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DIAGNOSTICS

Supine Magnetic Resonance Imaging Cobb Measurements for Idiopathic Scoliosis Are Linearly Related to Measurements From Standing Plain Radiographs

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Study Design. Retrospective.

Objective. To demonstrate a relationship between adolescent idiopathic scoliosis Cobb angle measurements obtained with standing plain radiographs and standard supine magnetic resonance (MR) images.

Summary of Background Data. Patients with adolescent idiopathic scoliosis are exposed to repeated doses of ionizing radiation during the course of their treatment with significant potential long-term health consequences. Supine MR images of the spine may allow measurements of coronal plane spinal deformity equivalent to plain radiographs while minimizing exposure to ionizing radiation.

Methods. A retrospective chart and radiograph review was conducted for patients with adolescent idiopathic scoliosis. Cobb angle measures were derived from available plain radiographs and MR images obtained within 6 months of each other. Pearson correlation and linear regression analysis was used to test the relationship between plain radiographical and magnetic resonance imaging Cobb measures. Inter- and intraobserver reliability for the Cobb measures was tested with a random sample of 20 patients using intraclass correlation coefficients.

Results. Supine MR images tended to underestimate plain radiographs by 10° on average. However, radiographical and MR measures showed a strong positive correlation (r = 0.90–0.94) for all curves, structural or nonstructural, and this correlation was not influenced by patient age or body mass index. The relationship allowed the development of a simple linear equation for converting MR image measures to radiograph measures with an acceptable absolute error of ±5°.

Conclusion. Cobb angle measures from supine magnetic resonance imaging of the spine can reliably be translated to the equivalent radiographical measures with an acceptable range of error. The data suggest that standard supine magnetic resonance imaging sequences may be a viable substitute for plain radiographs in the clinical diagnosis and serial evaluation of adolescent idiopathic scoliosis while obviating the associated dangers of ionizing radiation from plain radiographs.

Key words: scoliosis, Cobb angle, plain radiograph, supine MRI, linear relationship, interobserver reliability, intraobserver reliability, radiation, partial Cobb angle.

Level of Evidence: 3

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Standing plain radiographs remain the "gold standard" for monitoring and clinical decision making in adolescent idiopathic scoliosis. However, the repeated exposure to ionizing radiation in developing children is of significant concern. Nash *et al*[1] measured the surface radiation exposure of 13 female patients with adolescent idiopathic scoliosis during the course of treatment and found that these patients had a 7.5% increased risk of developing lung cancer and a 110% increased risk of breast cancer. Goldberg *et al*[2] noted that for patients treated for scoliosis before the 1990s, there existed dose-dependent correlations to low-birth-weight infants. Although modern radiographical techniques have been able to reduce these dangers, full-length scoliosis radiographs continue to pose a potential threat to a patient's long-term health. Bone and Hsieh[3] repeated Nash's study in 2000 and found that, although the current radiation risks are notably improved, female patients with scoliosis still had a 4.2% increased risk of breast cancer.

Magnetic resonance (MR) image is a radiationless alternative to plain radiographs for imaging of the spine. One of the concerns with using MRI routinely for the diagnosis and serial evaluation of scoliosis is that the curve magnitudes on supine MR images will underestimate that on standing plain radiographs because the effect of gravity is eliminated. However, Wessberg *et al*[4] demonstrated that if a spine is axially loaded during a supine MRI study to simulate the force of gravity,

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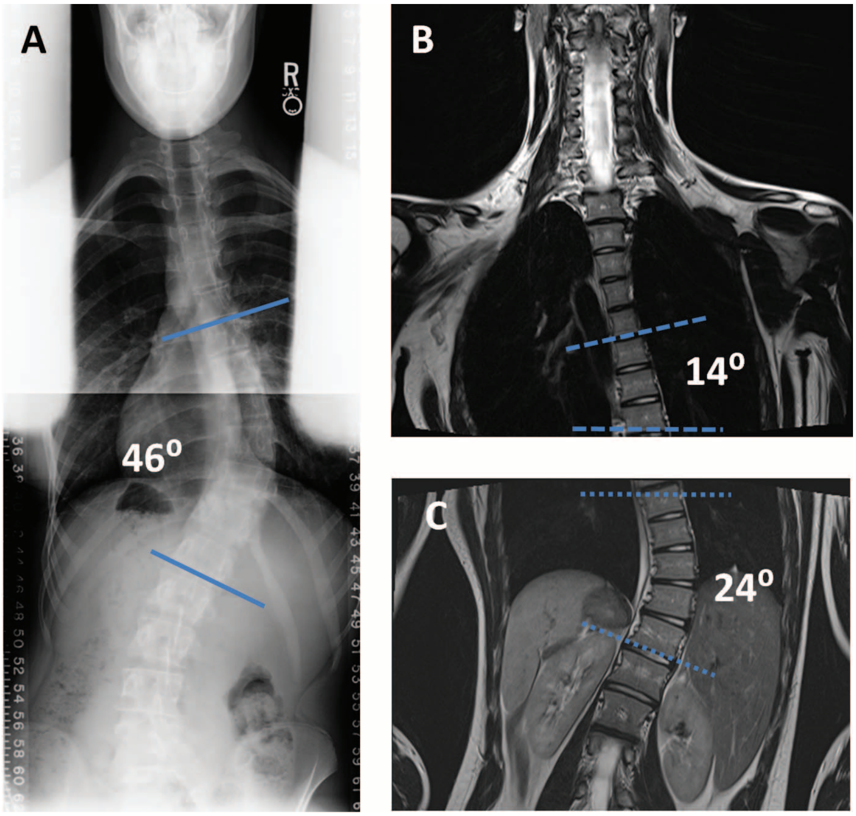

Figure 1. (**A**) Standing posteroanterior radiograph demonstrating the standard Cobb angle measurement method. (**B,C**) Coronal T1-weighted magnetic resonance (MR) image of the same patient demonstrating the partial Cobb angle measurement method used for curves extending across 2 MR images. The Cobb angle for the upper image is calculated from the angle made by a line parallel to the upper end vertebra and a horizontal line. The Cobb angle for the lower image is calculated from the angle made by a line parallel to the lower end vertebra and a horizontal line. The sum of these 2 angles yields the complete Cobb angle measure for the curve that extends across the 2 images. The end vertebrae used for the MR measurement are determined from the initial standing plain radiograph.

excellent correlation with standing Cobb angle measures could be achieved. Specifically, Wessberg *et al* noted an average difference of 2.1° between the axially loaded MR image Cobb angle measurements and the plain radiograph Cobb measurements, with a strong linear relationship between the 2 imaging modalities.

Although the results of Wessberg *et al*[4] support the ability of MR images to reproduce Cobb values obtained from plain radiographs, the use of an axial loading device in MRI can be cumbersome. Furthermore, not all institutions have access to such a device. We hypothesized that because gravity is a constant, a direct correlation can be established between the Cobb measurements obtained from supine MR images and standing plain radiographs in the absence of an axial loading device. Such a correlation would allow MR images to be a more easily usable alternative to standing plain radiographs for the evaluation of adolescent idiopathic scoliosis.

MATERIALS AND METHODS

The study was approved by The Connecticut Children's Medical Center review board. Patients with a diagnosis of adolescent idiopathic scoliosis who obtained a standing plain scoliosis radiograph and an MR image between January 1, 2005, and January 1, 2010, were included. Additional inclusion criteria consisted of no more than 6 months of lag time between the standing radiograph and the MR image, age between 10 and 18 years at the time of the study, no underlying congenital or neurological abnormalities, and no leg length discrepancy of more than 2 cm. Leg length discrepancy was determined by measuring the height of the iliac crests on standing plain radiographs using calibrated digital measuring tools. All plain radiographs were obtained using a Rad Speed X-ray machine (Shimadzu, Kyoto, Japan) and all the MR images were obtained from a 1.5T Siemens Avanto MRI scanner (Siemens, Munich, Germany). All images were digital and archived on an iSite PACS system (Philips Healthcare, Andover, MA).

Cobb angle measures for both the standing radiographs and supine MR images were obtained using the angle measurement tools provided by the iSite PACS system (Figure 1). For MR images, Cobb angles were calculated on the T1-weighted coronal plane cut that included the clearest depiction of the vertebral endplates for the end vertebrae of the curve. If one of the end vertebrae of a curve was truncated from the coronal plane image, a Cobb angle was calculated by measuring a partial Cobb angle for the cephalad and caudad end vertebra and then summing the 2 measures. The partial Cobb angle was obtained by measuring the angle the end vertebra forms with respect to a horizontal line drawn on the T1-weighted coronal plane image (Figure 1). The same end vertebrae were used to measure the Cobb angle on plain radiographs and MR images. Curve patterns were classified according to a modified Lenke system adapted for the study, as bending films and standing scoliosis laterals were typically not obtained in the time interval between standing posteroanterior radiographs and the execution of the MR images. In the modified system, the largest Cobb measure was considered structural and the other curves were considered structural only if measuring greater than 25° on the routine, standing posteroanterior scoliosis film.[5] Neither

TABLE 1. Patient Characteristics

N	70
Age, yr (± SE)	14 ± 2
Sex (%)	
Female	57
Ethnicity (%)	
African-American	15.7
Hispanic	12.8
Other	7.3
White	64.2
Average weight (kg)	57 ± 13
Average body mass index	23 ± 10
Initial modified Lenke curve type (%)	
1	44
2	16
3	4
4	6
5	19
6	11

a lumbar modifier nor a thoracic sagittal profile modifier was used.

Average Cobb measurements obtained on MR image and plain radiograph were calculated for only the major curves to allow a focused comparison of the agreement of these 2 measures. The Cobb angles from MR images and plain radiographs for all measured curves were plotted against each other, and Pearson correlation coefficients were calculated to describe the relationship of the Cobb measures from both imaging modalities. Additional correlations were evaluated for the subgroups of structural curves or nonstructural curves. Equations describing the line of best fit through the data were then developed. Pearson correlation was also used to determine whether age and weight were correlated to the measurement differences between plain radiographs and MR images.

The interobserver and intraobserver reliability for measuring Cobb angles from standing posteroanterior plain radiographs and a supine MR image of the spine were also assessed as part of this work. Two of the authors, responsible for the majority of radiographical measurements, measured MR images and plain radiographs as part of a separate trial from a convenience sample of 20 patients selected randomly from the 70 patients in this study. The MR images and plain radiographs from the same 20 patients were remeasured 2 weeks later by the same reviewers. Intraclass correlation coefficients were calculated to quantify interobserver and intraobserver reliability.

TABLE 2. Trend Equations

	Best-Fit Equation*	Absolute Error (°)
All measured curves (Equation 1)	XRAY = 1.05 (MRI) + 5.51	±5
Structural curves (Equation 2)	XRAY = MRI + 9.40	±5
Nonstructural curves (Equation 3)	XRAY = 1.02 (MRI) + 5.25	±4
Simplified equation	XRAY = MRI + 6	±5

*The variable XRAY = Cobb measure of scoliosis curve on plain radiograph in degrees, MRI = Cobb measure of scoliosis curve on MRI in degrees.

MRI indicates magnetic resonance imaging.

RESULTS

A total of 70 patients met the study's inclusion criteria, with 40 female patients and 30 male patients, with a total of 187 curves evaluated on both plain radiographs and MR images. All patients had received an MR image as a routine preoperative evaluation. The mean age of patients was 14 ± 2 years and the average body mass index was 23 ± 10. The average time between the plain radiographical study and the supine MRI study was 1 ± 1 month. The most frequent modified Lenke type was type 1 (Table 1).

The average difference between Cobb angles for the major curves measured from the radiographs and MR images was 10°, with an overlapping standard error range (58 ± 14° radiograph, 48 ± 14° MR image). The value suggests that, on average, Cobb measures obtained from the MR images tended to underestimate the radiographical measures by 10°.

Evaluation of the MRI and radiographical Cobb measurements for all 187 curves revealed a strong linear relationship with a Pearson coefficient of $r = 0.94$, where $r = 1$ is a perfect positive linear relationship. The extrapolated linear equation describing the data trend indicates a near one-to-one relationship between MRI and x-ray measures, with a mean absolute error of 5° throughout the full range of measurements (Table 2, Equation 1; Figure 2).

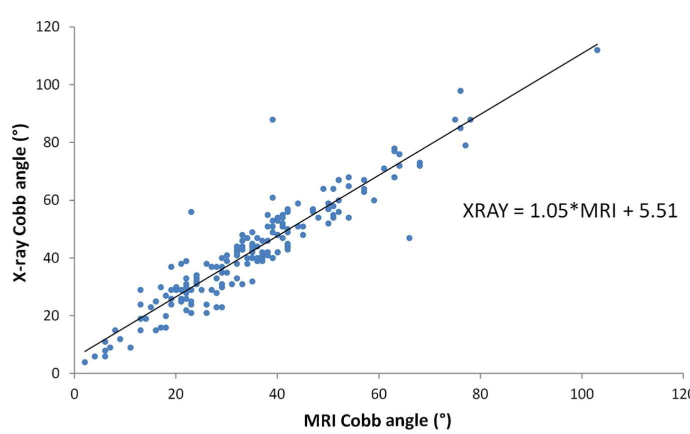

Figure 2. Scatter plot of plain radiograph and magnetic resonance Cobb angle measures for all curves, structural or nonstructural, with the associated trend line equation. MRI indicates magnetic resonance imaging.

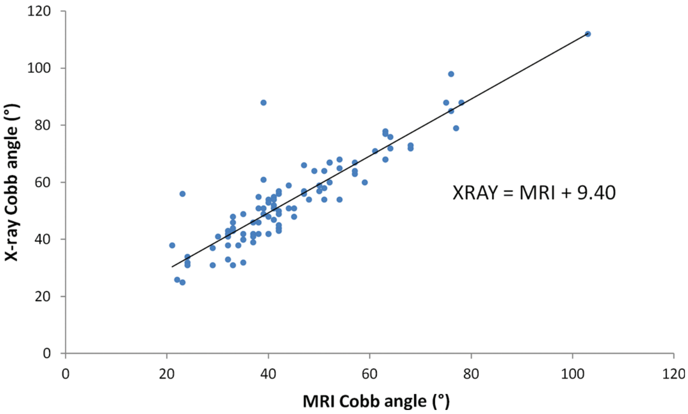

Figure 3. Scatter plot of plain radiograph and magnetic resonance Cobb angle measures for all structural curves, with the associated trend line equation. MRI indicates magnetic resonance imaging.

TABLE 3. Inter- and Intraobserver Reliability for Radiographical Measurements

	Plain Radiograph Cobb Measures	MRI Cobb Measures
Interobserver reliability (ICC)*	0.77	0.70
Intraobserver reliability (observer 1 ICC/ observer 2 ICC)	0.90/0.86	0.88/0.76

**Generally, a value of 0 to 0.2 = poor agreement, 0.3 to 0.4 = fair agreement, 0.5 to 0.06 = moderate agreement, 0.7 to 0.8 = strong agreement, and >0.8 = near perfect agreement.*

ICC indicates intraclass correlation coefficient; MRI, magnetic resonance imaging.

To determine whether the structural nature of the curve influenced the correlation between MR image and plain radiograph measurements, the 187 curves were divided into 2 subgroups. The first subgroup consisted of structural curves (n = 98), and the second subgroup consisted of nonstructural curves (n = 89). The Pearson coefficient suggested maintenance of a strong linear relationship between the Cobb angle measures for both the structural curves (r = 0.91) and the nonstructural curves (r = 0.90), with only a small variation in the trend line equation and comparable absolute errors (Table 2, Equations 2 and 3; Figures 3 and 4). A simplified equation was estimated from the results to allow a more clinically applicable equation for transforming MRI Cobb measures to radiographical Cobb measures (Table 2, simplified equation). The mean absolute error calculated from this equation was similar to the equations derived from the scatter plots.

Pearson correlation coefficients were calculated for the relationship of age and weight to the differences in Cobb measurements between plain radiographs and MR images. No significant correlation was identified for age (r = −0.02) and weight (r = −0.09). A Pearson correlation coefficient and trend line equation was also calculated for the subgroup of patients with MRI Cobb angles measured without use of the partial Cobb method to determine whether the partial Cobb method imparted additional variability to these calculations. The Pearson correlation remained excellent (r = 0.9) and the trend line equation was XRAY = 1.05X + 5.23 with a ±5 absolute error, differing little from Table 2, Equation 1. In addition, there was no significant difference in Pearson correlation coefficients for MR image and radiographical measures of curves grouped according to the different modified Lenke subtypes (data not shown).

Intraobserver reliability, as calculated for the measurements obtained from the random sample of 20 MR images and radiographs, demonstrated intraclass correlation coefficient values between 0.76 and 0.90, suggesting strong to near perfect agreement (Table 3). Interobserver reliability quantified by intraclass correlation coefficient values for the same sample of 20 MR images and plain radiographs fell in the range of 0.70 to 0.77, also suggesting strong agreement.

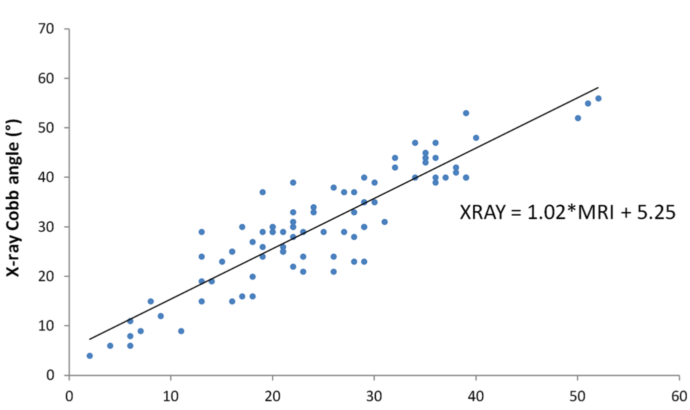

Figure 4. Scatter plot of plain radiograph and magnetic resonance Cobb angle measures for all nonstructural curves, with the associated trend line equation. MRI indicates magnetic resonance imaging.

DISCUSSION

Patients with adolescent idiopathic scoliosis are subjected to repeated doses of ionizing radiation as part of their treatment, and this has been shown in prior studies to increase the risk for health complications later in life.[3] Clouding the potential risks associated with radiation exposure in patients with adolescent idiopathic scoliosis is the lack of current literature evaluating the total radiation doses a patient with scoliosis receives on the basis of modern treatment protocols and modern imaging technologies. However, it is known that despite improvements in radiographical technology and technique to minimize radiation exposure, there remains an inherent risk of long-term health complications from even limited doses of radiation exposure.[6] Radiationless methods of diagnosing and tracking the progression of scoliotic curves should therefore be explored.

In this study, an excellent correlation between standing radiographical Cobb measures and supine MRI Cobb measures was identified. A near one-to-one relationship of standing plain radiograph and supine MRI Cobb measures was noted, with a 0.94 correlation coefficient for the Cobb measurements of all measured curves derived from the 2 imaging modalities. As anticipated, MR images tended to underestimate the values for plain radiographs by approximately 10° when compared directly. However, when regression analysis was used to construct a best fit trend line, the MRI measures could be used to reliably estimate plain radiographical measures with a mean absolute error of ±5°. Interestingly, the regression equations for structural and nonstructural curves yielded similar mean absolute errors, suggesting that the relative rigidity or size of the curve does not noticeably impact the ability of a Cobb measure on MR images to be translated to a Cobb measure on plain radiographs.

The results of this work are similar to those presented by Wessberg *et al*,[4] who found a correlation coefficient of 0.78 when comparing plain radiographical and MRI Cobb measures and showed a near linear relationship when using an axial load device to adjust for the unloaded spinal condition present in a supine MR image. However, this study suggests that an axial load device is unnecessary to estimate a Cobb measure reliably on standing plain radiographs from a Cobb measurement on a supine MR image. Using the simplified equation derived from this analysis, adding 6° to the Cobb measure derived from an MR image will yield a measurement that is within 5° of that calculated by radiographs. Because the commonly accepted error range for plain radiographical Cobb measurements between observers is 7° to 10°, a plain radiographical Cobb measure derived from an MRI Cobb measure using the simplified equation will yield a value that is within the currently accepted error range.[7,8] Therefore, any institution with an MRI scanner can potentially use this technology to follow patients with scoliosis without the need for a specially designed axial loading device.

Supine MRI, given the current data, would be an ideal imaging modality for diagnosis and follow-up of scoliosis. The method is devoid of potentially harmful ionizing radiation, allows a complete screen of all neurological elements for nonidiopathic causes of scoliosis, and provides a 3-dimensional understanding of the curve. The obvious challenge to using MRI for routine scoliosis evaluation rests in the current monetary and time costs of the study. A full-spine MRI with the range of multiplanar cuts costs thousands of dollars and requires up to 60 minutes, making it almost prohibitive for routine use. However, to think that these time and monetary costs will persist indefinitely would be short-sighted. MRI technology continues to progress rapidly, becoming faster, cheaper, and of higher resolution annually. Even today, a T2 HASTE (half-Fourier acquisition single-shot turbo spin-echo) imaging sequence can be constructed with the MRI scanner used in this study to generate a complete coronal section of the spine in less than 5 minutes. Further research into MRI algorithms for the rapid and inexpensive evaluation of the spine is therefore required.

Although supine MR image is demonstrated in this work to be a possible alternative for plain radiographs in the initial or follow-up evaluation of scoliosis, during which decisions regarding brace or surgical management need be made, the authors think that standing plain radiographs remain indispensable for understanding fusion levels in adolescent idiopathic scoliosis. Supine MR image is limited in its ability to provide the critical upright data necessary for operative planning, such as coronal plane balance, sagittal plane balance, and classic Lenke classification including the coronal and sagittal plane modifiers. However, the value of a supine MR image study lies in its potential ability to eliminate the numerous plain radiographs obtained for the purpose of routine serial evaluation in adolescent idiopathic scoliosis, not for the purpose of operative planning.

The strengths of the study include the relatively large number of curves compared between MR image and radiograph, the uniform digital tools used for all image measurements, and the evaluation of inter and intraobserver reliability for both radiographical and MRI measurements. Weaknesses of the study include the study's retrospective nature and the need to extrapolate Cobb measurements when the coronal plane cuts truncated the end vertebrae of the curve, although subgroup analysis demonstrated no impact on the data using this method of measurement.

CONCLUSION

Cobb angle measurements on a supine MR image of the spine can be directly translated to Cobb angle measures obtained from plain radiographs with an acceptable degree of accuracy without the use of adjunctive MRI body positioning tools. The information can be used to develop a supine MR imaging algorithm that could significantly reduce radiation exposure to patients requiring serial evaluations for adolescent idiopathic scoliosis.

➢ Key Points

- ❑ A linear relationship exists between supine MRI and standing plain radiographical Cobb measurements of scoliosis curves.
- ❑ The linear relationship is not influenced by age or weight.
- ❑ The standing plain radiographical Cobb angle for a particular curve may be derived from the supine MRI measure within an acceptable error range by simply adding 6° to the MRI Cobb value.
- ❑ Supine MR image has the potential to be a practical, radiationless alternative for plain radiographs for the evaluation of adolescent idiopathic scoliosis.

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