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Variability in Cobb Angle Measurements using Reformatted Computed Tomography Scans

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Abstract

Study Design: Survey of intra and inter-observer measurement variability. **Objectives:** To assess the use of reformatted computed tomography (CT) images for manual measurement of coronal Cobb angles in idiopathic scoliosis. **Summary of Background Data:** Cobb angle measurements in idiopathic scoliosis are traditionally made from standing radiographs, whereas CT scans are often used for assessment of vertebral rotation. Correlating Cobb angles from standing radiographs with vertebral rotations from supine CT is problematic since the geometry of the spine changes significantly from standing to supine positions, and two different imaging modalities are involved. **Methods:** We assessed the use of reformatted thoracolumbar CT images for Cobb angle measurement. Pre-operative computed tomography scans of twelve idiopathic scoliosis patients were used to generate reformatted coronal images. Five observers measured coronal Cobb angles on three occasions from each of the images. Intra and inter-observer variability associated with Cobb measurement from reformatted CT scans was assessed and compared with previous studies of measurement variability using plain radiographs. **Results:** For major curves, 95% confidence intervals for intra and inter-observer variability were $\pm 4.3^\circ$ and $\pm 7.5^\circ$ respectively. For minor curves, the intervals were $\pm 5.1^\circ$ and $\pm 7.4^\circ$. Intra and inter-observer TEMs were 2.4° and 2.7° , with reliability coefficients of 88% and 84%. There was no correlation between measurement variability and curve severity. **Conclusions:** Reformatted CT images may be used for manual measurement of coronal Cobb angles in idiopathic scoliosis with similar variability to manual measurement of plain radiographs.

Keywords

Idiopathic scoliosis, Cobb angle, computed tomography, inter and intra-observer variability

Key Points

1. Reformatted coronal images of idiopathic scoliosis patients were produced from thoracolumbar CT scans
2. Cobb measurement variability for manual assessment of coronal CT images is similar to previous studies using plain radiographs
3. CT Cobb measurements allow assessment of both transverse and coronal plane deformity with the same dataset

Introduction

The development of multi-slice computed tomography (CT) technology has increased the utility of CT scanning in scoliosis assessment, reducing radiation doses and enhancing image quality. A number of previous studies have used CT for accurate assessment of transverse plane deformity (vertebral rotation and ribcage shape) in idiopathic scoliosis¹⁻⁷, but to our knowledge there are no studies using CT for measurement of coronal plane deformity (Cobb angle).

The Cobb angle is usually measured from standing radiographs, and the measurement variability associated with this technique has been investigated on numerous occasions, both for manual measurement of plain films⁸⁻¹⁹ and computer-based measurement of digitised radiographs²⁰⁻²⁶. Although CT radiation doses still preclude their use for routine repeated scoliosis assessment, our clinical practice uses a single pre-operative CT scan for surgical planning in certain cases. In these cases, it is useful to assess both transverse plane deformity (vertebral rotation), and coronal plane deformity (Cobb angle) from the same scan, thus avoiding the changes in spinal geometry between standing and supine positions which occur when axial rotation from a CT scan is correlated with Cobb angle from a standing radiograph. Torell *et al*²⁷ reported an average 9° change in Cobb angle between standing and supine positions, and Yazici *et al*⁴ reported a reduction in average Cobb angle from 56° to 39° and reduction in apical vertebral rotation from 23° to 17° between standing and supine positions.

This paper reports on our use of reformatted CT scans to measure coronal Cobb angles in idiopathic scoliosis, and the inter and intra-observer measurement variability associated with this technique.

Materials and Methods

Twelve adolescent idiopathic scoliosis patients each received a single thoracolumbar CT scan using a low-dose scanning protocol. Scan parameters are given in Table 1. The estimated radiation dose for paediatric patients using this scanning protocol was 3.7mSv (Schick D, Computed tomography radiation doses for paediatric scoliosis scans. Internal report commissioned by Paediatric Spine Research Group from Queensland Health Biomedical Technology Services, 2004). Due to limitations of the dose model and variations between patients, uncertainties associated with the dose calculation are in the order of ±20%. A single pre-operative CT scan is part of our clinical assessment process for certain patients scheduled to receive surgery for adolescent idiopathic scoliosis.

Table 1. CT scan parameters

Scanner	Toshiba Aquilion Multi
Coverage	C7-S1
Source	100kV, 50mA
Raw image thickness	3mm
Pitch	6.0mm
Rotation time	1.0 sec

Reformatted coronal plane images were produced from the transverse CT slices using the *ImageJ* image processing software produced by the National Institutes of Health. The reformatted coronal slices were then combined into a single image by z-projection. Figure 1 shows typical reformatted coronal images obtained using this technique.

A hardcopy of each coronal image was then printed onto a sheet of A3 sized paper (420×297mm) at a scale of approximately 85% of full size. Hardcopy images were used to allow the observers to measure using standard clinical techniques. The aspect ratio of each image was maintained during scaling so as not to distort the image (which would affect angular measurements).

Five observers (two experienced spinal surgeons, two spinal fellows and one senior orthotist) were instructed to measure the Cobb angles for each patient using the same technique and goniometer as they would for normal clinical assessment. Each observer performed the measurements on three separate occasions, with subsequent measurements at least two weeks apart. Each repeat measurement was performed on a fresh sheet with no prior markings. The observers were blinded to patient identity and patient order was randomised. No preselection of endplates occurred. The observers were instructed to refrain from measuring a curve if they felt that the endplates were not clearly enough defined.

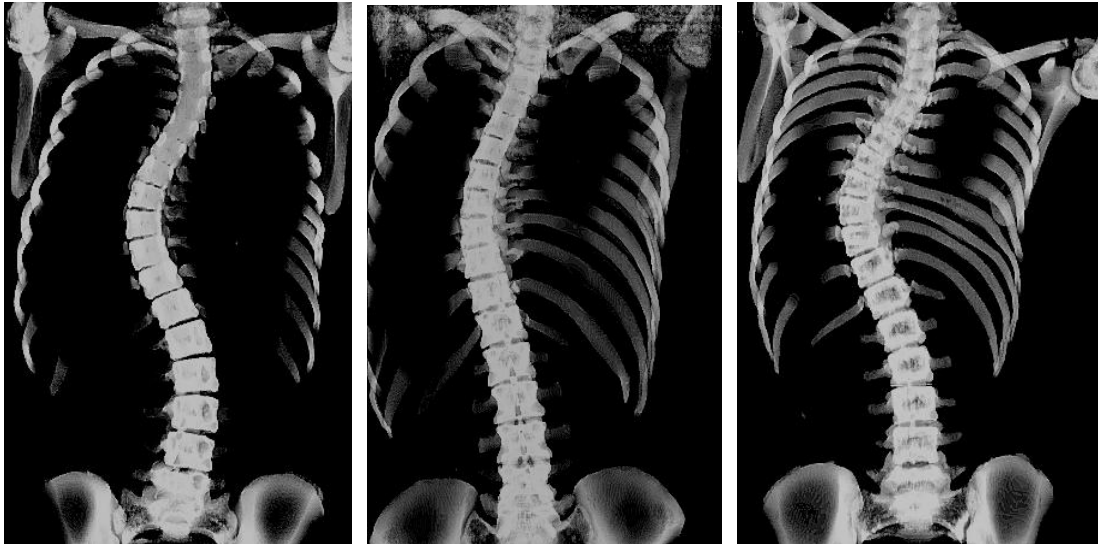


Figure 1. Reformatted coronal CT images used for Cobb angle measurement
(Anteroposterior view with right thoracic curves)

Results

Assessment of the twelve CT scans by five observers on three occasions gave a total of 180 possible sets of measurements, from which 177 major and 109 minor Cobb angles were recorded. For major curves, the overall mean Cobb angle was 41.0° , with a range of $33.4^\circ - 56.1^\circ$. Figure 2 shows a scatter plot of each individual major Cobb measurement versus the mean Cobb angle for a particular patient, with different symbols used for each of the five observers.

Intra-observer variability

Intra-observer variability was assessed by analysing the absolute difference between successive Cobb angle (α) measurements by the same observer,

$$\Delta\alpha = |\alpha_n - \alpha_{n+1}|$$

where n and $n+1$ are successive measurements. Since each observer made three measurements per patient, two absolute differences were calculated per observer. Table 2 gives the distribution of intra-observer differences for major curves, and compares the cumulative percentage of measurements inside a given range with previous studies^{16,23,26}. In our study, 9.4% of successive measurements by the same observer differed by 5° or more.

Figure 3 shows a scatter plot of signed measurement difference ($\alpha_n - \alpha_{n+1}$) versus mean curve magnitude for each pair of successive measurements. The sample mean was 0.33° , this is not significantly different from zero and suggests that no order bias existed between the first and second measurements of a pair. The mean absolute intra-observer difference was 2.6° , standard deviation (SD) was 2.2° , and 95% confidence interval ($1.96 \times SD$) was $\pm 4.3^\circ$. There was no significant

correlation between intra-observer variability and curve size. Figure 4 compares the 95% confidence interval for intra-observer differences with values reported in previous studies for manual measurement of major curves in idiopathic scoliosis. Only data from studies using plain radiographs with no endplate preselection were included in this graph.

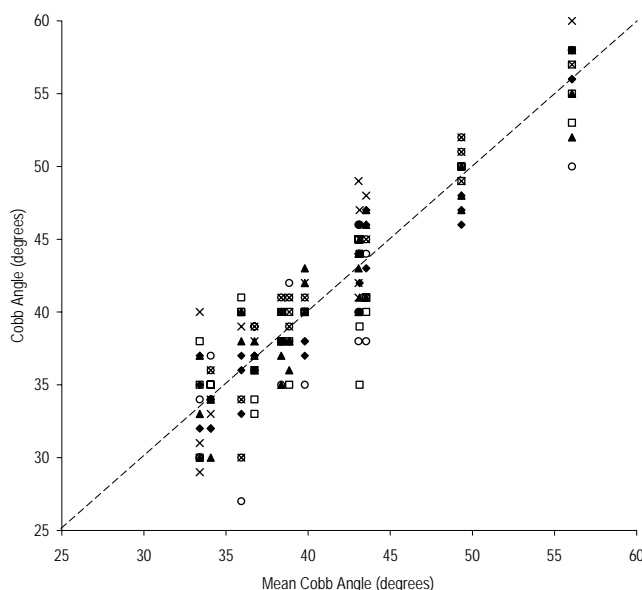


Figure 2. Individual measurements versus overall mean (major) Cobb angle for each patient

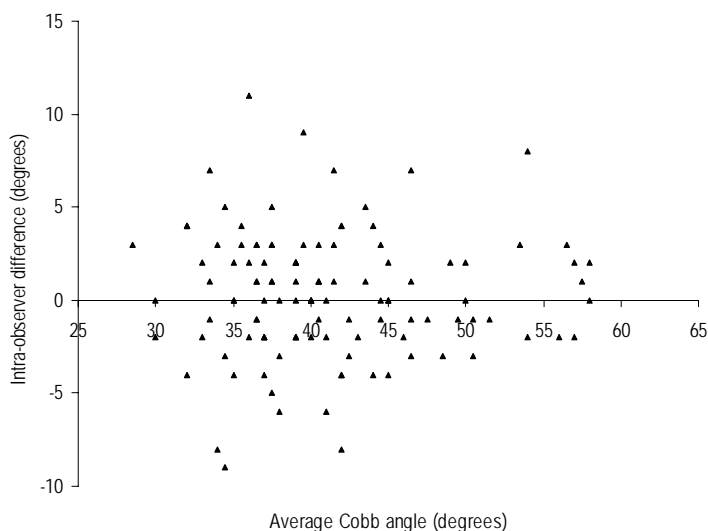


Figure 3. $(\alpha_n - \alpha_{n+1})$ versus average major Cobb angle for each pair of successive measurements

Inter-observer variability

Table 3 summarises the inter-observer variability for major Cobb angle measurements by the five observers. Based on a single reading by each observer, the *SD* of a Cobb angle measurement is 2.6° . If each observer makes three readings and the mean value is used, the *SD* of a Cobb measurement reduces to 1.8° . The inter-observer error (standard deviation of the difference between measurements by two different observers) is therefore $\sqrt{2} \times SD = 3.7^\circ$ for a single measurement and 2.5° for three measurements per observer. The 95% confidence intervals for inter-observer error with single and multiple readings per observer were $\pm 7.5^\circ$ and $\pm 5.5^\circ$ respectively, calculated using

$2.03 \times SD$ (t -distribution with 35 dof) for single readings and $2.20 \times SD$ (t -distribution with 11 dof) for three measurements per observer.

The only statistically significant difference in major Cobb measurements between observers occurred between observers 2 and 3 ($P=0.01$, paired t -test). The mean Cobb angle measurements across all patients for these two observers were 42.0° and 40.5° respectively. There was no significant correlation between inter-observer variability and curve size.

Figure 5 compares the 95% inter-observer confidence limits given above with values reported in previous studies for manual measurement of idiopathic scoliosis using plain radiographs with no endplate preselection.

Table 2. Intra-observer differences between successive major Cobb angle measurements

$\Delta\alpha$	Number of curves	Cumulative %	Cumulative % (previous studies)		
			Morrissy <i>et al</i>	Shea <i>et al</i>	Zmurko <i>et al</i>
0°	16	13.7%	20.8%	14.6%	19.0%
1°	24	34.2%	53.6%	36.1%	35.0%
2°	29	59.0%	76.6%	72.2%	55.0%
3°	19	75.2%	88.5%	90.3%	68.0%
4°	14	87.2%	93.8%	95.1%	78.0%
5°	4	90.6%	95.8%	96.5%	82.0%
6°	2	92.3%	97.9%	97.2%	86.0%
7°	3	94.9%	99.0%	98.6%	91.0%
8°	3	97.4%	99.5%	99.3%	95.0%
9°	2	99.1%	100.0%	99.3%	95.0%
10°	0	99.1%	100.0%	99.3%	97.0%
$>10^\circ$	1	100%	100.0%	100%	100%

Table 3. Inter-observer major Cobb angle measurement variations (5 observers per measurement)

Patient	Occasion 1		Occasion 2		Occasion 3		Average	
	$\bar{\alpha}^*$	SD_α^{**}	$\bar{\alpha}$	SD_α	$\bar{\alpha}$	SD_α	$\bar{\alpha}$	SD_α
A	48.6	2.1	49.4	1.5	50.0	2.0	49.3	1.9
B	36.0	3.4	35.2	5.0	36.6	5.5	35.9	4.6
C	37.6	1.3	36.4	1.8	36.2	2.0	36.7	1.7
D	40.2	1.5	39.2	2.9	40.0	1.9	39.8	2.1
E	43.8	3.1	42.6	3.2	44.2	3.3	43.5	3.2
F	34.4	3.6	34.2	4.3	31.6	2.1	33.4	3.3
G	44.4	2.1	42.0	4.1	43.0	3.4	43.1	3.2
H	38.4	2.5	39.0	2.2	39.3	1.5	38.9	2.1
I	43.6	3.8	41.8	2.9	43.8	1.9	43.1	2.9
J	39.0	1.4	38.8	1.6	37.0	2.4	38.3	1.8
K	57.0	2.6	56.8	1.6	54.4	3.2	56.1	2.5
L	34.6	1.7	33.8	2.6	33.8	1.1	34.1	1.8

*Mean Cobb, ** Standard deviation

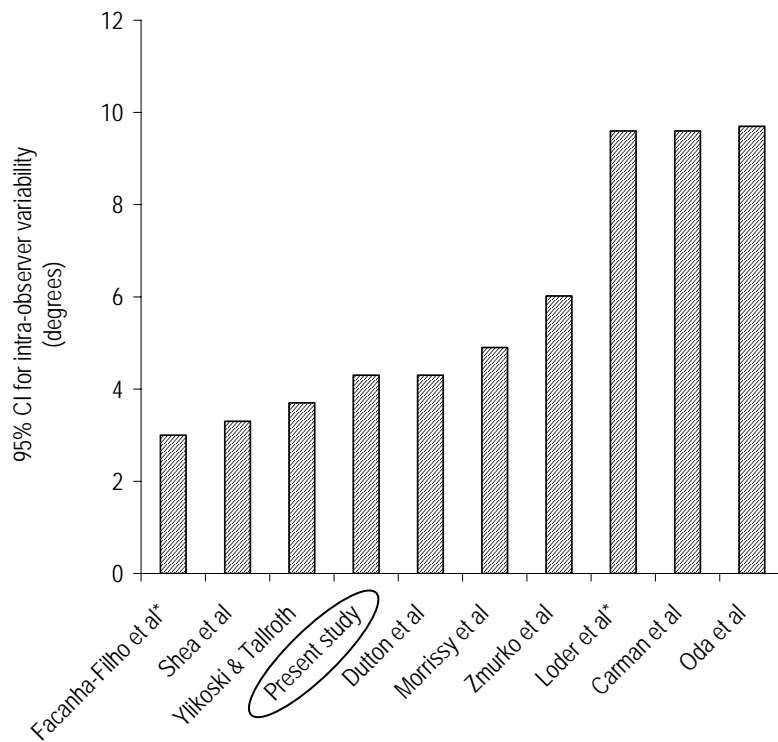


Figure 4. Comparison of intra-observer variability with previous studies
*(*Includes two studies on congenital scoliosis)*

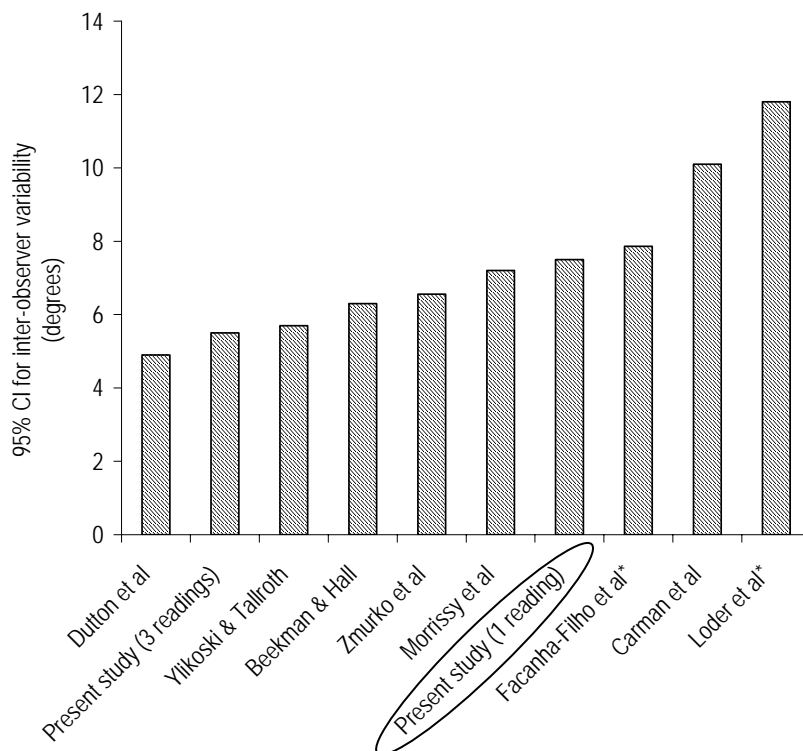


Figure 5. Comparison of inter-observer variability with previous studies
*(*Includes two studies on congenital scoliosis)*

Minor curves

The average Cobb angle for minor curves was 26.9°. The mean intra-observer difference between pairs of successive minor Cobb measurements was 2.8°, *SD* was 2.6°, and 95% confidence interval was ±5.1° (1.96×*SD*). Only 15 of the 109 minor curve measurements were less than 20°, and the *SD* of intra-observer difference for curves <20° was 1.0°. For a single reading by each observer, the inter-observer *SD* of a minor Cobb measurement was 2.7°. The inter-observer error for two observers measuring a minor curve is therefore $\sqrt{2} \times 2.7 = 3.8^\circ$, and the 95% confidence interval is ±7.4°. Inter-observer errors were not calculated for three readings per observer since many minor curves were not measured on all three occasions by the observers.

Technical error of measurement

The intra-observer technical error of measurement (TEM) was calculated using

$$TEM = \sqrt{\frac{\sum(\Delta\alpha)^2}{2N}}$$

where N is the number of pairs of successive major Cobb measurements. The inter-observer TEM was calculated using

$$TEM = \sqrt{\left(\sum_1^N \left[\sum_1^K M(n)^2 - \frac{\sum_1^K M(n)^2}{K} \right] \right) / N(K-1)}$$

where $N=12$ is the number of subjects, $K=5 \times 3=15$ is the number of determinations of the measurement taken on each subject, and $M(n)$ is the n th replicate of the measurement, where n varies from 1 to K . The coefficient of reliability R , can then be determined as

$$R = 1 - \left[(TEM)^2 / (SD)^2 \right]$$

where *SD* in this case is the overall inter-subject standard deviation. Table 4 gives the *TEMs* and reliability coefficients for the study.

Table 4. Technical error of measurement and reliability coefficient for major curves

	<i>TEM</i>	<i>R</i>
Intra-observer	2.38	0.88
Inter-observer	2.71	0.84

Discussion

On the basis of Figures 4 and 5, we conclude that the variability of manual Cobb angle measurements from reformatted CT scans is similar to previously reported studies for manual measurement of plain radiographs. In these graphs, only studies reporting data for manual Cobb measurement with no endplate preselection were included as these conditions best approximate standard clinical practice. The relatively low 95% confidence intervals reported by Dutton *et al*²² are based on the use of 2×*SD* even though a small number of patients ($N=5$) were measured. A *t*-distribution may have been more appropriate for calculation of confidence intervals in this case.

Shea *et al*²³ report a 95% confidence interval for intra-observer variability of 3.25°, which is only 1.35×*SD* based on their intra-observer *SD* of 2.4°. The reason for this apparently narrow confidence interval is not given. Zmurko *et al*'s²⁶ 95% confidence interval for inter-observer variability appears to be based on the standard deviation of a measurement of the Cobb angle, rather than based on the difference between two measurements of the Cobb angle by different observers. If this is the case, the 95% CI for inter-observer measurement difference for Zmurko *et al* would be approximately 6.56×1.414 = ±9.3°. Despite these uncertainties in statistical analysis methodology however, we believe it is safe to state that manual measurement of hardcopy reformatted CT scans is a comparable technique to current clinical practice using plain radiographs.

As mentioned by Carman *et al*¹⁵, the difference between two measurements due to observer error is a more clinically relevant parameter than the variability of a single measurement, since intra or inter-observer measurement differences can lead to misdiagnosis of curve progression. With reference to Figure 4, for repeat measurements by the same observer, the generally accepted Cobb angle increase of 5° between successive measurements taken to indicate progression is not 95% reliable in at least four of the studies. With reference to Figure 5, 95% confidence intervals for all studies except Dutton *et al*²² are greater than ±5°, therefore where the same patient is being monitored by different observers, the 5° guideline is not a 95% reliable indicator of progression either for plain radiograph or reformatted CT measurements. For reformatted CT measurements, if each observer performed three repeat measurements and averaged the results, the technique would be almost (5.5°) 95% reliable at the 5° level.

From Table 2, 95% of successive major Cobb measurements were within 7° of each other. This is comparable to the 8° reported by both Zmurko *et al*²⁶ and Carman *et al*¹⁵, although several degrees higher than the values reported by Morrissy *et al*¹⁶ (5°) and Shea *et al*²³ (4°). For minor curves, intra-observer measurement variability was marginally higher than for major curves. Only 14% of the minor curves measured were less than 20°, and contrary to the findings of Goldberg *et al*¹⁴ and Zmurko *et al*²⁶, intra-observer variability for minor curve measurements less than 20° in our study was much lower than the overall intra-observer variability for minor curves. A possible reason for this finding is that all of the 15 minor curves <20° were measured by only two of our observers, the others choosing not to measure them either due to lack of clarity or insufficient magnitude.

The technical error of measurement (*TEM*) has not been reported in previous studies, with the exception of Chockalingham *et al*²⁴, who found an inter-observer *TEM* of 1.9° for manual measurement of plain radiographs and coefficient of reliability *R*=0.78. These values are comparable to our reported values in Table 4.

While we chose to use hardcopy (printed) CT images to assess their suitability for measurement in a clinical environment, coronal CT images would also be well suited to computerised measurement techniques since their native format is digital. Zmurko *et al*²⁶ (2003) found no significant difference in variability between traditional and digital radiograph measurements, but Cheung *et al*²⁵ and Chockalingham *et al*²⁴ both presented computer-based techniques for Cobb angle measurement from digitised radiographs and found the reliability of the computer-based techniques was significantly better than conventional measurements. Shea *et al*²³ (1998) also found slightly lower variability with a computer-assisted measurement technique for digitised radiographs.

Although CT radiation doses currently preclude their use for repeated assessment of scoliosis on the same patient, future advances in multi-slice CT will allow lower dosages and faster acquisition times, and increased use of CT for assessment of scoliotic deformity in three-dimensions is likely to result. Reformatted CT scans could also be used to assess sagittal curvature (kyphosis and lordosis)

in idiopathic scoliosis, although we have not yet quantified the measurement variability associated with sagittal angular measurements using this technique.

Cobb angles measured from supine CT scans cannot be directly compared with standing radiograph Cobb measurements due to the previously mentioned changes in spinal geometry between standing and supine positions^{4,27}. The value of CT Cobb measurements is in allowing correlation with transverse deformity measurements from the same dataset. Supine CT curve measurements are also valuable in biomechanical modelling of scoliosis, since the supine position provides an approximate 'zero load' configuration for the spine which can be used as a starting point for numerical simulations.

We conclude that manual measurement of Cobb angles from reformatted CT images is a viable technique, with similar intra and inter-observer variability to manual measurement from plain radiographs. Printed (hardcopy) images allow measurement by clinicians using familiar techniques and equipment. Supine assessment of both transverse and coronal plane deformity is possible from the same CT dataset without changing patient position or imaging modality.

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