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ORIGINAL ARTICLE

The effect of patient positioning on the relative position of the aorta to the thoracic spine

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Abstract

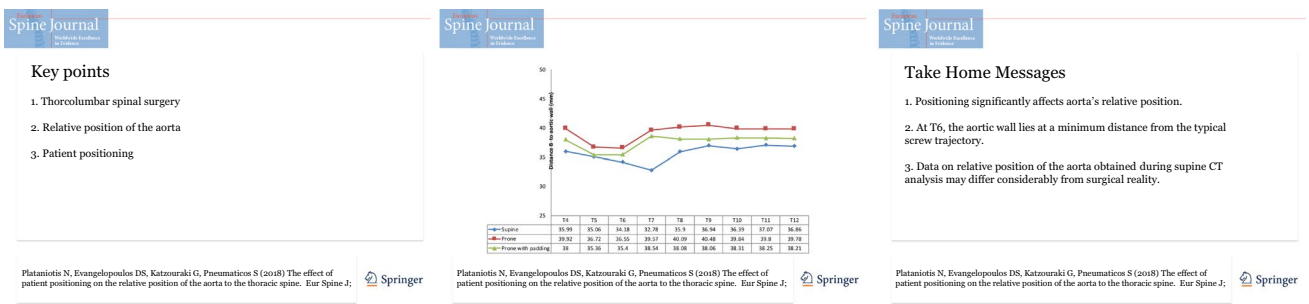
Purpose Detailed knowledge of the anatomy of the thoracic aorta is crucial for thoracolumbar spinal surgery. The purpose of the present study is to describe the relative displacement of the aorta to the spine in supine, prone and prone position with padding. Improved understanding of the magnitude and direction of this often-overlooked change could benefit preoperative planning and decision-making.

Methods A total of 200 patients underwent CT scan of the thoracic spine in the standard supine, prone and prone position with padding. Axial CT images from T4 to T12, in all three different positions, were selected and the following parameters were measured: (a) distance B connecting left pedicle entry point to the edge of the aortic wall and (b) projections Bx and By, representing the minimum AP depth and horizontal displacement of the aortic wall relative to the left pedicle entry point O.

Results There was a significant difference in the distance B between the three different positions across all thoracic vertebrae levels, confirming that positioning significantly affects aorta's relative position. Moreover, in the prone position with padding at the level of T6, the aortic wall lies at a minimum distance from the left pedicular axis and thus from the typical screw trajectory.

Conclusion The results of this study show that prone positioning for posterior thoracolumbar approach affects significantly the anatomic relationship of the aorta to the spine. Surgeons should be aware that standard supine CT evaluation represents a static technique, which can differ considerably from surgical reality.

Graphical abstract These slides can be retrieved from electronic supplementary material.



Keywords Thoracolumbar spine surgery · Relative position of thoracic aorta · Patient positioning

Introduction

Techniques in thoracolumbar spinal surgery continue to evolve in the field of both trauma and deformity correction. Traditionally, posterior approaches have been utilized; however, anterior approaches have also gained

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increased popularity among surgeons [1]. In addition, minimal invasive and endoscopy-assisted techniques have been developed with the aim of reducing intraoperative bleeding and postoperative mobilization time [2, 3]. Familiarity with different techniques and approaches allows the spinal surgeon to plan and execute an optimal surgical strategy. The normal anatomy of anterior structures, including the thoracic aorta, and the changes associated with kyphoscoliotic deformities is crucial to the preoperative planning [4–6]. A catastrophic, although rare, complication of both anterior and posterior instrumented thoracolumbar spine surgery is iatrogenic vascular injury [7, 8].

There are studies reporting shift of the thoracic aorta relative to the spine in scoliotic patients following surgery [9–11]. However, there are limited data regarding aortic migration associated with patient positioning. There is some indication that patient positioning to prone and prone with padding positions causes significant changes to the relative position of the aorta to the spine [12]. When taken into account preoperatively, these changes could influence surgical planning and dictate the need for different approaches.

The present study aims to describe the relative displacement of the aorta to the spine in supine, prone and prone with padding positions. Improved understanding of the magnitude and direction of this often-overlooked displacement could benefit preoperative planning and decision-making.

Materials and methods

A total of 200 patients (101 females and 99 males), who visited authors' spine outpatient clinic from 2014 to 2016 for lower back pain, were included in the study. Mean patient age was 67.8 years (range 51–95 years old), and mean BMI was 28.08 (range 18.3–38.2).

Patients with a scoliotic deformity of > 10° Cobb angle, previous spinal surgery with instrumentation and compression osteoporotic fractures were excluded from the study. All patients underwent CT scan of the thoracic spine with slice thickness of 5 mm. All CT scans were taken in the standard supine, as well as in prone and prone with padding positions, in an effort to reproduce surgical positioning during posterior thoracic spinal surgery.

Axial CT images of vertebrae including bilateral pedicles and transverse processes from T4 to T12 were selected for measurement, in all three different positions. The insertion point of a left pedicle screw was selected at the intersection of the left pedicle axis and transverse process and was defined as point O. A "*y*"-axis was defined by the left pedicle axial line, and the "*x*"-axis was drawn perpendicular to this, passing through point O. The following parameters were measured on the axial CT images: (a) minimum distance B connecting left pedicle entry point to the edge of the aortic wall and (b) projections Bx and By on an orthogonal coordinate system as defined by axes *x* and *y*, which represent the minimum AP depth and horizontal displacement of the aortic wall relative to the left pedicle entry point O (Fig. 1).

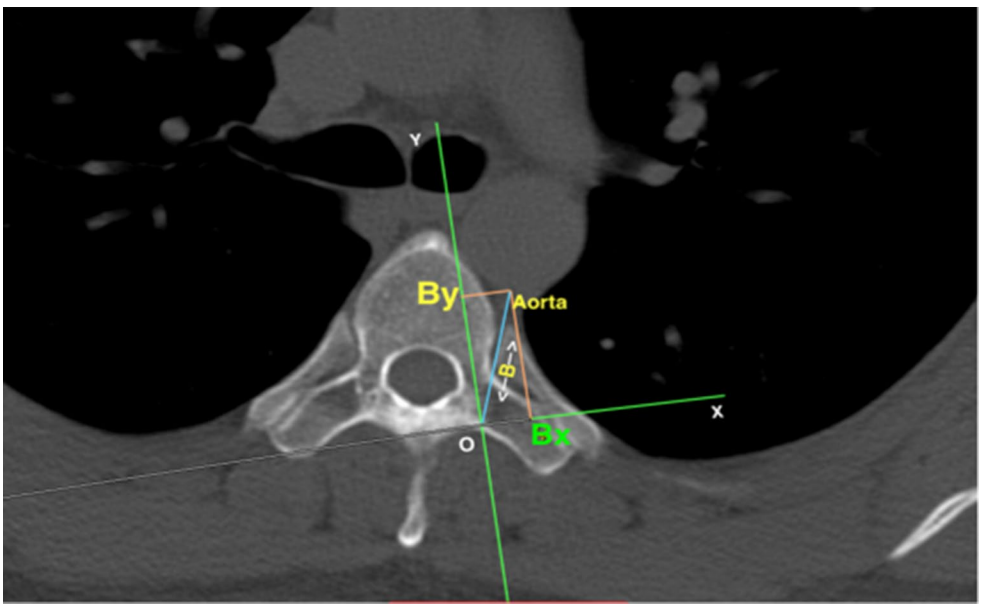

Fig. 1 Axial view of T4, supine position. Point O defined as the point of pedicular screw entry along the pedicular axial line (axis *y*). The minimum distance to the aortic edge B is drawn with the respective Bx – By projections defined on axes *x* and *y*

Two independent observers took all measurements, and mean values were calculated for each measurement (Vitrea 2 Imaging Software, Vital Images Inc.) Data were expressed as mean ± SD, and Kolmogorov–Smirnov test was applied for normality analysis of the quantitative variables. Intraobserver and interobserver reliabilities were examined using the intraclass correlation coefficient (ICC) between the two independent observers taking measurements at different time periods. The comparison of variables between the three different positions was made using the one-way repeated measures analysis of variance (ANOVA) model. Pairwise comparisons were made using the Bonferroni test. Friedman and Wilcoxon tests were used in case of violation of normality. All tests were two-sided, and a P value of <0.05 was used to denote statistical significance. All analyses were carried out using the statistical package SPSS version 17.00 (Statistical Package for the Social Sciences, SPSS Inc., Chicago, Ill., USA).

Results

The results of the analysis are presented in Table 1. In absolute values, aorta moves closer to the T5–T7 vertebrae across all three different positions (Fig. 2). In supine position, minimum distance B to the aortic wall decreased from T4 to T7 and then gradually increased again. The minimum distance was measured at T7 (32.78 ± 3.98 mm) (Table 1).

In prone position, the minimum distance was measured at T6 (36.55 ± 4.05 mm) with a tendency to increase in the caudal thoracic vertebrae, maintaining a mean value between 39 and 40 mm (Fig. 2).

In prone position with padding, a considerable drop in the minimum distance B was noted, from T4 to T5, reaching from 38 ± 1.05 to 35.36 ± 3.02 mm. In the caudal thoracic vertebrae, B distance tends to increase and maintains a mean value between 38.54 and 38.21 mm. (Table 1, Fig. 2).

For all three different positions, a statistically significant difference in the distance B was detected across all thoracic vertebrae levels (Table 1). This statistically significant difference was even more evident when adjusted for BMI and sex differences, confirming that patient position significantly affects the relative position of the aorta to the thoracic spine.

Plotting of the measured Bx and By values (Tables 2, 3), from the left pedicle entry point, allows better understanding of the relative changes in aortic position for all three different positions, from T4 to T12. Our data demonstrate a tendency of the aorta to shift anteromedially relative to the thoracic spine as the patient goes from supine to prone and to prone with padding positions (Fig. 3). At the level of T9, the aortic wall demonstrates maximum anterior shift in prone position and maximum lateral shift in both prone positions. In both prone positions, the aortic wall approaches the "y"-axis, across most thoracic vertebrae levels, being closer to the left pedicular axis and thus to the typical screw trajectory. In particular, at T6 level, the aortic wall lies closest to the left pedicle axis, when patient is placed in the prone with padding position.

Discussion

In the current study, the relative position of the aorta to the thoracic spine (levels T4–T12) was evaluated relative in supine, prone and prone with padding positions. Normally, thoracic aorta lies anteriorly and laterally to the spine and gradually shifts anteromedially as it approaches the diaphragmatic hiatus [13]. From that point, abdominal aorta continues anteriorly to the vertebral bodies and divides into the common iliac vessels at the level of L3–L4 [14]. The data of this study demonstrated a significant migration

Table 1 Mean values of the minimum distance B to the aortic wall with their respective SDs, F values and P values

Distance B to edge of aortic wall (mm)	Supine		Prone		Prone with padding		F value	P value
	Mean	SD	Mean	SD	Mean	SD		
T4	35.99	3.98	39.92	2.92	38.00	1.05	47.05	<0.001
T5	35.06	4.3	36.72	4.47	35.36	3.02	10.38	<0.001
T6	34.18	5.5	36.55	4.05	35.40	2.64	8.26	0.004
T7	32.78	5.85	39.57	2.44	38.54	0.72	186.51	<0.001
T8	35.90	3.80	40.09	2.64	38.08	1.21	113.68	<0.001
T9	36.94	3.01	40.48	2.65	38.06	0.89	114.06	<0.001
T10	36.39	3.90	39.84	2.70	38.31	1.05	75.48	<0.001
T11	37.07	3.62	39.80	2.96	38.25	1.00	51.84	<0.001
T12	36.86	3.43	39.78	2.45	38.21	0.95	66.06	<0.001

Across all vertebrae levels there is a statistically significant difference ($P<0.001$), confirming a significant displacement of the aortic edge relative to the thoracic spine. All values are presented as mean ± SD

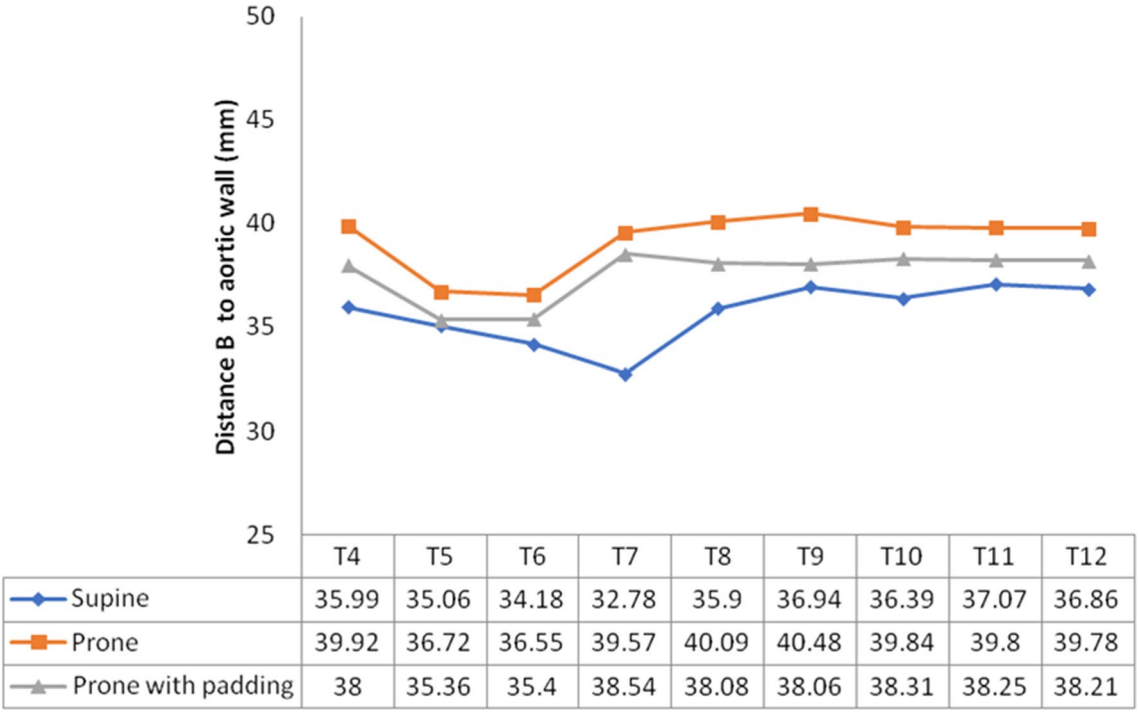

Fig. 2 Graphical summary of the mean B values across all vertebrae in the three different patient positions. The distance tends to decrease at T5, T6, T7 levels before increasing again in the supine position. In both prone positions, the lowest distance B is observed at T5 and T6 with a tendency to increase again at T7. All values are presented as mean

Table 2 Mean distance Bx from pedicular entry point O across thoracic levels T4–T12

Distance Bx (mm)	Supine		Prone		Prone with padding		*F* value	*P* value
	Mean	SD	Mean	SD	Mean	SD		
T4	16.81	1.94	15.31	1.23	13.99	0.45	227.47	< 0.001
T5	18.66	3.1	15.53	2.37	13.73	1.25	223.53	< 0.001
T6	18.33	3.50	13.94	1.54	13.45	1.10	279.48	< 0.001
T7	18.12	4.13	15.17	1.02	14.21	0.31	134.78	< 0.001
T8	16.91	1.84	15.35	1.10	13.97	0.46	266.10	< 0.001
T9	19.75	3.02	15.47	1.10	14.00	0.40	499.71	< 0.001
T10	17.04	1.93	15.26	1.11	14.11	0.45	247.56	< 0.001
T11	17.39	1.95	15.29	1.26	14.06	0.41	315.92	< 0.001
T12	17.21	1.68	15.18	1.00	14.13	0.39	351.65	< 0.001

There is a statistically significant difference between supine, prone and prone with padding positions ($P < 0.001$). All values are presented as mean ± SD

of the aorta from a posterolateral to a more anteromedial position as patients switched from supine to prone positions. To the best of our knowledge, there is one comparable study evaluating the migration of the aorta in discrete supine and prone positions [12]. In this study, 50 non-scoliotic patients have been investigated with CT and/or MRI scans and an anteromedial migration of the aorta was also demonstrated. Jiang et al. [15] have also investigated 26 patients with single RT-AIS with MRI scans in supine and prone positions and found that the aorta shifts more anteromedially and closer to the spine at the T5–T10 levels in the prone position.

In our study, the above findings are confirmed, and more importantly an even greater and more substantial migration toward the midline was observed when comparing the supine to the prone with padding position. This change was more marked at the at T5–T7 and T9 levels. Similarly, there was a significant increase in the anteroposterior distance (By) from the left pedicle entry point, as the patient assumed prone positions. The increase in this

Table 3 Lateral distance By from pedicle entry point O, across thoracic levels T4–T12

Distance By (mm)	Supine		Prone		Prone with padding		*F* value	*P* value
	Mean	SD	Mean	SD	Mean	SD		
T4	31.81	3.56	36.87	2.71	35.33	1.00	198.41	< 0.001
T5	29.58	3.83	33.23	4.13	32.57	2.84	63.44	< 0.001
T6	28.75	4.91	33.78	3.79	32.74	2.46	103.62	< 0.001
T7	27.14	5.20	36.54	2.26	35.83	0.68	480.37	< 0.001
T8	31.66	3.39	37.02	2.46	35.42	1.15	238.32	< 0.001
T9	31.09	2.78	37.41	2.45	35.38	0.85	427.33	< 0.001
T10	32.15	3.45	36.79	2.50	35.62	1.00	182.48	< 0.001
T11	32.72	3.13	36.75	2.73	35.57	0.90	147.98	< 0.001
T12	32.59	3.08	36.76	2.28	35.49	0.86	170.61	< 0.001

There is a statistically significant difference between supine, prone and prone with padding positions ($P < 0.001$). All values are presented as mean ± SD

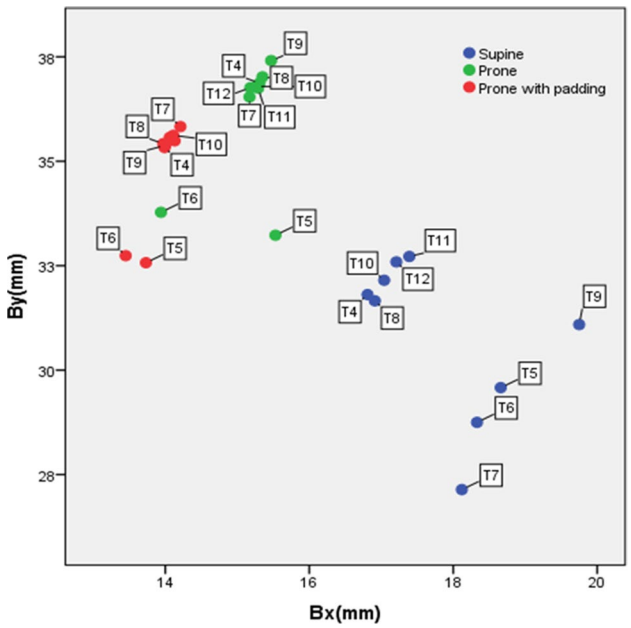

Fig. 3 Relative position of the aortic wall to the thoracic spine depending on patient position. The aorta moves more medially and anteriorly toward the midline as the patient changes position from supine to prone and prone with padding positions. All values are presented as mean

distance was more evident in the direct prone position. A possible explanation for this noted difference is that the presence of padding may act as an external barrier to a further anterior aortic migration.

Sucato et al. analyzed the position of the aorta in patients with idiopathic scoliosis in MRI scans and found that the thoracic aorta is positioned more posterolaterally compared to normal spines. In their analysis, the aorta begins to be seen in front of the T4 vertebral body and moves posterolaterally while descending to the lower thoracic spine. Then, it turns back anteromedially as it passes in front of T12, through the diaphragmatic hiatus. Our study supports their findings [16].

By defining measuring coordinates around the left pedicular entry point, the authors of this study tried to establish a set of parameters that can be intuitively understood by the surgeon. During free hand or fluoroscopic pedicle screw placement, the surgeon uses landmarks such as facet joints, transverse processes and laminae. Vaccaro et al. analyzed non-scoliotic spines and found that the aorta and the esophagus are at risk of injury when a pedicle screw penetrates the anterior vertebral cortex [17–21]. From the present study, it is apparent that an anterolateral cortical breach during left pedicular screw placement places the aorta into greatest risk, particularly when the patient is resting on the prone with padding position.

All measurements were taken on CT scans of 5 mm thickness. CT scans present with difficulties and limitations in defining the soft tissue structure, and an MRI scan may be preferable. However, in a similar study by Huitema et al. [22], where both CT and MRI scans have been utilized, the authors did not find significant differences between the two techniques, except from L1 level, at prone position [12]. Furthermore, to ensure measurement validity, we have attempted to minimize measurement errors by using small thickness slices and correcting for interobserver variability. Also, in contrast to similar studies, the closest distance of the aortic wall to the left pedicle entry point was calculated for each measurement, with no need to define by approximation the whole outline of the aortic structure and its center.

The position of the aorta relative to the spine has been previously studied in scoliotic and kyphotic patients [4, 15, 18–20] and also in relation to other anterior structures [21]. Sucato et al. have studied the relation of aorta to the thoracic spine between scoliotic and non-scoliotic patients, with their findings demonstrating a more anterior position of the aorta in patients with left thoracic scoliosis compared to a more posterior position in patients with right thoracic scoliosis

[10, 16]. The current study, comprising a relatively large non-scoliotic population, demonstrates that aortic migration associated with patient position is significant and may have important implications for thoracolumbar spine surgery. In contrast to previous studies, the coordinates of the shortest distance from the aortic edge to the left pedicle entry point (minimum distance before aortic wall injury as a result of direct screw penetration) were calculated. In posterior spine surgery, understanding the relative position of the aorta to the spine determines the safe pedicle screw trajectory as well as the safe screw length. Although direct iatrogenic injury is rarely reported in the literature, direct contact of hardware with the aorta has been reported as high as in 17% of treated patients [22]. Sucato et al. [23] observed the screw tip–aorta position in 14 patients with 106 screws (average 7.6 screws/patient) and found 13 screws (12.3%) thought to cause a contour deformity of the aorta, with no vascular complications. Comparably, Bullmann et al. [24] reported that in 20 scoliotic patients, 5.8% (13/226) of the screws were within 1–3-mm proximity to the aorta. Screw migration carries higher risks of aortic injuries following corrective spinal surgery. A distance of 1–3 mm from the screw tip to the aortic wall was regarded as a significant risk. This may pose a problem following corrective spinal surgery leading to subsequent screw revision [25]. Aortic complications of corrective spinal surgery are reported infrequently. However, they include not only early postoperative iatrogenic perforation of the aorta but also late injury due to aortic wall erosion by the screw tip [8, 26–28]. Therefore, the true incidence of iatrogenic aortic injury following thoracolumbar surgery may be underestimated.

This study aims to stress the significant difference in the changes in the relative position of the aorta to the thoracic spine between the CT scan of the standard supine and the surgical prone with padding positions. The study group, although limited, is the largest encountered in the literature dealing with changes in the relative position of the aorta. The authors decided not to include patients with scoliotic deformities (either congenital or idiopathic) in the study group. This is because each deformity is unique, and therefore, standard anatomy may be altered. For such subjects, a per-case analysis should be performed.

Our study's findings can be useful in the preoperative planning of thoracic spine surgery. The position of the aorta both in the supine and in the prone patients should be thoroughly examined preoperatively. Assessment of the aortic migration may allow the surgeon to choose optimal operative approach. Prone positioning for posterior thoracolumbar approach affects significantly the anatomic relationship of the aorta to the spine, and the surgeon should be aware that standard CT evaluation in the supine position represents a static technique that can differ considerably from surgical reality.

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Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

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