also noted that the rotation and the anterior displacement of the vertebral body in scoliosis resulted in a more posterior deviation of the aorta in relation to the vertebral body with a possible increased length of the intercostal artery on the right side [13].

Pectus excavatum is one of the associated deformities of Marfan syndrome. With bilateral flattening of the sides of the chest, the heart, lungs, and diaphragm may be compressed and displaced, depending on the severity of the internal depression of the sternum, and the aorta could be more left posteriorly at radiography [18]. In Marfan-related scoliosis, 53 % of the curves demonstrate a typical curve pattern and 47 % are atypical; and even in "typical" curve patterns, all of the curves demonstrate some "atypical" features, that is, a shift of the apical and/or the end vertebrae [19]. They require more levels of surgical corrections, more distal fusions, greater correction of sagittal balance and more reoperations, and they are more complicated by intraoperative cerebrospinal fluid leaks and instrumentation-related complications [10]. Therefore, in non-idiopathic etiology scoliosis, a careful screening is required before treatment planning.

Aorta migration

Several conditions such as patient's posture, hypo- and hyperkyphosis, aorto-vertebral angle, and operative method cause aorta migration (Table 1). The influences from these factors have to be taken into consideration during scoliotic operations. Clinical observations revealed aortic migration occurred from a posterolateral to a more anteromedial position with an average aorto-vertebral angle change of 31.4° postoperatively. The aorto-vertebral distance increased at the upper and lower fusion levels, closer to the vertebral body at the curve apex [20]. Peeling off the parietal pleura at levels T_5–T_{12} away from the vertebral body may push away the aorta from the vertebrae; whereas segmental vessel ligation may release the parietal pleura, and may cause a more posterolateral aorta migration [21].

Screw tip-aorta relation

Sucato et al. [22] observed the screw tip-aorta position in 14 patients with 106 screws (average, 7.6 screws/patient) and found 78 (73.6 %) screws were distant from the aorta, 15 (14.2 %) were adjacent to the aorta, and 13 (12.3 %) caused a contour deformity of the aorta, but no vascular complications occurred at 2-year postoperative follow-up. Similarly, Bullmann et al. [23] reported in 20 scoliotic patients with 226 screws used that 5.8 % (13/226) screws were within 1–3 mm proximity to the aorta and 94.2 % (213/226) screws were > 3 mm away from the aorta. The closest screw tip-aorta distance was found at the upper

Table 1 Conditions that cause aorta migration

Condition	Aorta migration
Body posture [21]	
Supine	More posterolateral
Prone	More anteromedial
Hypo- & hyperkyphosis [20]	
Hypokyphosis	More posterior
Hyperkyphosis	Posterior
Aorto-vertebral angle [20]	
78°–92°	Posterolateral (at T_5–T_{10}, preoperative)
62°–16°	Anteromedial (at T_{11}–L_2, postoperative)
Operative method [20, 21]	
Posterior instrumentation	Non-displaced
Anterior curve correction with pleural closure	Anteriomedial
Parietal pleural peeling off	Away from the vertebral body
Segmental vessel ligation	More posterolateral

end vertebrae (T_5, T_6, or T_7), with no screws perforating the spinal canal. Anterior instrumentation with a dual rod – dual screw system enabled a safe screw placement in scoliotic patients and therefore it was recommended avoiding the excessive bicortical screw perforation in scolitic operations.

Surgical options

An agreement has not been reached as to the exact parameters for whether an anterior or a posterior fusion is required to prevent crankshaft deformity. However, superior correction and rotational control with pedicle screw instrumentation can be an alternative for lessening the aortic complications associated with scoliotic operations [24]. If structural scoliosis is confined at the thoracic, thoracolumbar, or lumbar only, then it can be resorted to a pure anterior operation with single or double rods by way of anterior instrumentation correction. Compared with the posterior instrumentation as for the same scoliosis, anterior instrumentation can achieve similar or even better treatment therapeutic effect with less spinal fusion requirements. Anterior operation is associated with more chances of postoperative false joints than posterior. A combined anterior and posterior approach is indicated for the cases with a Cobb angle > 75°, rigid scoliosis (the scoliosis requiring a correction cannot be < 50° on the lateral bending posture in an X-ray film) and young children. At present, most combined anterior and posterior operations can be completed in one stage. Particularly serious scoliosis requires staged procedures: anterior and posterior releases in stage I followed by stage II for fixation of anterior and posterior instrumentation 7–14 days after traction. Anterior release includes discectomy, anterior longitudinal ligament loosening, and vertebral epiphyseal cartilage resection [25]. Anyway, the anterior instrumentation can be a safer approach for the surgical treatment of scoliosis. Caution has to be taken in the scoliotic patients with a larger preoperative aorto-vertebral angle and possible posterior aorta migration.

Major complications

Screw migration carries higher risks of aortic injuries after corrective spinal surgery. A 1–3 mm proximity of the screw to the aorta or other tissues (including the pleura, azygos vein, and trachea) was regarded as a significant risk screw. This can be a problem secondary to screw misplacement or migration early after corrective spinal surgery (Table 2). The aorta could move closer to the screw tips both at the apex and distally; whereas the distal screws were more juxtaposed to the descending aorta [26]. Screw revision was only performed in symptomatic patients with screw misplacement after scoliotic operations [27]. Aortic complications of scoliosis surgery reported sporadically included early postoperative perforation of the aorta by instrumentation and late aortic perforation due to aortic wall erosion by the screws [8, 28, 29]. Strain forces on elongation of the aorta leading to aortic wall weakness have been considered the underlying pathogenesis of late aortic complication after corrective scoliosis surgery [28]. Delayed aortic rupture associated with anterior instrumentation is extremely rare but can occur. An anteromedial aorta migration in relation to the vertebral bodies may occur following corrective spinal surgery, which may affect the adjacent structures, such as aorta and its branches [28]. Despite improved implant design, the placement of implants near the aorta and subsequent changes in the close anatomical relationship between the aorta and the implant may eventually result in aortic complications [30]. Open surgical repair or stent graft can be the therapeutic options for the complicated aortic injury (Table 2). The migrated anterior spinal fixation device can be a cause of aortic pseudoaneurysm formation, which was successfully treated by revision anterior surgery with vascular repair and implant removal [31].

Conclusions

The spatial relations between the aorta and vertebrae are changing with patient's position and scoliotic operation. In the scoliotic operations of any etiology, preoperative aorto-vertebral metrology is of crucial importance in order to avoid early and later aortic morbidities. Although no definite agreement is reached on preoperative measurements, but anterior instrumentation seems to be a safer approach. Improved implant design can be an alternative solution to decrease the aortic morbidities.

Table 2 Early and late complications secondary to scoliotic operations

Author	Case No.	Gender (M/F)	Age (year)	Procedure	Screws per patient	Screw tip-aorta distance (mm)	Risky screw (*n*, %)	Postoperative complication	Onset time (m)	Management
Kuklo et al. [26]	20	3/17	12.4–18.5	Open anterior spinal fusion with instrumentation	7.5	1.6–2.4	15 (15.2)	No		
Bullmann et al. [23]	20		12–20	Anterior scoliosis surgery	11.3		13 (5.8)	No		
Sarlak et al. [27]	19	4/15	9–27	Thoracic screw insertion	9.8		13 (7.0)	Screw misplacements ($n=54$); persistent pain ($n=2$)		Screw revision ($n=2$)
Lavigne et al. [8]	1	0/1	15	Corrective surgery for idiopathic left thoracolumbar scoliosis				Laceration of the posterior wall of the thoracic aorta by an impending screw thread	84	Thoracic aorta repair
Mani et al. [28]	1	0/1	56	Posterior spinal correction				Aortic rupture	0.5	Stent graft
Sokolić et al. [29]	1	0/1	16	Vertebral fixation				Descending aorta perforation & peri-aortic hematoma formation	5	Hematoma evacuation & aorta repair

Conflict of Interest
The authors declare that there are no actual or potential conflicts of interest in relation to this article.

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