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ORIGINAL ARTICLE

Computerized tomography imaging in adolescent idiopathic scoliosis: prone versus supine

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Abstract
Background The aim of the present study was to assess the degree of apical vertebral rotation values in Adolescent Idiopathic Scoliosis (AIS) that were obtained on CT scans, and to analyze the influence of patient position (supine versus prone) on the degree of rotation.
Methods The study included 50 apical vertebra rotation measurements of 34 patients with Type 1A and Type 3C curvature according to the Lenke classification. CT imaging was applied to the patients in supine and prone positions to measure the apical vertebral rotation (AVR). The average AVR angles were measured using the Aaro–Dahlborn method and the results were compared.
Results No significant differences were found between the vertebral rotation measured in the prone and supine positions for the Lenke 1A subgroup and the Lenke 3C thoracic group ($p = 0.848$; $p = 0.659$, respectively). In the Lenke 3C lumbar group, however, the vertebral rotation in the supine position was found to be significantly lesser than that in the prone position (difference $-1.40° \pm 1.79°$, $p = 0.007$).
Conclusion The assessment of the apical vertebra rotation is crucial in AIS. Even though the vertebral rotation in the supine position was found to be significantly lesser than that in the prone position, CT imaging in a prone position could not be considered clinically more relevant than the CT images in a supine position as there was less than 3° difference.

Keywords Adolescent idiopathic scoliosis · Apical vertebral rotation · CT

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Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformity characterized by a deformation in the sagittal, frontal and transverse planes [1]. Axial vertebral rotation (AVR) is one of the most important parameters for the evaluation of spinal deformities [2]. The assessment of vertebral rotation is important not only for predicting the prognosis of the curve and monitoring the progression of the scoliotic deformity, but at the same time, axial rotation has been equally valuable in providing information to better understand the effect of brace treatment or surgical interventions [3]. During operative planning for AIS, accurate definition of vertebral rotation is of critical importance. Insufficient knowledge of vertebral rotation may lead to unnecessary surgical operations and misplacement of the pedicle screws causing a risk of spinal cord injury [4]. A number of techniques have been developed for the assessment of vertebral rotation in scoliosis. Perdriolle used the measurement of the pedicle shift with a specific template [5], while Cobb used the displacement of the spinous process from the midline for the assessment of the rotation [6]. Nash and Moe assessed vertebral rotation using the displacement of the convex-side pedicle towards the midline [7] and Mehta used convex-side pedicles, the transverse process and the vertebral body for the measurement of rotation at different degrees [8]. In the Fait and Janovec [9] method, with *a* representing the distance between the pedicle at the convex side and the edge of the vertebral body, and *b* representing the full width of the vertebral body, an approximate rotation angle can be obtained based on the ratio of *a*/*b*. In 1986, Stokes et al. [10] developed a procedure that separately marked six landmarks on both an AP view and oblique X-ray to calculate vertebral rotation angles. Alternative techniques have been described by many others, including ultrasonography [11], computerized tomography (CT) [12], surface topography such as the traditional Automatic Scoliosis Analyser (AUSCAN) [13] and more recently, Diers Formetric [14] and three-dimensional magnetic resonance imaging (MRI) [15]. Routine measurement of AVR from radiographic images is prone to error because of the different properties of imaging techniques, variable characteristics of the observed anatomy, and difficulties in image navigation and representation. Recently, measurement of the degree of axial rotation using computed tomography (CT) has become more widespread. The use of CT in the assessment of vertebral rotation results in an inherently high level of exposure to ionizing radiation and higher cost. However, several measurement methods (Aaro and Dahlborn [16], Ho et al. [17], Krismer et al. [12] and Gocen et al. [18]) have been developed, with the Aaro and Dahlborn method as the most widely accepted [12, 19] as it has high interobserver and intraobserver reliability [6, 16, 20].

When taking images in AIS, the different positions of the patient, standing, or lying supine and prone, could lead to different results due to the spontaneous correction which occurs in the supine position [21, 22]. When standing radiographs have been compared with radiographs taken in a supine position, spontaneous recovery in the deformity has been determined at a rate of 30 % [22, 23]. In a study by Ho et al. [16], this recovery was in the coronal plane and no statistically significant effect on rotation of the deformity was observed. Zetterberg et al. [23] reported spontaneous coronal deformity correction rates of 19 and 31 % for thoracic and lumbar curves. Standard CT imaging of the vertebral column is made in a supine position. As the application of supine CT imaging in many patients, particularly those with rib hump, can be made in semisupination, this can cause errors in the measurement of apical vertebral rotation (AVR). A semisupination axial slice is shown in Fig. 1.

Fig. 1 15-year-old female, Lenke Type 1A supine position CT (Semisupine axial slice)

The aim of the present study was to assess the degree of apical vertebral rotation values that were obtained on CT scans and measured according to the Aaro–Dahlborn method, and to analyze the influence of patient position (supine versus prone) on rotation degrees. The hypothesis of the study was that there would be no difference in vertebra rotation angles whether the patient is in the prone or supine position for the scan. To the best of our knowledge, there have been no published reports in English language literature of comparisons between measurements of apical vertebra rotation obtained from CT scans in the prone versus supine position using the Aaro and Dahlborn method.

Materials and method

The study was conducted with the approval of the Local Ethics Committee and informed consent was obtained from all the patients. Subjects were selected prospectively and consecutively. A total of 52 AIS patients presented for treatment at our institute between January 2012 and January 2014. Of these, 34 met the study criteria so evaluations were made of 50 apical vertebrae of 34 AIS patients. Patients included in the study were those with idiopathic scoliosis from whom fully informed consent was received. Exclusion criteria were patients with congenital scoliosis, neuromuscular disorders (cerebral palsy, spinal muscular atrophy, muscular dystrophy, etc.), and previous operations due to scoliosis, or those unwilling to participate in the study. All the included cases had rib hump deformity and no case had leg length discrepancy.

Computed tomography was routinely performed on soft sheets preoperatively to provide information about the selection of appropriate pedicle screws, especially in the apical side of the concavity due to the small pedicle width and the limited epidural safe zone [26]. Computed tomography was performed by a spiral CT scanner (Toshiba Asteion 4® 4-row CT, Tokyo, Japan) with the following parameters: 120 kV, tube current 260 mA, slice thickness 1 mm, rotational speed 0.75 s/rotation, respectively. CT imaging for the whole vertebral column was applied to the patients in both supine and prone positions. To eliminate positional errors originating from the patient during the CT imaging, care was taken to ensure that in the prone and supine position both shoulders and the pelvis were parallel to the floor. If there was a significant rib hump, or anterior chest deformity which would disrupt the alignment of the shoulder and pelvis, a silicone support was used under the shoulder or chest to balance the costal hump that occurred on the curvature side, as defined by Göçen et al. [18].

All CT investigations included a coronal plane pilot scanogram (supine anteroposterior radiograph) that showed the entire spine from T1 to S1 in a single image. A CT scan of the apex vertebra is conventionally used to indicate rotation severity. First, the regional apical vertebra was defined from the standing anteroposterior orthoroentgenogram of the patient (Fig. 2). The apical vertebra was that which most deviated laterally from the central sacral line. Verification of the apical vertebra was also made on the scanogram of the whole vertebra of the patient on CT. After defining the apical vertebrae, 1 mm axial slices were taken in both prone and supine positions. In the supine and prone position CT images, axial image slices were defined crossing the same area of the determined reference apical vertebrae. The Aaro–Dahlborn method was used to make the measurements of the angular rotation of the thoracic apical vertebrae in patients with Type 1A deformity, and of both the thoracic and lumbar apical vertebrae in patients with Type 3C deformity. On the transverse CT slice at the curve apex, the AVR is given by the angle formed between a perpendicular line starting from the posterior central aspect of the spinal canal and the line drawn from the posterior central aspect of the spinal canal, crossing the middle part of the vertebral body.

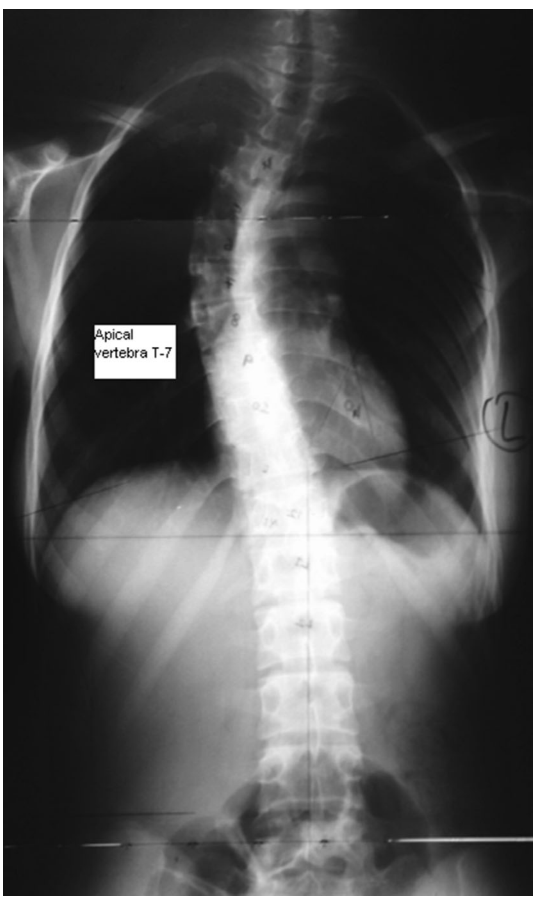

Fig. 2 Anterior–posterior standing preoperative orthoradiograph of a 15-year-old girl with AIS with a Lenke Type 1 curve. The apical vertebra was T 7

All radiographic alignment measurements were taken by two independent radiographic reviewers who were blinded to the study. The independent observers assessed all radiographs twice at an interval of 1 week. All of the reviewers had ample time to review the radiographs as no time limit was imposed on the review. All measured values were calculated to two decimal places. Measurements were taken using PACS software [PACS (Picture archiving and communication system) (Novarad Corporation, Utah, USA] (Figs. 3, 4, 5).

Statistical analysis

Statistical calculations were performed using NCSS (Number Cruncher Statistical System) 2007 and PASS (Power Analysis and Sample Size) 2008 Statistical Software (NCSS LLC, Kaysville, UT, USA). The Shapiro–Wilk test was used to determine normality of the parameters. The mean measurement values of both assessors were used for the statistical analysis (NUT, GB).Besides the use of descriptive statistical methods (mean, standard deviation) to evaluate the data, a paired samples *t* test was used to test the significance of the difference between the rotation angles measured in the prone and supine positions. Linear mixed-effects modeling was used to analyze the fixed effects of gender, group (3C or 1A), age, apex (lumbar or thoracic) and prone–supine on measurements where vertebrae were nested within subjects. In the calculation of interobserver and intraobserver reliability of the prone and supine measurements, the intraclass correlation coefficient and Bland–Altman plots [27] were used. Using G*Power (v3.1.7) program with the data obtained in the study, post hoc power analysis was applied to the 3-C Lumbar prone and supine measurements. A value of $p < 0.05$ was accepted as statistically significant.

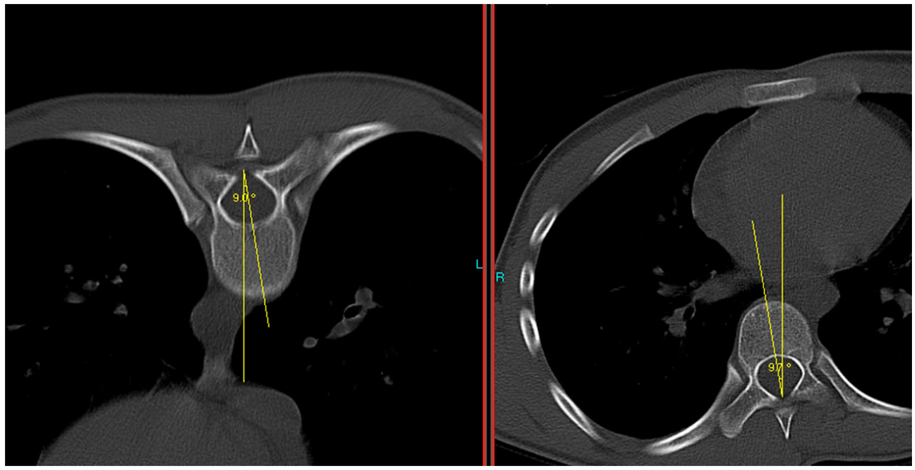

Fig. 3 Axial CT images of the thoracal apical vertebra (T11 vertebra) of a 15-year-old girl with Lenke Type 1A AIS. *Left* CT image with 9° in supine position. *Right* CT image with 9.7° in prone position

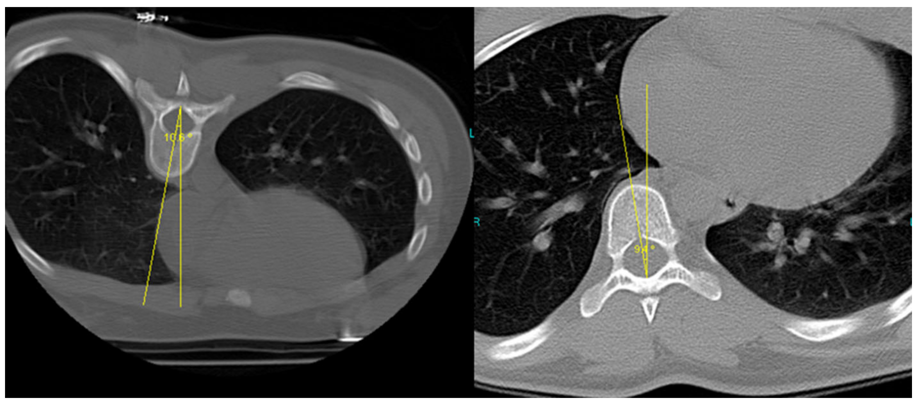

Fig. 4 Axial CT images of the thoracal apical vertebra (T8 vertebra) of a 16-year-old girl with Lenke Type 3C AIS. *Left* CT image with 10.6° in supine position. *Right* CT image with 9.4° in prone position

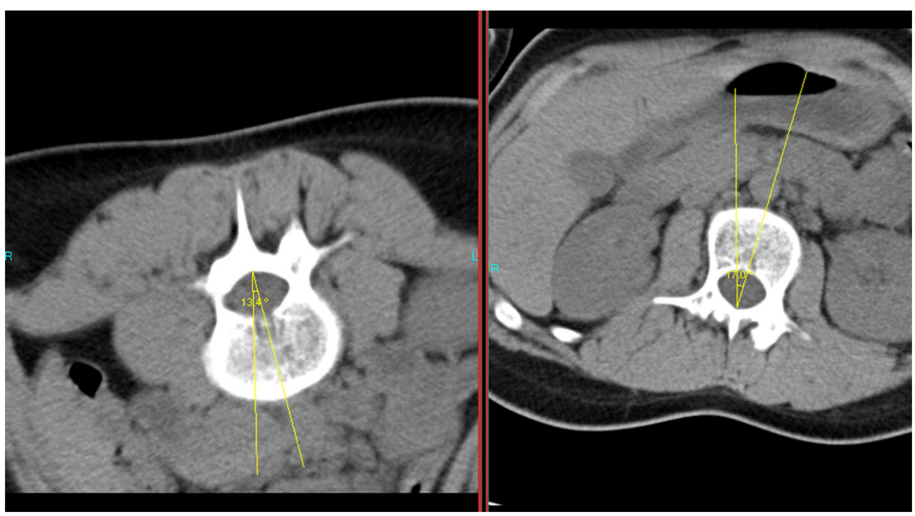

Fig. 5 Axial CT images of the lumbar apical vertebra (L2 vertebra) of a 16-year-old girl with Lenke Type 3C AIS. *Left* CT image with 13.4° in supine position. *Right* CT image with 17.0° in prone position

Results

Eighteen patients were Lenke [24] Type 1A and 16 patients were Lenke Type 3C. For all curves, apexes of the curves as described by Lenke [25] were used to define curve location. Thoracic curves were defined as curve apex T10 or above, apexes between T11 and L1 were defined as thoracolumbar curves, and lumbar curves included apexes at the L1–L2 disc or below. The Type 1A patients were 14 females (77.7 %) and 4 (22.3 %) males with a mean age of

Table 1 Evaluation of the differences between the prone and supine position angles

	Prone Mean ± SD	Supine Mean ± SD	Difference Mean ± SD	p
Total	17.49 ± 3.93	17.86 ± 5.50	−0.36 ± 3.42	0.453
1-A	16.19 ± 3.61	16.36 ± 5.52	−0.17 ± 3.78	0.848
3-C thoracic	16.70 ± 3.01	16.24 ± 5.43	0.46 ± 4.10	0.659
3-C lumbar	19.74 ± 4.32	21.15 ± 4.22	−1.40 ± 1.79	0.007**

Paired samples t test was used ** $p < 0.01$

15.7 ± 3.45 years (range 13–20 years). The Type 3C patients were 12 females (75 %) and 4 (25 %) males with a mean age of 15.3 ± 3.05 years (range 13–20 years).

No significant differences were found between the vertebral rotation measured in the prone and supine positions for the Lenke 1A subgroup and the Lenke 3C thoracic group ($p = 0.848$; $p = 0.659$, respectively). In the Lenke 3C lumbar group, however, the vertebral rotation in the supine position was found to be significantly lesser than that in the prone position (difference −1.40° ± 1.79°, $p = 0.007$). Detailed results are shown in Table 1. The ICC values were all very high [minimum 0.998 (CI 0.996–0.998)], as shown in Table 2. The Bland–Altman graphics were examined (Fig. 6a, b), the difference between supine 1 and supine 2 measurements had mean values 0.196° ± 0.298° and this was the worst agreement. Considering only prone 1 measurements, the difference between 1st and 2nd observers was 0.002° ± 0.243°, and this was the best agreement (Table 3).

Linear mixed-effects modeling is used to analyze the fixed effects of gender, group (3C or 1A), age, apex (lumbar or thoracic) and prone–supine on measurements where vertebrae were nested within subjects (Table 4). As a result, the effects of age and apex were found to be statistically significant ($p = 0.009$; $p = 0.001$, respectively), where the fixed effects of gender, group and prone–supine were found to be not statistically significant. One-year increase of age resulted in 0.710 increase in the measurement, where apex being lumbar instead of thoracic resulted in 3.975 increase in the measurement. The statistical significance of the random effect of intercept ($p = 0.047$) suggests that each individual has different estimation intercepts. The residual of the model is significant ($p = 0.001$), meaning that with the existing model we are still missing some (residual estimate = 12.884) information in terms of measurements. Linear mixed-effects analysis was applied to the risk factors on the measurements.

Table 2 Examination of intraobserver and interobserver reliability of prone and supine position measurements

	ICC	95 % CI
Observer 1		
Prone 1–prone 2	0.998	0.996–0.999
Supine 1–supine 2	0.999	0.997–1.000
Observer 2		
Prone 1–prone 2	0.998	0.996–0.998
Supine 1–supine 2	0.999	0.997–0.999
Prone 1		
Observer 1–observer 2	0.999	0.998–0.999
Prone 2		
Observer 1–observer 2	0.999	0.999–1.000
Supine 1		
Observer 1–observer 2	0.999	0.998–0.999
Supine 2		
Observer 1–observer 2	0.999	0.998–1.000

ICC intraclass correlation coefficient

Discussion

The present study has shown that lumbar apical vertebral rotation in Lenke Type 3C was statistically significantly affected by the position of the patient in CT, but there was no significant change in thoracic apical vertebral rotation in Lenke 1A and Lenke 3C. Yazici et al. [22] concluded that the changes in position (standing versus supine) would influence the deformity on the transverse plane and Sugimoto et al. [28] stated that there is a low correlation between preoperative vertebral rotation in the supine position and intraoperative rotation in the prone position because of the oblique supine position when there is rib hump deformity. However, the present study determined a high correlation between the results in supine and prone positions for the thoracic apical vertebra rotation in Lenke 1A and Lenke 3C curves. This could be due to the silicone elevator under the shoulder or chest to balance the deformity. Rotation in a deformed vertebra was first described by Adams [29] in 1865. When planning surgery in AIS, it is important to determine vertebral rotation [21, 30, 31]. If vertebral rotation is not determined in the correct way, spinal cord and vascular injuries may develop associated with misplacement of the pedicle screws [4]. The present study has shown that lumbar apical vertebral rotation in Lenke Type 3C was statistically significantly affected by the position of the patient in CT (supine leading to a greater rotation

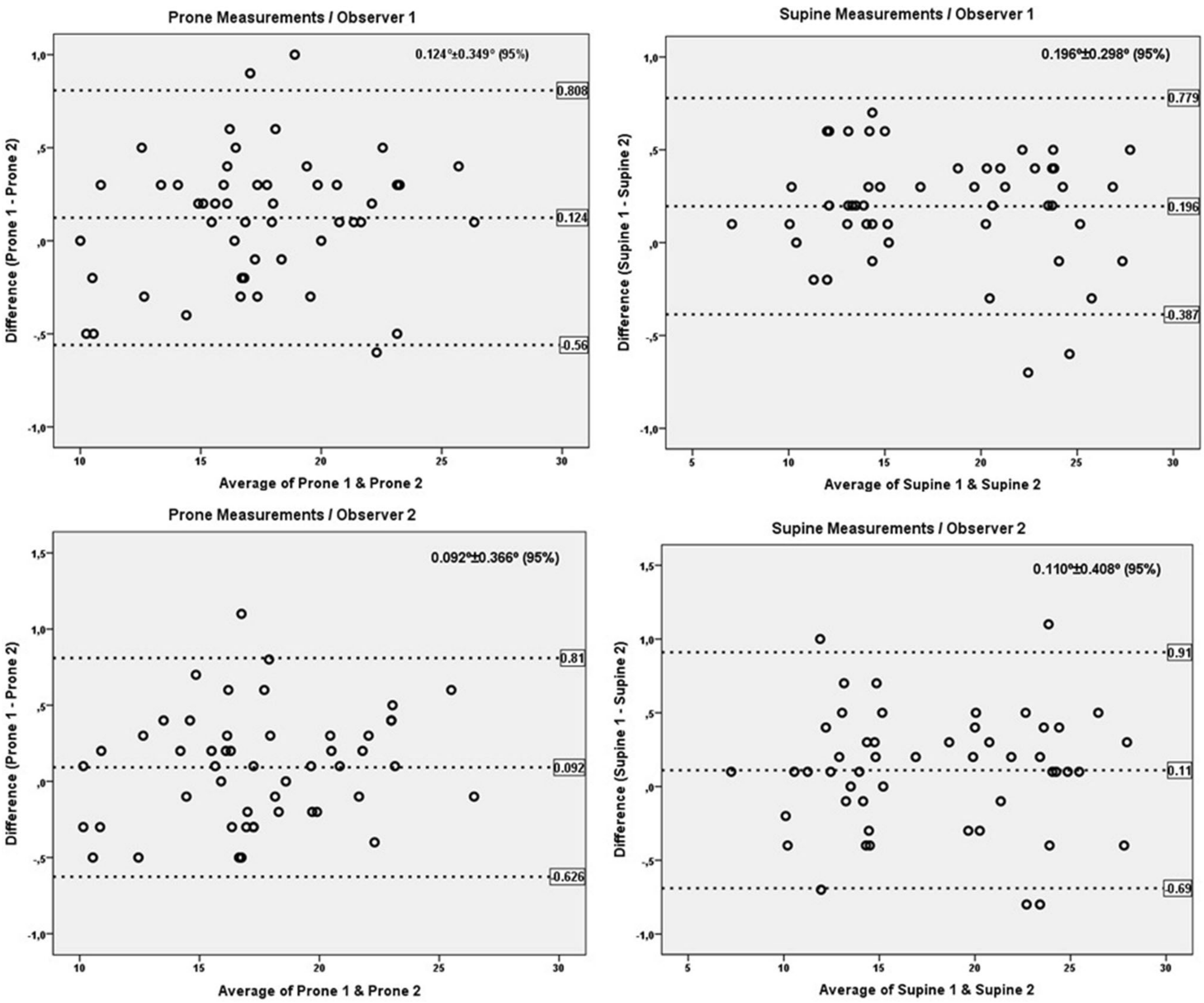

Fig. 6 Evaluation with Bland–Altman plot of all the measurements of both observers. **a** Prone and supine measurements of the observer 1 and observer 2, **b** Prone measurements of average of observer 1 and observer 2 with 1-week interval, supine measurements of average of observer 1 and observer 2 with 1-week interval

angle), but there was no significant change in thoracic apical vertebral rotation in Lenke 1A and Lenke 3C due to patient position.

Adolescent idiopathic scoliosis should be evaluated on standing images for all three planes. Rotation of the vertebra can be measured on routine scoliosis radiographs but it can be difficult to evaluate the convex pedicle of a vertebra with more than 30° rotation [22, 30, 32]. There has been wide acceptance of the effectiveness of CT in the measurement of vertebral rotation [17, 21, 22, 31, 33]. The Aaro–Dahlborn method is a widely accepted method for AVR measurement, which obtains measurements with a greater correlation to the actual rotation value, even with tilt in the sagittal and coronal planes [34] compared to other CT methods, such as that of Ho et al. Therefore, the Aaro–Dahlborn method was used in the present study.

The supine position measurements of the lumbar AVR were found to be statistically significantly higher than the prone position measurements ($p = 0.007$). Rotation in AIS develops from both disc and vertebra origin [28, 35]. In the thoracic region, the vertebral rib joints provide a more stable spinal segment and limit the amount of disc movement. The lumbar region is the area of movement in the spinal system and is easily affected by positional changes in the trunk. The differences in the lumbar region measurements of the cases in the current study are thought to arise from this. Although a statistically significant difference was determined in the measurement of lumbar apical

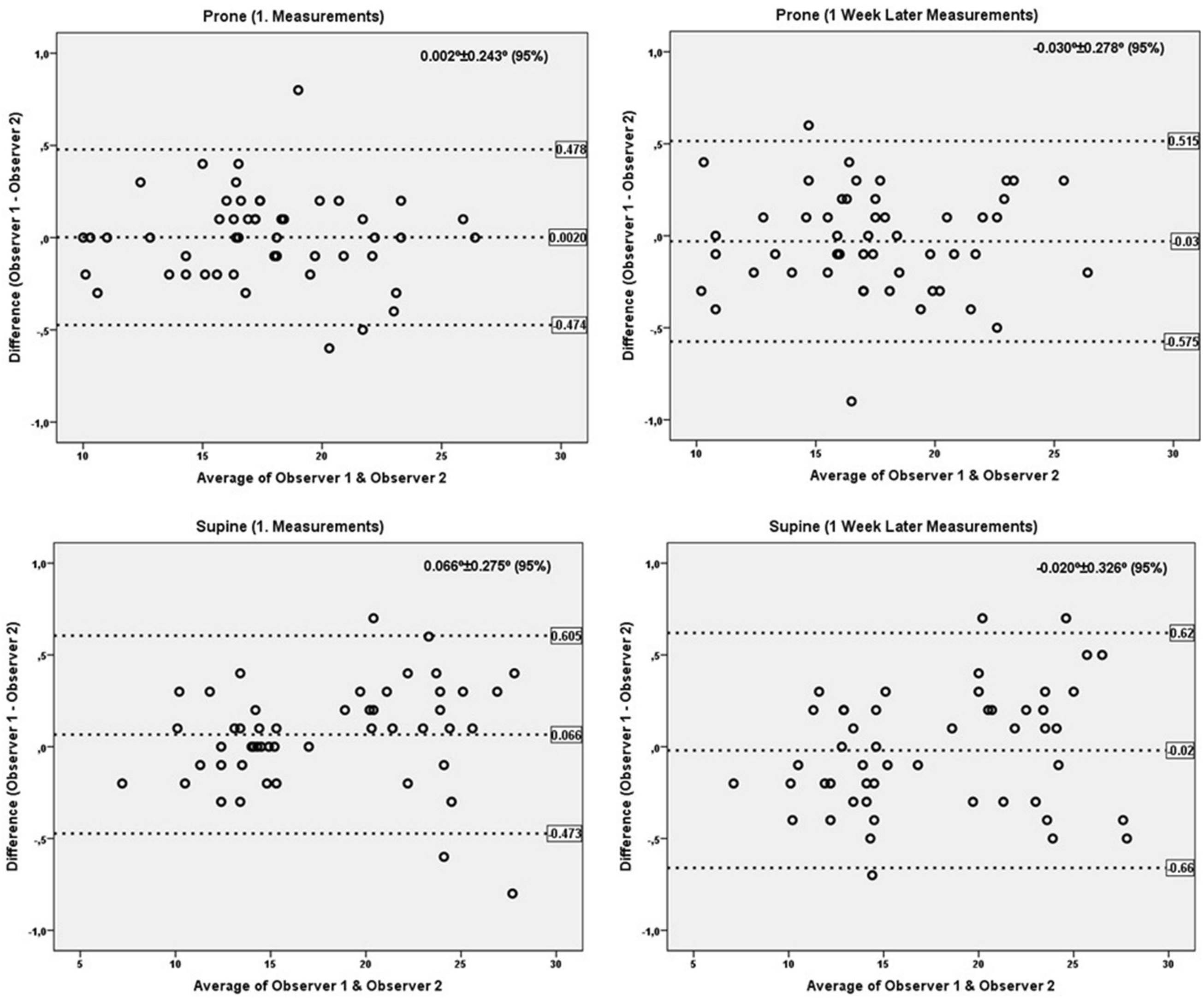

Fig. 6 continued

vertebral rotation of 1.4° between the prone and supine position CT images, this could be considered to have a negligible effect on relevance as standard deviations for measurement defaults were stated as ±4° by Matteri et al. [36] and 3° ± 4° by Drerup et al. [37].

The asymmetry in the dorsal region of AIS patients with rib hump causes a raised trunk when lying supine and this can lead to incorrect imaging of the deformity. Anterior deformity may not always occur but it certainly can occur in scoliosis patients [26]. Therefore, to overcome the positional adverse effect of the deformity, a soft silicone elevator was used in the current study. The results of this study suggest that there would be no benefit in measuring the vertebral rotation from prone position CT images for the planning of pedicle screw placement to avoid mortal complications.

Radiation exposure is of critical importance in this evaluation, considering the young age of AIS patients and their vulnerability during crucial growth stages [3]. Furthermore, some studies have concluded that inclination and tilt have a greater effect on the accuracy of CT measurements [3, 38] and the high cost of CT can also be a prohibitive factor. However, intervention with CT scans could be an alternative for the evaluation of bony details such as congenital scoliosis, and evaluation of vertebral rotation for patients with previous scoliosis surgery or those with severe scoliosis.

Between 16 prone and supine measurements, when values were determined as difference = 1.40, SD = 1.79, effect size = 0.782, $\alpha = 0.05$, then power was determined as 83.2 %. The limitations of this study are that the number of cases was limited and that no comparison could be made

Table 3 Examination of Bland–Altman results of prone and supine position measurements

	Mean values—upper and lower limits
Observer 1	
Prone 1–prone 2	0.124° ± 0.349° (0.808, −0.56)
Supine 1–supine 2	0.196° ± 0.298° (0.779, −0.387)
Observer 2	
Prone 1–prone 2	0.092° ± 0.366° (0.81, −0.626)
Supine 1–supine 2	0.110° ± 0.408° (0.91, −0.69)
Prone 1	
Observer 1–observer 2	0.002° ± 0.243° (0.478, −0.474)
Prone 2	
Observer 1–observer 2	−0.030° ± 0.278° (0.515, −0.575)
Supine 1	
Observer 1–observer 2	0.066° ± 0.275° (0.605, −0.473)
Supine 2	
Observer 1–observer 2	−0.020° ± 0.326° (0.62, −0.66)

Table 4 Linear mixed-effects analysis of risk factors on measurements

Source	Estimate	*p*	95 % CI	
			Lower	Upper
Fixed effects				
Intercept	5.277	0.214	−3.209	13.764
Gender (male)	−0.073	0.954	−2.621	2.476
Group (3C)	0.489	0.686	−1.938	2.917
Age	0.710	0.009*	0.187	1.233
Apex (lumbar)	3.975	0.001*	2.182	5.768
Prone–Supine (prone)	−0.365	0.612	−1.800	1.069
Random effects				
Intercept (subject = ID)	5.585	0.047*	2.084	14.965
Residual	12.884	0.001*	9.099	18.243

* $p < 0.05$

between different types and flexibility. In addition, CT scans may be too expensive and involve too much radiation exposure to be feasible for serial clinical or routine academic assessment.

Conclusion

The operative treatment of AIS patients is often performed with a posterior approach. Although CT imaging in a prone position provides a real-time image for posterior spinal surgery, it could not be considered to be more beneficial than the supine position for Lenke Type 3C and 1A scoliosis.

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Conflict of interest All authors declare no conflict of interest.

References

1. Hattori T, Sakaura H, Iwasaki M, Nagamoto Y, Yoshikawa H, Sugamoto K (2011) In vivo three-dimensional segmental analysis of adolescent idiopathic scoliosis. Eur Spine J 20:1745–1750
2. Stokes IAF (1994) Three-dimensional terminology of spinal deformity: a report presented to the Scoliosis Research Society by the Scoliosis Research Society Working Group on 3-D terminology of spinal deformity. Spine 19:234–248
3. Lam GC, Hill DL, Le LH, Raso JV, Lou EH (2008) Vertebral rotation measurement: a summary and comparison of common radiographic and CT methods. Scoliosis 2:16. doi:10.1186/1748-7161-3-16
4. Sugimoto Y, Tanaka M, Nakanishi K, Misawa H, Takigawa T, Ozaki T (2007) Predicting Intraoperative Vertebral Rotation in Patients With Scoliosis Using Posterior Elements as Anatomical Landmarks. Spine 32:E761–E763
5. Perdriolle R, Vidal J (1987) Morphology of scoliosis: three dimensional evaluation. Orthopedics (United States) 10:909–915
6. Russel GG, Hill Raso VJD, McIvor J (1990) A comparison of four computerized methods formeasuring vertebral rotation. Spine 15:24–27
7. Nash CL, Moe JH (1969) A study of vertebral rotation. J Bone Joint Surg [Am] 51:223–230
8. Mehta MH (1973) Radiographic estimation of vertebral rotation in scoliosis. J Bone Joint Surg [Br] 55:513–520
9. Fait M, Janovec M (1970) Establishing the rotation angle in the vertebrae. Scripta Med 43:207–215
10. Stokes IAF, Bigalow LC, Moreland MS (1986) Measurement of axial rotation of vertebrae in scoliosis. Spine 11:213–218
11. Burwell RG, Aujla RK, Cole AA, Kirby AS, Pratt RK, Webb JK, Moulton A (2002) Preliminary study of a new real-time ultrasound method for measuring spinal and rib rotation in preoperative patients with adolescent idiopathic scoliosis. Stud Health Technol Inform 91:262–266
12. Krismer M, Sterzinger W, Haid C, Frischhut B, Bauer R (1996) Axial rotation measurement of scoliotic vertebrae by means of computed tomography scans. Spine 21:576–581
13. Negrini S, Negrini A, Rainero G, Sibilla P, Santambrogio GC (1995) Correlation between trunk gibbosity and spinal torsion measured by the AUSCAN system. Studies in Health Technology and Informatics: Three-Dimensional Analysis of Spinal Deformities 15:279–283
14. Mangone M, Raimondi P, Paoloni M, Pellanera S, Di Michele A, Di Renzo S, Vanadia M, Dimaggio M, Murgia M, Santilli V (2013) Vertebral rotation in adolescent idiopathic scoliosis calculated by radiograph and back surface analysis-based methods: correlation between the Raimondi method and rasterstereography. Eur Spine J 22:367–371
15. Birchall D, Hughes DG, Hindle J, Robinson L, Williamson JB (1997) Measurement of Vertebral Rotation in Adolescent Idiopathic Scoliosis Using Three-Dimensional Magnetic Resonance Imaging. Spine 22:2403–2407
16. Aaro S, Dahlborn M (1981) Estimation of vertebral rotation and the spinal and rib cage deformity in scoliosis by computertomography. Spine 6:460–467

17. Ho EKW, Upadhyay SS, Chan FL et al (1993) New methods of measuring vertebral rotation from computed tomographic scans: an intraobserver and interobserver study on girls with scoliosis. Spine 18:1173–1177
18. Gocen S, Havitcioglu H, Alici E (1999) A new method to measure vertebral rotation from CT scans. Eur Spine J 8:261–265
19. Vrtovec T, Vengust R, Likar B, Pernus F (2010) Analysis of four manual and a computerized method for measuring axial vertebral rotation in computed tomography images. Spine 35:E535–E541
20. Skalli W, Lavaste F, Descrimes JL (1995) Quantification of threedimensional vertebral rotations in scoliosis: what are the true values? Spine 20:546–553
21. Kuklo TR, Potter BK, Lenke LG (2005) Vertebral rotation and thoracic torsion in adolescent idiopathic scoliosis: what is the best radiographic correlate? J Spinal Disord Tech. 18:139–147
22. Yazici M, Acaroglu ER, Alanay A, Deviren V, Cila A, Surat A (2001) Measurement of vertebral rotation in standing versus supine position in adolescent idiopathic scoliosis. J Pediatr Orthop 21:252–256
23. Zetterberg C (1983) Postural and time-dependent effects on body height and scoliosis angle in adolescent idiopathic scoliosis. Acta Orthop Scand 54:836–840
24. Lenke LG, Betz RR, Harms J, Bridwell KH, Clements DH, Lowe TG, Blanke K (2001) Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am 83:1169–1181
25. Lenke LG, Betz RR, Clements D, et al (2002) Curve prevalence of a new classification of operative adolescent idiopathic scoliosis: Does classification correlate with treatment? Spine 27:604–611
26. Liljenqvist UR, Allkemper T, Hackenberg L, et al (2002) Analysis of vertebral morphology in idiopathic scoliosis with use of magneticresonance imaging and multiplanar reconstruction. J Bone Joint Surg Am 84-A:359–368
27. Bland JM, Altman DG (1999) Measuring agreement in method comparison Studies. Stat Methods Med Res 18:135–160
28. Sugimoto Y, Tanaka M, Nakanishi K, Misawa H, Takigawa T, Ozaki T (2007) Predicting intraoperative vertebral rotation in patients with scoliosis using posterior elements as anatomical landmarks. Spine 32:E761–E763
29. Hooker Hyperlınk MS, Yandow SM, Fillman RR, Raney EM (2006) Pedicle rotation in scoliosis: a marker for occult intrathecal abnormalities. Spine HYPERLINK 31:E144–E148 (http://www.ncbi.nlm.nih.gov/pubmed/?term=pedicle+rotation+in+scoliosis+hooker
30. Lam GC, Hill DL, Le LH, Raso JV, Lou EH (2008) Vertebral rotation measurement: a summary and comparison of common radiographic and CT methods. Scoliosis 3:16
31. Chi WM, Cheng CW, Yeh WC, Chuang SC, Chang TS, Chen JH (2006) Vertebral axial rotation measurement method. Comput Methods Programs Biomed 81:8–17
32. Richards BS (1992) Measurement error in assessment of vertebral rotation using the Perdriolle torsionmeter. Spine 17:513–517
33. Kouwenhoven JWM, Vincken KL, Bartels LW et al (2006) Analysis of preexistent vertebral rotation in the normal spine. Spine 31:1467–1472
34. Krismer M, Chen AM, Steinlechner M, Haid C, Lener M, Wimmer C (1999) Measurement of vertebral rotation: a comparison of two methods based on CT scans. J Spinal Disord 12:126–130
35. Birchall D, Hughes D, Gregson B, Williamson B (2005) Demonstration of vertebral and disc mechanical torsion in adolescent idiopathic scoliosis using three-dimensional MR imaging. Eur Spine J 4:123–129
36. Matteri RE, Pope MH, Frymoyer JW (1976) A biplane radiographic method of determining vertebral rotation in postmortem specimens. Clin Orthop Relat Res. 116:95–98
37. Drerup JR (1985) Improvements in measuring vertebral rotation from the projections of the pedicles. J Biomech 18:369–378
38. Negrini S, Negrini A, Atanasio S, Santambrogio GC (2006) Three-dimensional easy morphological (3-DEMO) classification of scoliosis, part I. Scoliosis 1:20