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How Does the Supine MRI Correlate With Standing Radiographs of Different Curve Severity in Adolescent Idiopathic Scoliosis?

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Study Design. A retrospective study.

Objective. To study how the supine magnetic resonance image (MRI) correlates with standing radiographs of different curve severity in adolescent idiopathic scoliosis (AIS).

Summary of Background Data. Linear correlation between Cobb angles measured on supine MRI and standing radiographs has been identified. However, the effects of different curve severity on the correlation have not been studied in depth.

Methods. Girls with AIS with standing radiographs and supine MRI were reviewed. From standing radiographs, all structural and nonstructural Cobb angles were measured. For those with simultaneous lateral radiographs, thoracic kyphosis (TK) and lumbar lordosis (LL) angles were measured. On supine MRI, the coronal Cobb angles, TK and LL were measured accordingly. The coronal Cobb angles were divided into 3 groups based on values measured on standing radiographs: mild group for Cobb angles less than 20°, moderate group for 20° to 40°, and severe group for more than 40°. Correlation was analyzed using scatter plot.

Results. Eighty patients with AIS with 122 coronal curves were reviewed. On standing radiographs, the coronal Cobb angles were 14.7° ± 3.2°, 28.2° ± 5.1°, and 54.9° ± 11.3° for mild, moderate, and severe groups. On supine MRI, the Cobb angles averaged 10.1° ± 5.6°, 20.0° ± 6.3°, and 49.4 ± 12.3° for each group, respectively. TK were 16.3 ± 9.1° and 11.8 ± 6.1° for radiographs and MRI ($P < 0.001$), whereas the LL averaged 45.5 ± 12.2° and 39.5 ± 10.5° for radiographs and MRI ($P < 0.001$). Cobb angles measured on standing radiographs and supine MRI were linearly correlated with the adjusted R^2 being 0.0627, 0.2118, and 0.7999 for the mild, moderate, and severe groups.

Conclusion. Cobb angles measured on supine MRI were linearly correlated with Cobb angles measured on standing radiographs and the correlation was more reliable in those with Cobb angles more than 40°. Therefore, the supine MRI could serve as a reliable alternative to standing radiographs in the assessment of Cobb angles more than 40° in AIS.

Key words: adolescent idiopathic scoliosis, standing radiographs, supine MRI, linear correlation, severe cobb angle.

Level of Evidence: 3

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Adolescent idiopathic scoliosis (AIS) is prevalent among children during puberty, which presents considerable challenges in its prognosis due to the possible significant morbidities.[1,2] In order to monitor the development of curvature and the effect of bracing treatment, patients with AIS need to be regularly followed up for several years during their whole growth period, especially during their peak growth phase.[3,4] Until now, traditional standing radiographs of the whole spine remains the "gold standard" for the assessments of spinal alignments both in coronal and sagittal plane. However, there are several disadvantages of radiographs used in the measurements of spinal alignments. Previous studies[5–7] have demonstrated that radiographs brings inevitable exposure of repeated doses of ionizing radiation, which has been proven to significantly increase the risk of developing a variety of diseases including lung cancer, breast cancer, and low birthweight infants. Besides, the inherent variability of patient's standing posture may lead to the misestimation of the curvature. In addition, though most of the radiographs measurements in coronal plane are reported to have good or excellent intra- and interobserver reliability, the measurements of sagittal parameters on radiographs are only of moderate precision

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and reliability due to the overlapping of shoulder joints, scapulae, and other tissue.[8–10]

Originally used for the screening of neurological and soft-tissue deformities, supine magnetic resonance image (MRI) has been considered as an alternative option to standing radiographs for several years due to its radiation-free advantage.[11–13] Schmitz *et al*[11] proposed that the MRI total spine imaging could allow better monitoring of scoliosis, which revealed relevant clinical data without radiation exposure. Wessberg *et al*[12] showed the coronal Cobb angles measured on axial loading supine MRI was similar to the Cobb angles measured on standing radiographs. They concluded that loading supine MRI was a way to acquire reliable Cobb angles in the monitoring of idiopathic scoliosis though the axial loading device in MRI was not conveniently applied. Lee *et al*[13] further reported that the Cobb angle measurements from supine nonloading MRI could also be linearly translated to the equivalent radiographical measurements with an acceptable range of error. As for the sagittal profile, Wang *et al*[14] demonstrated supine MRI served as a valid alternative to standing radiographs for the measurement for upper thoracic kyphosis (TK) as well as the T3–T5 sagittal vertebral angles with excellent measurement reproducibility. Despite the encouraging results, no study, however, has addressed the different utilizations of supine MRI as an alternative to standing radiographs in the assessment of mild, moderate, and severe Cobb angles in patients with AIS.

The main purpose of the current study was to analyze the correlation between Cobb angles measured on supine MRI and that measured on standing radiographs in patients with AIS to determine whether the supine MRI with its additional 3-dimensional data could also serve as an alternative option to standing radiographs in the assessment and monitoring of curve evolution.

MATERIALS AND METHODS

Subjects

Ethical approval of this retrospective study was obtained from the Clinical Research Ethics Committee of the university hospital. The girls with AIS visited our scoliosis clinic center from April 2008 to December 2013 were reviewed. The inclusion criteria were as follows: (1) patients with both standing postero-anterior (PA) spinal radiographs and supine MRI total spine imaging[11,15]; and (2) the time interval between radiographs and MRI was no more than 6 months. The exclusion criteria included: (1) patients with previous spinal surgery; (2) with abnormalities of maturation or height; and (3) with any neurological abnormalities.

In the present study, the supine MRI total spine imaging was used for measurements because it provided clearer visibility of the curvatures in coronal and sagittal plane, which therefore reduced the measuring errors compared with the traditional nonloading MR imaging. The indications for MRI assessments were as follows: (1) preoperative assessment for patients with severe curve undergoing corrective surgery; (2) assessment of patients with mild and moderate curve followed an institutional review board approved study protocol as part of our MRI imaging research study on brain and spinal cord in patients with AIS.

Radiographical Measurements

All the radiographs and MR images were assessed on the Picture Archiving and Communications Systems workstation (Carestream solution working station, Carestream Health, Version 11.0, Rochester, NY). On standing PA radiographs, all the Cobb angles of both structural and nonstructural curves were measured and the levels of upper and lower end vertebrae were also recorded, respectively (Figure 1A). For a subgroup with full-length lateral radiographs of whole spine,

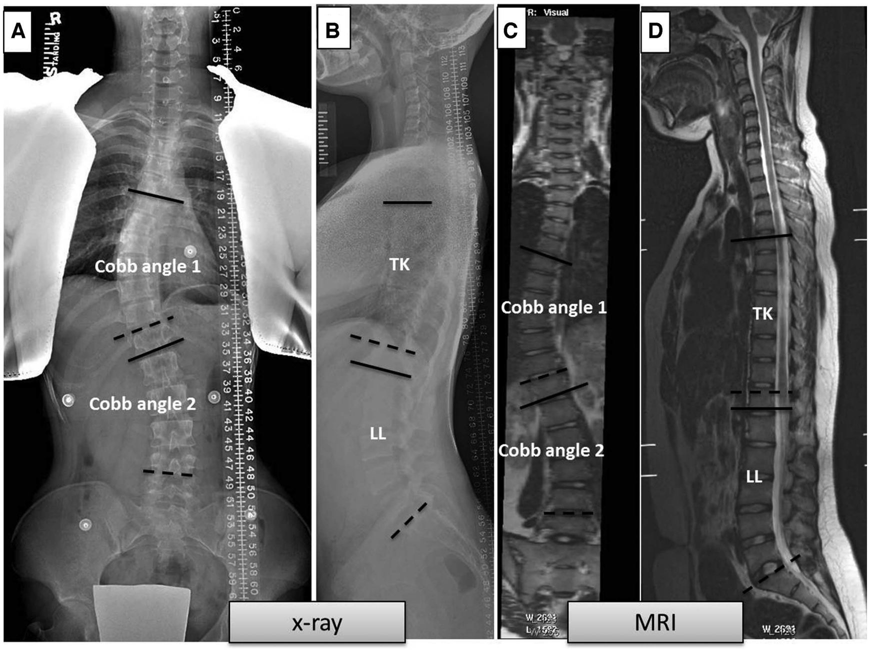

Figure 1. Parameters measured on radiographs and MRI total spine imaging. (A) Structural and nonstructural Cobb angles on standing postero-anterior radiographs. (B) TK and LL on standing radiographs taken in sagittal plane. (C) Structural and nonstructural Cobb angles on MRI. (D) TK and LL on MRI. TK indicates thoracic kyphosis; LL, lumbar lordosis.

the TK (the angle between the superior endplate of T5 vertebra and the inferior endplate of T12 vertebra)[16] and lumbar lordosis (LL, the angle between the superior endplate of T12 vertebra and the endplate of S1 vertebra)[16] were also obtained simultaneously (Figure 1B). Kyphosis was recorded as positive for TK, whereas lordosis was regarded as positive for LL. On supine MRI, the Cobb angles were measured according to the upper and lower vertebrae recorded from standing radiographs (Figure 1C). In addition, the sagittal profiles including TK and LL were also measured on sagittal MRI total spine imaging for those patients with AIS with available lateral radiographs (time interval between x-ray and MRI was also less than 6 mo) (Figure 1D).

Two independent spinal surgeons respectively measured each parameter twice at an interval of 2 weeks and the mean values were adapted for the analysis. Finally, the coronal Cobb angles were divided into 3 groups based on the average values measured on standing radiographs: mild group for Cobb angles less than 20°, moderate group for between 20° and 40°, and severe group for more than 40°.

Statistical Methods

Data were statistically analyzed using the SPSS software 17.0 version (SPSS, Inc, USA). Descriptive statistics was performed to analyze the patients' demographics and data were shown as the mean ± standard deviation. The Cobb angles measured on standing radiographs and supine MRI were plotted against each other, and the linear correlation was evaluated using the adjusted R^2 values. For the intra- and interobserver reliability analysis, the intraclass correlation coefficient was calculated. Statistical significance was set at a level of $P < 0.05$.

RESULTS

A total of 80 patients with AIS with an average age of 14.4 ± 1.8 years were retrospectively reviewed in this study. The average time interval between radiographs and MRI was 3.2 ± 2.0 months. The curve patterns were single thoracic or lumbar curve in 38 patients and double-main curve in 42 patients. As a consequence, there were 122 coronal curves included in the analysis, of which the average Cobb angles measured on standing radiographs and supine MRI were 29.4 ± 13.7° and 22.4 ± 14.3°, respectively (Table 1). Twenty-seven curves were involved in the mild group, 76 curves were in the moderate group, and 19 curves were in the severe group. In addition, there were 52 patients with available lateral standing radiographs and supine MRI.

On standing PA radiographs, the average coronal Cobb angles were 14.7 ± 3.2°, 28.2 ± 5.1°, and 54.9 ± 11.3° for mild, moderate, and severe groups, respectively. On supine MRI, the Cobb angles averaged 10.1 ± 5.6°, 20.0 ± 6.3°, and 49.4 ± 12.3°, respectively. Significant differences were found between Cobb angles measured on standing radiographs and supine MRI in all the 3 groups ($P < 0.01$). For the 52 patients with sagittal radiographs, the TK were 16.3 ± 9.1° and 11.8 ± 6.1° for radiographs and MRI ($P < 0.001$), whereas the LL averaged 45.5 ± 12.2° and 39.5 ± 10.5° for radiographs and MRI ($P < 0.001$), respectively. These results implied that, both in coronal and sagittal planes, the average Cobb angles measured on supine MRI significantly underestimated the values measured on standing radiographs in varying degrees. The data are shown in Table 2.

Figure 2 showed the total Cobb angles measured on standing radiographs and supine MRI were of significant linear correlation (R^2= 0.8246). When patients were classified into 3 groups according to the magnitude of Cobb angles, the values of adjusted R^2 were 0.0627, 0.2118, and 0.7999 for the mild, moderate, and severe groups, respectively (Figures 3–5). In addition, the linear correlations between standing radiographs and supine MRI were significant in the sagittal plane with the adjusted R^2 being 0.4889 and 0.3832 for TK and LL, respectively.

The intra- and interobserver reliabilities were shown in Table 3. Both on standing radiographs and supine MRI, the highest intra- and interobserver reliabilities occurred in the severe group. The intraobserver reliabilities of TK and LL were good to excellent on radiographs and excellent on MRI. However, the interobserver reliabilities of TK and LL were good on radiographs and fair to good on MRI.

DISCUSSION

Considering the repeated doses of ionizing radiation using standing radiographs in the longitudinal assessment of Cobb angles in patients with AIS, the supine MRI has been proposed

TABLE 1. Demographics of the 80 Patients

	Mean ± SD	Range
Age (yr)	14.4 ± 1.8	10.5–17.1
Time interval between radiographs and MRI (mo)	3.2 ± 2.0	0–5.9
Cobb angle on radiographs (°)	29.4 ± 13.7	10–79
Cobb angle on MRI (°)	22.4 ± 14.3	3–74

TABLE 2. Cobb Angles Measured on Standing Radiographs and Supine MRI

Cobb Angle	Radiographs*	MRI*	P
Mild group (°)	14.7 ± 3.2	10.1 ± 5.6	<0.001
Moderate group (°)	28.2 ± 5.1	20.0 ± 6.3	<0.001
Severe group (°)	54.9 ± 11.3	49.4 ± 12.3	<0.001
TK (°)	16.3 ± 9.1	11.8 ± 6.1	<0.001
LL (°)	45.5 ± 12.2	39.5 ± 10.5	<0.001

*Data are shown as mean ± SD.

TK indicates thoracic kyphosis; LL, lumbar lordosis.

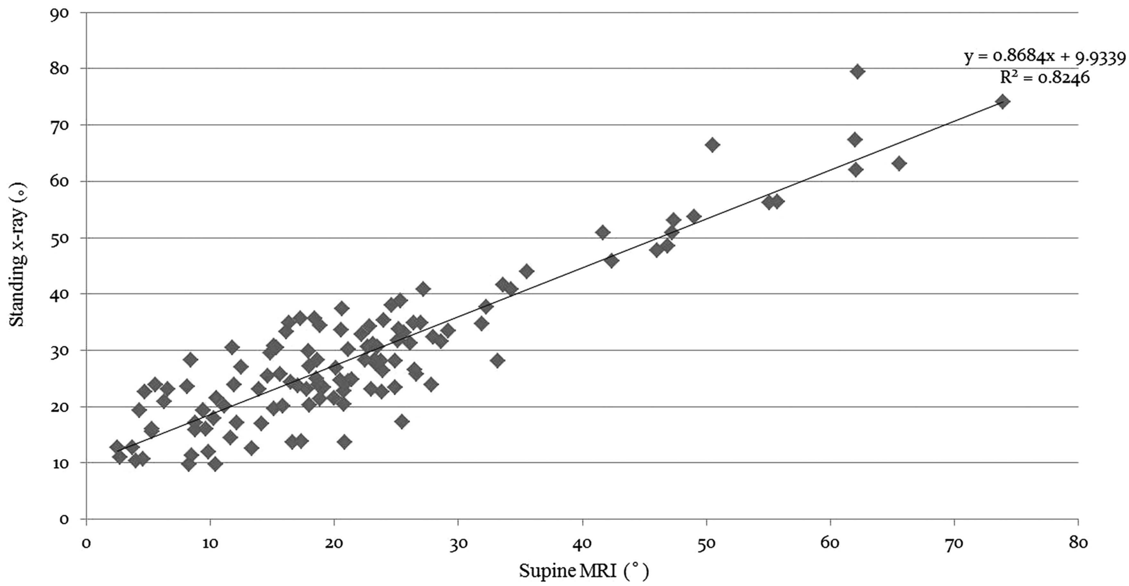

Figure 2. Scatter plot of 122 coronal Cobb angles measured on standing radiographs and supine MRI.

as an alternative to standing radiographs for years.[11–13] For the convenience and accuracy of Cobb angle measurement on supine MRI, Schmitz *et al*[11] reported that MRI total spine imaging could be used. Though the effect of gravity was unable to be simulated, Lee *et al*,[13] based on 187 curves from 70 patients with AIS, proved the significantly linear correlation between coronal Cobb angles measured on standing radiographs and supine MRI. However, there are several limitations in the study performed by Lee *et al*.[13] The Cobb angles were calculated by the sum of partial Cobb angles on cephalad and caudad half imagines instead of being measured on MRI total spine imaging. As a consequence, the measuring error was relatively enlarged. Besides, the Cobb angles were not divided into 3 groups according to the Cobb magnitudes, and the different correlations between standing radiographs and supine MRI in different Cobb angle ranges were not evaluated. We thought that different Cobb angles measured on supine MRI and standing radiographs should have different linear correlations. The present study, for the first time, was designed to investigate the correlations between Cobb angles measured on supine MRI and standing radiographs in patients with AIS with mild, moderate, and severe Cobb angles, and to determine whether the supine MRI with its additional 3-dimensional data could also serve as an alternative option to standing radiographs in the assessment and monitoring of curve evolution.

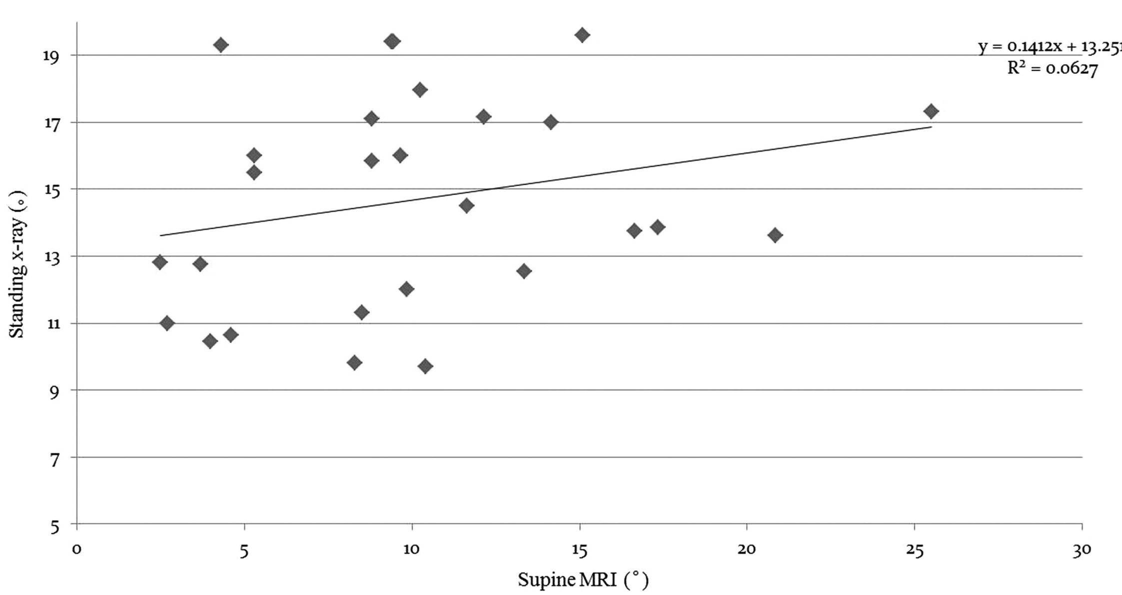

Figure 3. Scatter plot of mild Cobb angles measured on standing radiographs and supine MRI.

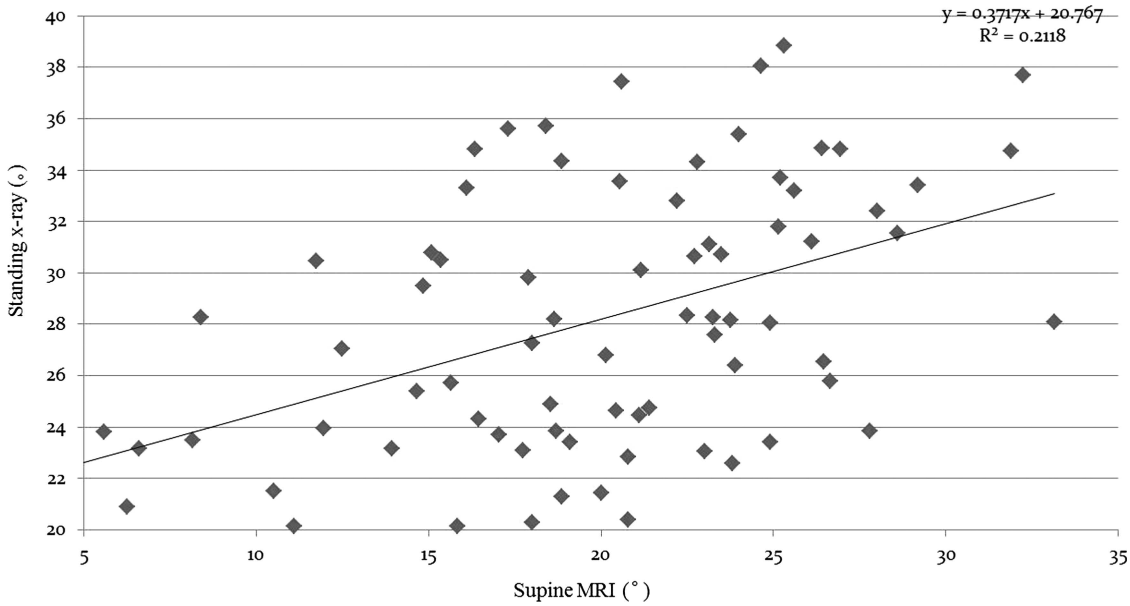

Figure 4. Scatter plot of moderate Cobb angles measured on standing radiographs and supine MRI.

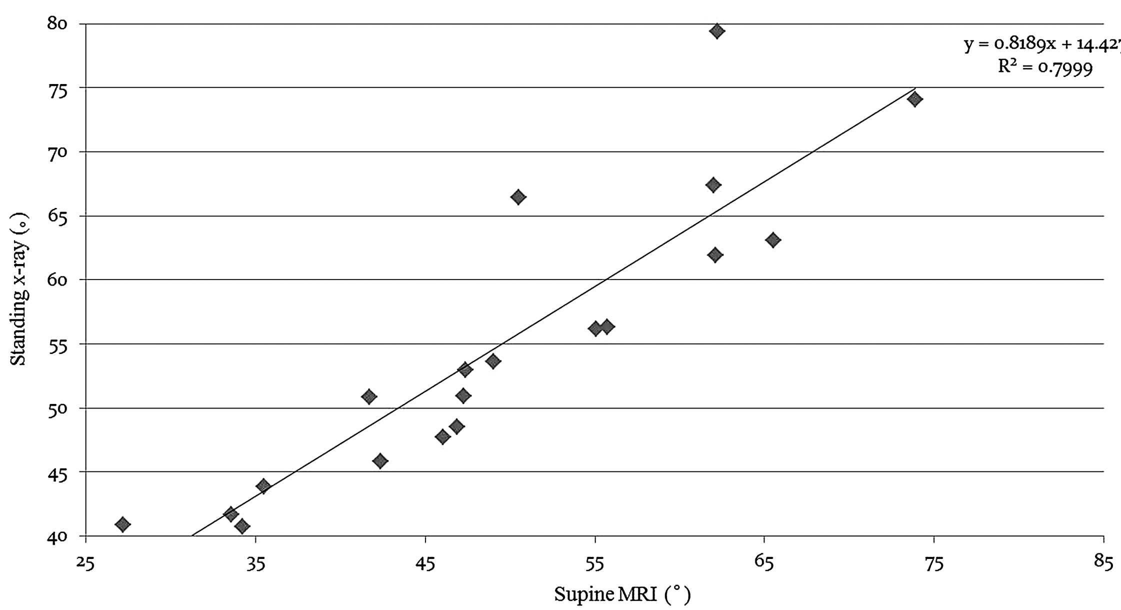

Figure 5. Scatter plot of severe Cobb angles measured on standing radiographs and supine MRI.

TABLE 3. Intra- and Interobserver Reliabilities Analysis

Cobb Angle	Intraobserver Reliability (Observer 1/Observer 2)		Interobserver Reliability	
	Radiographs	MRI	Radiographs	MRI
Mild group (°)	0.035/0.229	0.679/0.700	0.128	0.467
Moderate group (°)	0.658/0.784	0.677/0.771	0.642	0.661
Severe group (°)	0.838/0.865	0.884/0.929	0.683	0.702
TK (°)	0.711/0.765	0.925/0.908	0.612	0.561
LL (°)	0.895/0.827	0.876/0.879	0.636	0.678

TK indicates thoracic kyphosis; LL, lumbar lordosis.

Lee *et al*[13] found the excellent linear correlation coefficient was 0.94 between coronal Cobb angles on standing radiographs and supine MRI. In the current study, the correlation coefficient was 0.908 (R^2= 0.8246, Figure 2), which was similar to the previous study. To the best of our knowledge, the relatively lower correlation coefficient in the current study was attributed to the longer time gap between radiographs and MRI (3.2 mo in our study *vs*. 1 mo in Lee's study). Lee *et al*[13] also reported that MRI tended to underestimate the values for standing radiographs by approximately 10° when compared directly. However, the underestimation of coronal Cobb angles by supine MRI ranged from 4.6° to 8.2° compared with standing radiographs in the current study. Additionally, previous studies demonstrated that supine MRI could also serve as a valid alternative option to standing radiographs in the measurements of sagittal spinal alignments.[8,14] In the present study, the supine MRI trended to underestimate the TK for 4.5° and the LL for 6.0°, respectively, though the linear correlation were significant. The underestimations of TK and LL in our study were lower than the results reported by Bernstein *et al*.[8]

To investigate in more depth the linear correlation between Cobb angles measured on standing radiographs and supine MRI, we divided the coronal Cobb angles into mild, moderate, and severe groups. Our results demonstrated that the correlation coefficients were more reliable in the severe group than in the mild and moderate groups (R^2= 0.0627, 0.2118, and 0.7999 for mild, moderate, and severe groups, respectively). In addition to the measuring error averaging 5°, the supine MRI should be more feasible to be used in patients with AIS with severe Cobb angles. Deviren *et al*[17] demonstrated that flexibility of the structural curvature inversely correlated with curve magnitude. Higher curve magnitude significantly correlated with worse spinal flexibility in idiopathic scoliosis. We thought that the relatively worse spinal flexibility could also be used to explain our results that the correlation of Cobb angles measured on standing radiographs and supine MRI were more satisfactory in severe groups. For those patients with AIS with mild and moderate Cobb angles, using the supine MRI as an alternative to standing radiographs should be careful though statistical significance could be found. However, we thought the supine MRI was still of great help for the assessments of mild and moderate Cobb angles. In addition, the values of adjusted R^2 in the current study were 0.4889 and 0.3832 for TK and LL, respectively. Bernstein *et al*[8] concluded that supine MRI could added up the accuracy for the assessment of the postoperative spinal alignment, which was supported by our study.

Moreover, the intra- and interobserver reliabilities analysis demonstrated that the highest intra- and interobserver reliabilities occurred in the severe group both on standing radiographs and supine MRI, which further supported our conclusion that the supine MRI should be more feasible to be used in patients with AIS with severe Cobb angles.

As an alternative to radiographs for monitoring the change of Cobb angles, MRI not only avoided the harmful ionizing radiation, but also provided a better vision of the neurological elements as well as other soft tissues.[18,19] Supine MRI also showed its superiority for severe scoliosis with vertebral wedging and rotation. For those obese patients whose endplates were invisible in radiographs, whereas MRI could clearly show landmarks for measurements in these occasions. However, there were several disadvantages that limited the wide use of supine MRI in the assessment of spinal alignment. Though satisfied linear correlation between standing radiographs and supine MRI was found in those patients with AIS with severe Cobb angles, the correlative relationship still could not reach total one-to-one. Similar to previous studies,[8,12–14] some significantly wider discrepancies between standing radiographs and supine MRI could be observed on the scatter plots (Figures 2–5). We speculated that the wider discrepancies could be due to the variation in spine flexibility, time interval between standing radiographs and supine MRI, influence of rapid linear growth, and other factors. As standing radiographs remains the "gold standard" for the assessments of spinal alignments, the treatment strategies for these patients with AIS would rely mostly on the standing full-length PA, lateral and bending radiographs. Besides, the linear correlations in patients with AIS with mild and moderate Cobb angles were not as good as those with severe Cobb angles. For some patients with AIS, the supine MRI alone will lead to the uncertain evaluation of the curvature. Another important limitation of using supine MRI to evaluate Cobb angles lies on its incapability of evaluating both coronal and sagittal spinal balance. Moreover, the cost and time cost are of great challenge for supine MRI to become a routine tool for management of AIS. In addition, the potential risks of anesthesia or sedation, especially in younger patients, significantly limit its clinical use.

Several limitations should be addressed in this study. The sample size was not large enough, especially in the severe group, though significant linear correlation was identified. The relatively long time intervals between standing radiographs and supine MRI was another weakness of this study. Moreover, the curve patterns included single thoracic/lumbar curve and double-main curve, which were not unified. Nevertheless, our study, for the first time, demonstrated that the supine MRI was more feasibly adapted to those patients with AIS with severe Cobb angles in the monitoring the changes of curvature.

CONCLUSIONS

In conclusion, the Cobb angles measured on supine MRI were significantly linearly correlated with the Cobb angles measured on standing radiographs in patients with AIS. The linear correlation was more reliable in those patients with AIS with Cobb angles more than 40°. Therefore, the supine MRI could also serve as a reliable alternative to standing radiographs in the assessment of Cobb angles more than 40° in patients with AIS and provides additional information of the 3-dimensional deformity and images of the surrounding soft tissues and the central nervous system.

➢ Key Points

- ❑ Supine MRI has been considered as a radiation-free alternative to standing radiographs in the measurement of Cobb angles and linear correlation has been identified. However, the effects of different body position, curve type, and curve severity on the correlation have not been studied in depth.
- ❑ We found that Cobb angles measured on supine MRI were significantly linearly correlated with the Cobb angles measured on standing radiographs in AIS. The linear correlation was more reliable in those with Cobb angles more than 40°.
- ❑ Our conclusion is that supine MRI could serve as a reliable alternative to standing radiographs in the assessment of Cobb angles more than 40° in AIS and provides additional information of 3-dimensional deformity, images of surrounding soft tissues and central nervous system.

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