Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

A Comparison of Cobb Angle: Standing Versus Supine Images of Late-Onset Idiopathic Scoliosis

Ludvig Vavruch[1,2ABCDEF], Hans Tropp[1,2ABCDEF]

[1] Department of Spinal Surgery and Department of Clinical and Experimental Medicine, Linköping University, Linköping, Sweden
[2] Center for Medical Image Science and Visualization (CMIV), Linköping University, Linköping, Sweden

Author's address: Hans Tropp, Department of Clinical and Experimental Medicine, IKE, Linköping University, Linköping, Sweden, e-mail: hans.tropp@regionostergotland.se

Summary

Background: Scoliosis is traditionally evaluated by measuring the Cobb angle in radiograph images taken while the patient is standing. However, low-dose computed tomography (CT) images, which are taken while the patient is in a supine position, provide new opportunities to evaluate scoliosis. Few studies have investigated how the patient's position, standing or supine, affects measurements. The purpose of this study was to compare the Cobb angle in images from patients while standing versus supine.

Material/Methods: A total of 128 consecutive patients (97 females and 21 males; mean age 15.5 [11–26] years) with late-onset scoliosis requiring corrective surgery were enrolled. One observer evaluated the type of curve (Lenke classification) and measured the Cobb angle in whole-spine radiography (standing) and scout images from low-dose CT (supine) were taken on the same day.

Results: For all primary curves, the mean Cobb angle was 59° (SD 12°) while standing and 48° (SD 12°) while in the supine position, with a mean difference of 11° (SD 5°). The correlation between primary standing and supine images had an r value of 0.899 (95% CI 0.860–0.928) and an intra-class correlation coefficient value of 0.969. The correlation between the difference in standing and supine images from primary and secondary curves had an r value of 0.340 (95% CI 0.177–0.484).

Conclusions: We found a strong correlation between the Cobb angle in images obtained while the patient was standing versus supine for primary and secondary curves. This study is only applicable for patients with severe curves requiring surgical treatment. It enables additional studies based on low-dose CT.

MeSH Keywords: Scoliosis • Spine • Supine Position

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Background

Scoliosis is typically evaluated by measuring the Cobb angle using whole-spine radiographic images obtained while the patient is standing (posterior-anterior view) [1]. Several studies have shown the variability and reliability of Cobb angle measurements [2–4]. A scoliotic deformity consists of axial rotation of the vertebrae and displacement and rotation in the coronal plane, resulting in a three-dimensional deformity. The apical vertebra of the primary curve is always the most rotated of all the vertebrae. This axial rotation limits the use of the Cobb angle because it only measures the projection of the curve onto a two-dimensional plane.

Although plane radiographs can be used to measure vertebral rotation [5], they are unreliable because high-quality images are required. Consequently, some studies have assessed vertebral rotation using computed tomography (CT) images [6,7]. Because two-dimensional images provide limited information about scoliosis, several researchers have highlighted the need for 3-dimensional methods4[8,9]. Three-dimensional images and reconstructions can be generated using biplanar standing radiographs [10], CT, or magnetic resonance imaging (MRI). MRI does not use radiation, but it is time-consuming and not ideal for skeletal assessments compared with CT.

CT, which is performed while the patient is in a supine position, is readily available but requires relatively high radiation doses. Recently, however, low-dose CT was shown to be reliable for evaluating scoliosis [11,12]. Basically, a low-dose protocol for spinal CT defines the radiation settings of the X-ray tube to give as low an effective dose to the patient as possible, while ensuring that the image quality is at the lowest acceptable level for a correct assessment. Compared to the standing position used with whole-spine radiography, the supine positioning results in a weaker gravitational load on the spine. This difference should be considered when comparing such images; that is, gravitational loads influence how the magnitude of the deformity is evaluated in all planes. Only a few studies have investigated these changes [13–17].

Measurements made while the patient is in a supine position may also be affected by derotation due to the rib hump. Three-dimensional reconstructions of scoliotic deformities would allow us to assess the complex shape of the deformed spine. In addition, the deformity and rotation of each vertebra can be evaluated separately, providing more complete information about the spinal deformity and its etiology. To continue with planned studies of a new technique for 3-dimensional reconstructions and evaluation of vertebral rotation based on low-dose CT, we investigated the characteristics of deformities seen while the patient was in a supine position. The aim of this study was to compare the Cobb angle in images while the patient was standing (whole-spine radiation) versus supine (low-dose CT).

Material and Methods

This retrospective observational study included raw data collected from patients requiring surgical correction for scoliosis at the Department of Spinal Surgery in Linkoping, Sweden, from May 2006 to December 2011. The inclusion criteria were patients diagnosed with late-onset (>10 years of age) idiopathic scoliosis who required corrective surgery. Patients with neuromuscular scoliosis, congenital scoliosis, early-onset idiopathic scoliosis, previous spinal surgery or atypical left-convex thoracic curves were not included. A total of 128 consecutive patients met the inclusion criteria (97 females and 31 males), with 82 thoracic and 46 lumbar main structural curves. Patients' baseline characteristics are shown in Table 1.

Days prior to the operation, whole-spine radiographs (standing position) and low-dose CT images (supine position) were obtained less than one hour apart. The mean effective doses were 0.1 mSv and 0.36 mSv for radiographs and low-dose CT, respectively. The protocol for obtaining low-dose CT images was the same as that used by Abul-Kasim et al. [11] and was used with their permission. One observer (LV), who was an intern at the time with two years of experience in spinal imaging evaluation, measured the Cobb angles (IDS 7, Sectra Imtec AB, Linkoping, Sweden). The Cobb angle was defined as the angle between the endplates of the vertebrae in a curvature using the coronal plane images from the whole-spine radiographs and the scout picture from the low-dose CT image (Figure 1). The scout picture is available only for the frontal plane. Blinded measurements were performed on separate

Table 1. Baseline characteristics for the primary curves.

Number of patients	**128**
Thoracic curves	82
Lumbar curves	46
Females	**97**
Thoracic curves	63
Lumbar curves	34
Males	**31**
Thoracic curves	19
Lumbar curves	12
Lenke classification	
Type 1	22
Type 2	21
Type 3	27
Type 4	10
Type 5	23
Type 6	25
Age	
Mean	15.5 years
Range	11–26 years

occasions. The low-dose CT scan is part of our pre-operative routine; thus, this study did not involve the use of additional radiation. The purpose of the low-dose CT scan is for pre-operative planning and safer instrumentation.

Age at the pre-operative examination, Lenke classification [18], Cobb angle for the standing and supine positions, and the absolute and relative difference between the standing and supine images were recorded for all patients. The correlation between the standing and supine images was calculated for both the primary and secondary curves. To determine the reliability of the observer, the measurements were repeated twice in 10 randomly chosen patients, resulting in a total of 30 measurements.

The regional ethics committee (Linkoping, Sweden) approved the study (2012/366-31). All patients were informed that their images could be used in research and all had the opportunity to decline participation. Since no additional radiological examinations were performed and the treatment was unchanged regardless of participation, no written consent was considered necessary.

Statistical analyses were performed with Statistica version 10 (StatSoft. Inc. 2011) and IBM SPSS statistics version 20. Data are presented as proportions or means with standard deviations (SD). The Student's t-test was used to determine the significance of the differences between standing and supine Cobb angles, age of females and males, and thoracic
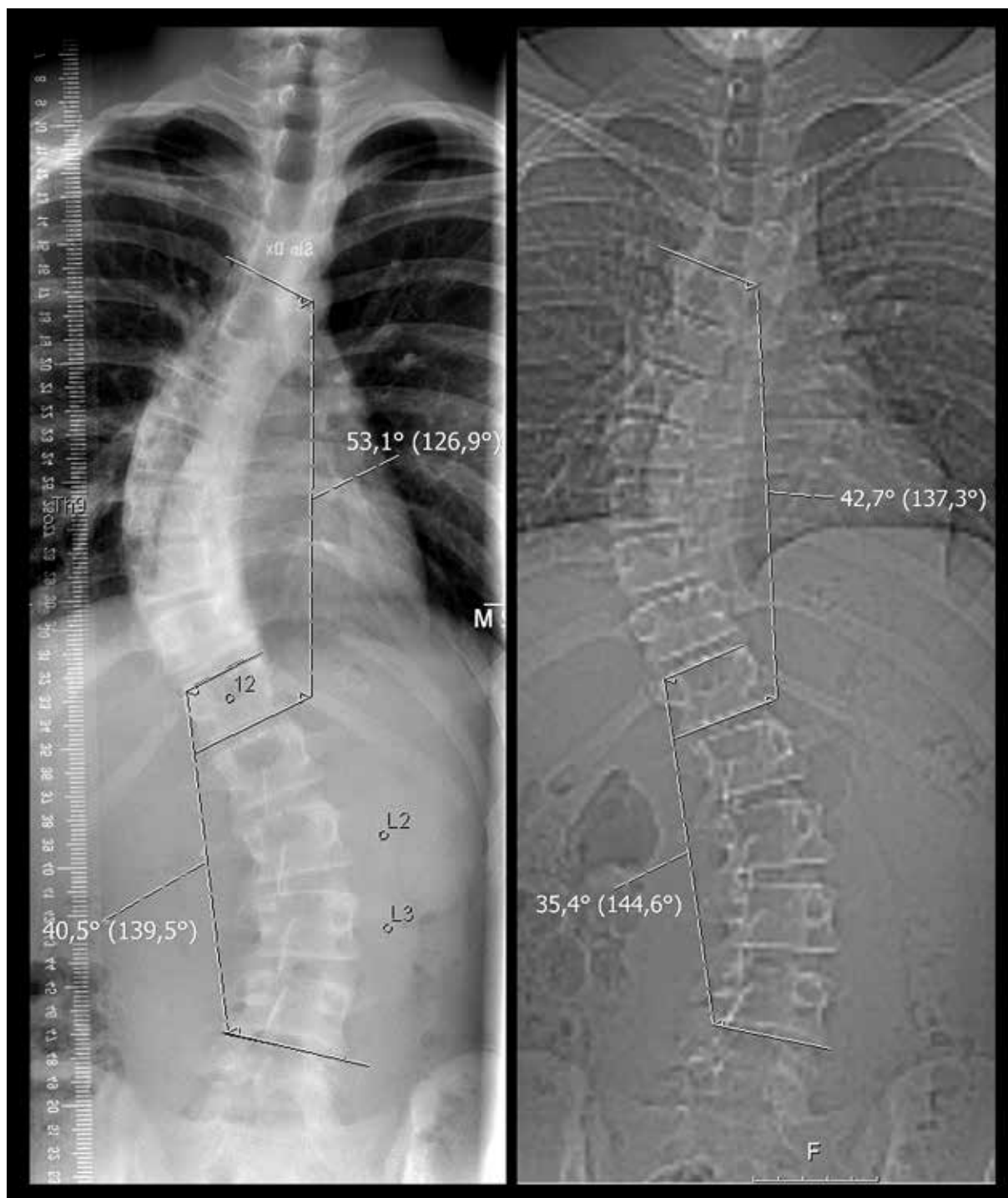
Figure 1. The left image shows a traditional whole spine radiograph. The right image shows the scout picture obtained with low-dose CT in the same patient. The images were taken on the same day before planned corrective surgery.

and lumbar curves among females and males. Pearson correlation coefficient was used to compare the correlation between the Cobb angle measurements in the standing and supine images. An r value of 1 or −1 indicated a perfect linear correlation, whereas an r value of 0 indicated a total absence of a linear correlation [19]; 95% confidence intervals (CI) were also calculated for the correlations. The Fisher r-to-z transformation was used to investigate differences in correlations. The difference between standing and supine measurements was evaluated by means of a Bland-Altman plot. The intra-class correlation coefficient (ICC) was calculated to evaluate the reliability of the measurements. An ICC value of 1 indicated perfect agreement and a value of 0 indicated no agreement at all [20]. A value of $P<0.05$ was considered statistically significant. Based on numbers from Torell et al. (1985), at least 47 patients were needed to obtain a 95% two-sided CI and a power of 80%.

Table 2. Mean data grouped by curve type. All angles are given in mean degrees (standard deviation).

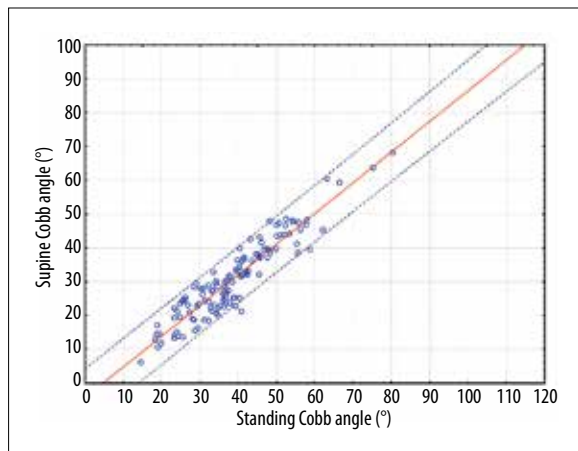|	N	Standing Cobb	Supine Cobb	Difference	95% CI
Primary curves	128	59.2 (11.5)	48.1 (11.7)	11.1 (5.2)	10.2–12.0
Thoracic curves	82	61.5 (12.4)	50.2 (12.1)	11.3 (5.6)	10.1–12.5
Lumbar curves	46	55.1 (8.4)	44.4 (9.9)	10.7 (4.5)	9.4–12.0
Secondary curves	128	38.6 (11.8)	30.8 (11.5)	7.8 (4.3)	7.1–8.6
Thoracic curves	41	39.2 (12.2)	33.0 (10.7)	6.2 (4.0)	5.0–7.9
Lumbar curves	87	38.4 (11.7)	29.8 (11.8)	8.6 (4.2)	7.7–9.5

Figure 2. The linear correlation between the Cobb angles measured while patients were standing and in a supine position for the 128 primary curves, both thoracic and lumbar. y=0.91*x – 5.96; r=0.899; r²=0.809. The blue bars indicate predicted values.
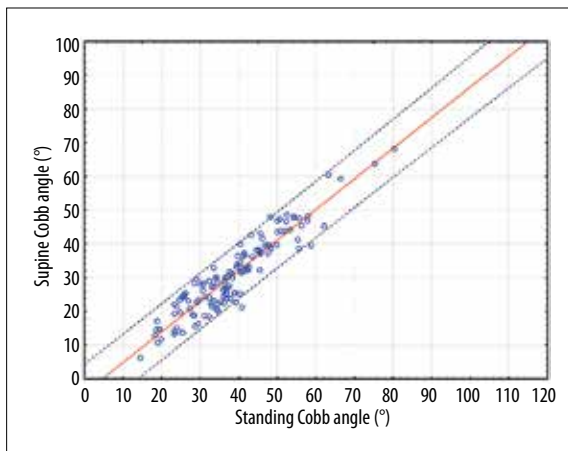

Figure 3. The linear correlation between Cobb angles measured while the patient was standing and in a supine position for all secondary curves, both thoracic and lumbar. y=0.91*x – 4.21; r=0.933; r²=0.870. The blue bars indicate predicted values.

Results

For all primary curves, the mean Cobb angle was 59.2° (SD 11.5°, range 41.1° to 116.4°) for standing images and 48.1° (SD 11.7°, range 23.1° to 93.5°) for supine images. The mean difference between the standing and supine measurements was 11.1° (SD 5.2, range 1.9° to 27.0°). For secondary curves, the mean Cobb angle was 38.6° (SD 11.8°, range 14.5° to 80.3°) for standing images and 30.8° (SD 11.5°, range 6.2° to 68.1°) for supine images (Table 2).

The regression line for all primary curves was calculated using the following equation:

$$y = 09.1 * \chi – 5.96$$

where y is the supine Cobb angle and x is the standing Cobb angle. The r value was 0.899 (95% CI 0.860–0.928) and the r² value was 0.809 (Figure 2). The Fisher r-to-z transformation revealed no significant difference between the correlations for primary thoracic and lumbar curves (two-tailed $P = 0.960$).

The equation for the regression line for all secondary curves was calculated using the following equation:

$$y = 09.1 * \chi – 4.21$$

where y is the supine Cobb angle and x is the standing Cobb angle. The r value was 0.933 (95% CI 0.907–0.952) and the r² value was 0.870 (Figure 3). The Fisher r-to-z transformation revealed no significant differences between the correlations for secondary thoracic and lumbar curves (two-tailed $P = 0.555$).

Subgroup characteristics were collected with regards to age, standing and supine Cobb angles, and the difference between the standing and supine Cobb angles in females and males with thoracic or lumbar curves (Table 3). A significant difference was found between standing and supine Cobb angles for all types of curves ($P < 0.001$) and between age in females and males ($P < 0.021$). The difference between standing Cobb angles for primary and secondary curves and the difference between standing and supine Cobb angles in both primary and secondary curves were significant (all $P < 0.001$). No significant difference was found between females and males with regard to standing ($P = 0.504$) and supine ($P = 0.361$) Cobb angles or the difference between standing and supine Cobb angles ($P = 0.568$). Table 4 presents the results from the repeated measurements. No significant differences were found between the measurements, but the correlations between them were significant (Table 5). The ICC was 0.969 (95% CI 0.913–0.991). Figure 4 shows a Bland and Altman diagram over the difference between standing and supine Cobb angle measurements.

Table 3. Subgroup characteristics for primary curves. Data are shown as mean (standard deviation) [95% confidence interval].

	Females, thoracic curves (n=63)	Females, lumbar curves (n=34)	Males, thoracic curves (n=19)	Males, lumbar curve n=12
Age, years	14.5 (2.0)	16.4 (2.8)	16.1 (2.2)	16.9 (2.4)
Standing Cobb, °	61.1 (12.4) [58.0–64.3]	54.4 (6.3) [52.2–56.6]	62.6 (12.5) [56.6–68.6]	56.9 (12.8) [48.7–65.0]
Supine Cobb, °	49.5 (11.6) [46.6–52.4]	43.9 (7.9) [41.2–46.7]	52.4 (13.9) [45.7–59.1]	45.6 (14.6) [36.3–54.9]
Difference	11.6 (5.7) [10.2–13.1]	10.5 (4.0) [9.1–11.9]	10.2 (5.3) [7.6–12.7]	11.3 (5.7) [7.7–14.9]

Table 4. Baseline characteristics for the repeated measurements. Data are shown as mean degrees (standard deviation).

Measurement	N	Mean
1	10	12.64 (6.9)
2	10	12.45 (7.3)
3	10	12.48 (7.6)

Discussion

In recent years, the need for 3-dimensional reconstructions has been suggested by both clinicians and organizations such as the *Scoliosis Research Society* for the evaluation and diagnosis of scoliosis. The use of CT for this purpose has been questioned, mainly because of the radiation exposure. However, Kalra et al. [12] showed that good-quality images can be obtained using very low radiation doses. The combination of low-dose CT and the high availability of CT scanners provide an interesting opportunity to use CT for 3-dimensional reconstructions. We currently work with such a method to generate 3-dimensional reconstructions. In order to continue with our method, we wanted to investigate the relationship between supine and standing Cobb angles.

Our results show strong correlations between the Cobb angles measured from radiographs while the patient is standing and low-dose CT scout images while the patient is in a supine position. The correlation was strong irrespective of the size of the curve or its location (thoracic or lumbar). Repeated measurements by a single observer showed that the variance between the measures was small, with a high ICC value and small differences in absolute degrees. These results indicate that the Cobb angle decreases approximately 11° for primary curves, irrespective
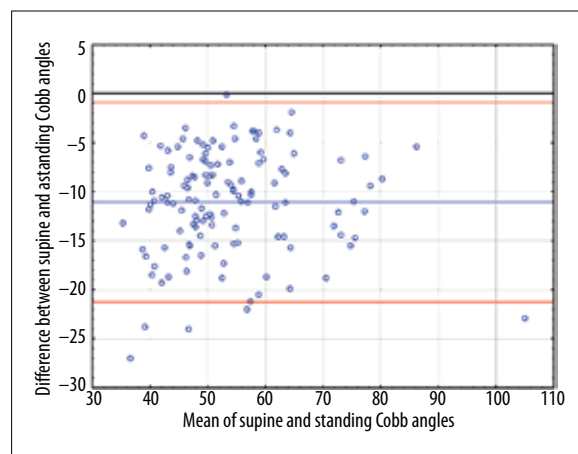

Figure 4. A Bland and Altman diagram showing the difference between Cobb angle measurements obtained while the patient was in a supine position and standing on the y-axis, and the mean between the Cobb angle measurements taken while supine and standing on the x-axis. Both axes are given in degrees.

of the size of the deformity (approximately 40° to 120°) in the coronal plane when measured while the patient is in the supine position versus standing. Our results support the assumption that the difference is absolute rather than proportional. Although these findings concur with Torell et al. [13], Torell's material does not differentiate between thoracic and lumbar curves and does not include males.

Our study found one significant difference between females and males; females were younger. This finding may reflect the earlier skeletal growth and maturation of females. Despite this difference in age, our study found no significant difference in either the distribution of curve type or the size of the Cobb angle. Our study shows a larger

Table 5. The differences between repeated measurements. Data are shown in degrees.

Measurement	Mean	95% CI of difference	Correlation
1 *vs.* 2	0.19 (2.2)	−1.4–1.7 (p=0.79)	0.96 (P<0.001)
1 *vs.* 3	0.16 (1.4)	−0.9–1.2 (p=0.73)	0.99 (P<0.001)
2 *vs.* 3	−0.03 (1.8)	−1.3–1.2 (p=0.96)	0.97 (P<0.001)

difference between standing and supine Cobb angles than Torell et al. (11.1° [SD 5.2°] *vs.* 8.9° [SD 6.2°]), Wessberg et al. (7.6° [SD 4.6°]), and Lee et al. (10° [SD unknown]). This difference may be due to the fact that our measurements were performed at a later stage, just before corrective surgery, although each study included all means within overlapping SDs. We did not expect that the differences would be so similar for both small and large Cobb angle curves, and we found nothing in the literature about this. One theory is that the curves are mostly structural in this category of patients and that this is the inherent difference between standing and supine measurements. This could explain why gravity does not seem to affect the larger curves more than the smaller ones.

Unlike Torell et al. and, to some extent, Wessberg et al. [14] and Lee et al. [15], our study investigated the correlation between Cobb angles taken from images in secondary curves taken while the patient was standing versus in a supine position. We found a strong correlation between the Cobb angles measured from images while the patient was standing versus in a supine position. The mean difference for secondary curves was approximately 8°. The correlation and mean difference in Cobb angles for the secondary curves were similar to those reported by Lee et al. Although the correlation was strong, the range of measured Cobb angles was considerable.

One of the major concerns with this study is the fact that low-dose CT was used instead of regular plain X-rays and the increased radiation exposure that comes with it. According to the *2007 recommendations of the international commission on radiological protection* [21], the increase in effective dose from 0.1 to 0.36 mSv in a single examination will induce a fatal cancer in approximately 1 of 55 000 examinations. This is based on the assumption that 1 Sv increases the overall risk coefficient of getting a fatal cancer by 5%. This is to be compared with the radiation dose from the cone beam O-arm intraoperative imaging system (Medtronic), which gives a radiation dose of between 4.8 and 9.52 mSv for a whole-spine examination (22). We consider this a low cost for more accurate pre-operative planning. The cost of CT is 200 € compared to 100 € for standing preoperative conventional X-ray. In addition, the need for peri-operative X-ray examinations is considerably reduced. Since low-dose CT is performed with the lowest possible radiation settings, the effective dose will probably be even lower in the future as the CT hardware and software become more refined.

One already existing system utilizing biplanar standing radiographs provides 3-dimensional reconstructions of the spine [10]. These reconstructions seem to work well in the everyday clinical work-up. However, these reconstructions are only approximations of the 3-dimensional deformity. So far, the only way to obtain true 3-dimensional reconstructions with the possibility to assess the complexity of the scoliotic spine, both regionally and in extreme detail locally, is with CT. This study aimed to investigate the relationship between Cobb angles measured from images taken while the patient was standing versus in a supine position. Our goal was not to obtain exact numbers for use in pre-operative planning, but to estimate how the Cobb angle changes from the standing to supine position for use in ongoing studies based on low-dose CT scans. Using these results, we intend to proceed with studies aimed at developing a new method of creating 3-dimensional reconstructions based on low-dose CT. This method should describe the deformity in 3 dimensions, allowing for a more complete analysis of the role of vertebral rotation, its correlation to the Cobb angle, and its significance in the development of idiopathic scoliosis.

Conclusions

In conclusion, this study supports the findings of previous studies in a larger and more diversified population.

Statement

No specific grant from any funding agency in the public, commercial, or nonprofit sectors was received for this research.

Declaration of conflicting interests

The authors declare that they have no conflicts of interest.

Ethical approval

The study was approved by the regional ethics committee in Linkoping, Sweden (2012/366-31).

References:

1. Cobb JR: Outline for the study of scoliosis. In: Instructional course lectures. The American Academy of Orthopedic Surgeons. 5th ed. Ann Arbor: J. W Edwards; 1948; 261–75

2. Morrissy RT, Goldsmith GS, Hall EC et al: Measurement of the Cobb angle on radiographs of patients who have scoliosis. Evaluation of intrinsic error. J Bone Joint Surg Am, 1990; 72: 320–27

3. Carman DL, Browne RH, Birch JG: Measurement of scoliosis and kyphosis radiographs. Intraobserver and interobserver variation. J Bone Joint Surg Am, 1990; 72(3): 328–33

4. Adam CJ, Izatt MT, Harvey JR et al: Variability in Cobb angle measurements using reformatted computerized tomography scans. Spine, 2005; 30(14): 1664–69

5. Perdriolle R, Vidal J: Thoracic idiopathic scoliosis curve evolution and prognosis. Spine, 1985; 10(9): 785–91

6. Aaro S, Dahlborn M, Svensson L: Estimation of vertebral rotation in structural scoliosis by computer tomography. Acta Radiol Diagn, 1978; 19: 990–92

7. Lam GC, Hill DL, Le LH et al: Vertebral rotation measurement: A summary and comparison of common radiographic and CT methods. Scoliosis, 2008; 3: 16

8. Stokes IA: 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, 1994; 19(2): 236–48

9. Labelle H, Aubin CE, Jackson R et al: Seeing the spine in 3D: How will it change what we do? Journal of pediatric orthopedics. 2011; 31(1 Suppl.): S37–45

10. Illes T, Tunyogi-Csapo M, Somoskeoy S: Breakthrough in three-dimensional scoliosis diagnosis: significance of horizontal plane view and vertebra vectors. Eur Spine J, 2011; 20(1): 135–43

11. Abul-Kasim K, Overgaard A, Maly P et al: Low-dose helical computed tomography (CT) in the perioperative workup of adolescent idiopathic scoliosis. Eur Radiol, 2009; 19(3): 610–18

12. Kalra MK, Quick P, Singh S et al: Whole spine CT for evaluation of scoliosis in children: Feasibility of sub-milliSievert scanning protocol. Acta Radiol, 2013; 54: 226–30

13. Torell G, Nachemson A, Haderspeck-Grib K et al: Standing and supine Cobb measures in girls with idiopathic scoliosis. Spine, 1985; 10(5): 425–27

14. Wessberg P, Danielson BI, Willen J: Comparison of Cobb angles in idiopathic scoliosis on standing radiographs and supine axially loaded MRI. Spine, 2006; 31(26): 3039–44

15. Lee MC, Solomito M, Patel A: Supine MRI Cobb measurements for idiopathic scoliosis are linearly related to measurements from standing plain radiographs. Spine, 2013; 38(11):E656–61

16. Abul-Kasim K, Karlsson MK, Hasserius R et al: Measurement of vertebral rotation in adolescent idiopathic scoliosis with low-dose CT in prone position – method description and reliability analysis. Scoliosis, 2010; 5: 4

17. Yazici M, Acaroglu ER, Alanay A et al: Measurement of vertebral rotation in standing versus supine position in adolescent idiopathic scoliosis. J Pediatr Orthop, 2001; 21(2): 252–56

18. Lenke LG, Edwards CC II, Bridwell KH: The Lenke classification of adolescent idiopathic scoliosis: how it organizes curve patterns as a template to perform selective fusions of the spine. Spine, 2003; 28(20): S199–207

19. Petrie A: Statistics in orthopaedic papers. J Bone Joint Surg Br, 2006; 88(9): 1121–36

20. Watson PF, Petrie A: Method agreement analysis: A review of correct methodology. Theriogenology, 2010; 73(9): 1167–79

21. Valentin J: The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Annals of the ICRP, 2007; 37(2–4): 1–332

22. Abul-Kasim K, Soderberg M, Selariu E et al: Optimization of radiation exposure and image quality of the cone-beam O-arm intraoperative imaging system in spinal surgery. J Spinal Disord Tech, 2012; 25(1): 52–58.