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DIAGNOSTICS

Is Radiation-Free Diagnostic Monitoring of Adolescent Idiopathic Scoliosis Feasible Using Upright Positional Magnetic Resonance Imaging?

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Study Design. Prospective clinical trial.

Objective. The purpose of this study was to determine if an upright positional magnetic resonance imaging (MRI) protocol could produce reliable spinal curvature images and measurements compared with traditional radiograph.

Summary of Background Data. Concerns about the oncological potential from cumulative doses of ionizing radiation in children and adolescents being monitored for adolescent idiopathic scoliosis (AIS) initiated a search for radiation-free diagnostic imaging modalities, including MRI. We submit that upright, positional MRI (uMRI) produces reliable spinal curvature images compared with traditional radiograph.

Methods. Twenty-five consecutive patients (16 female; 9 male; average age, 14.6 yr; range, 12–18 yr) with a diagnosis of AIS were enrolled. Average major curve magnitude was 30° (range, 6°–70°). Subjects received anterior-posterior and lateral plain radiographical scoliosis imaging followed within 1 week by uMRI. MRI data acquisition was performed in less than 7 minutes. Two independent observers performed all Cobb angle, T5–T12 kyphosis, and vertebral rotation measurements for comparison. The Pearson correlation method was performed to compare radiograph to uMRI measurements, while inter-rater and intrarater correlations were performed to assess reliability.

Results. We found outstanding correlation between all plain film radiography and uMRI measurements ($P = 0.01$); major Cobb angles (R = 0.901), minor Cobb angles (R = 0.838), and kyphosis (R = 0.943). Inter-rater reliability for both radiographical and MRI measurements of major Cobb angles (R = 0.959, 0.896, respectively), minor Cobb angles (R = 0.951, 0.857, respectively), and vertebral rotation (R = 0.945) were outstanding. Intrarater reliability for both radiographical and MRI measurements of major Cobb angles (R = 0.966, 0.966, respectively) and minor Cobb angles (R = 0.945, 0.943, respectively) were also outstanding.

Conclusion. Our results show that uMRI is capable of producing coronal and sagittal plane measurements that highly correlate with traditional plain film radiographical measurements. This, in addition to reliable vertebral rotation measurements, makes uMRI a valuable, radiation-free alternative/substitute for diagnostic evaluation in AIS.

Key words: adolescent idiopathic scoliosis, diagnostic imaging, upright MRI, monitoring AIS, radiation-free. **Spine 2013;38: 576–580**

Scoliosis is a 3-dimensional, rotational deformity of the spinal column that in most cases does not have an identifiable etiology and is termed idiopathic scoliosis. Left untreated, spinal curvatures may continue to progress to cause significant morbidity related to impaired pulmonary function, low back pain, and poor self-esteem and self-appearance.[1–8] The guidelines dictating conservative and surgical treatment, which have been extensively studied during the past 3 decades, rely heavily on the quantification of the curve magnitude and classification of curve type. Curve magnitude and classification are assessed at frequent intervals (typically 4–6 mo) during childhood and, in particular, during the growth spurt until skeletal maturity, using plain film radiography.[2]

While plain film diagnostic radiography remains essential to manage and treat children (and adults) properly with spinal deformities, there is a growing concern regarding the long-term effects that result from multiple low-dose radiation exposures during childhood.[7,9–13] A recent study of 5466 women with scoliosis who were initially diagnosed and treated before age 20 years evaluated the risk of mortality from breast cancer. The mean age at diagnosis was 10 years, and the average follow-up was 40 years. An average of 24.7 radiographical examinations took place for each patient during that time. The authors found that the risk of mortality from breast cancer was significantly elevated (odds ratio 1.69, 95% confidence intervals 1.3–2.1) in women who had undergone multiple diagnostic radiographical examinations for scoliosis, and that the risk increased significantly with increasing radiation

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exposure and number of radiographs taken.[13] Other studies have confirmed that radiation exposure at a young age may also increase the risk for later morbidity.[9,11,14,15]

In response, researchers have evaluated numerous radiation-free imaging modalities to provide information about spinal curve magnitude. Such measures have included surface topographical measures, electromagnetic topographical techniques, noninvasive structured light modalities, among others.[16–21] Although radiation free, these measures are fraught with limitations including inability to visualize the bony architecture, provide precise or reproducible curve magnitude measurements, no ability to assess vertebral body rotation, inability to evaluate anything other than the main structural curve, and inability to evaluate the sagittal profile. The search continues for a noninvasive, radiation-free imaging tool that can provide useful information to help clinicians appropriately manage and care for patients with spinal deformities.

Recently, dynamic upright MRI that has been studied extensively in the degenerative lumbar and cervical spine, has been developed (Fonar, Melville, NY). Visualizing the spine in different postures has been shown to increase the sensitivity dramatically of the detection of several degenerative spinal conditions, including cervical disc herniation, cervical stenosis, lumbar instability, and lumbar stenosis.[20–26] In the past year, a special MRI protocol modification has been developed, enabling the entire spinal column to be imaged using the upright MRI. It is now possible to use the dynamic upright MRI to scan patients with spinal deformities, thereby providing *in vivo* assessment of spinal curve magnitudes, sagittal alignment, rotational/axial spine measurements, and intervertebral disc health. This assessment provides radiation-free comprehensive spinal imaging, but no study has evaluated the feasibility or efficacy of this technique in comparison with the "gold standard," plain film radiographical measurements. If upright MRI is found to be equivalent or superior, this technology has the potential to change the way that diagnostic scoliosis monitoring is performed.

MATERIALS AND METHODS

Study Design

This was a prospective study. All enrolled patients were recruited at the investigator's clinic. Radiographs were obtained at the surgeon's office, whereas MRI scans were performed at a facility in Melville, New York (Fonar Inc.).

Patient Selection

Following Institutional Review Board approval and statistical power analysis, 25 consecutive patients undergoing evaluation for adolescent idiopathic scoliosis (AIS) were recruited for the study. Patients were enrolled using an Institutional Review Board-approved consent and/or assent form. The consent form included the purpose of the study, a description of the study, costs and reimbursements, potential risks and discomforts, as well as the primary investigator's contact information. If the patient was a minor, consent was obtained from the patient's guardian. No charge was incurred by the patient or the third-party payer for the MRI.

Data Collection

Each patient underwent plain film diagnostic radiography (standing PA and lateral radiographs), which is standard of care for patients with AIS, and thus did not require any additional radiographical imaging for the purpose of this study. Patients were then asked to receive a dynamic upright MRI (uMRI) of the spine at Fonar Inc., facility (Melville, New York) within 1 week of obtaining their standing radiographs. Patients were positioned in the uMRI machine with their upper arms straight at their sides and their forearms bent to 90°. A secured rest that the patient could hold on to was provided (Figure 1). This position was similar to that used for obtaining radiographs. MRI data was acquired using a steady-state gradient echo 3D pulse sequence. The 2 volumes were stitched together for multiplanar reconstruction analysis. Patient movement resulted in unsatisfactory image quality for 3 patients; these scans were repeated, resulting in 53 total scans for the 25 patients.

Major and minor Cobb angles, T5–T12 kyphosis and vertebral rotation were measured by 2 researchers on 2 separate occasions. Vertebral rotation was measured, *via* axial uMR images, for the apical plus 1 or 2 vertebra above and below for 5 patients with the largest major Cobb angles. (*Note*: vertebral rotation was only measured on uMR images.) All measurements were made in duplicate on separate occasions with all patient identifiers removed.

Data Storage

Data was deidentified and entered into a password-protected computer. Only the investigators and research assistants had

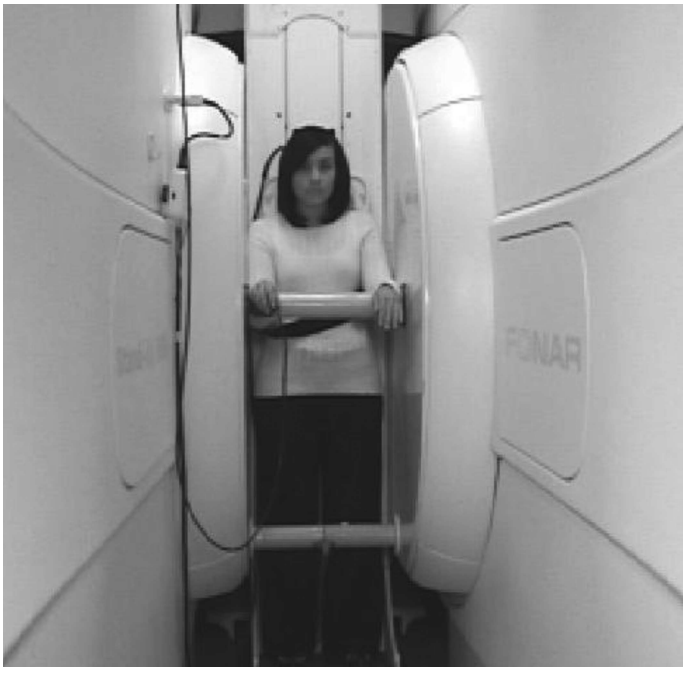

Figure 1. Positional magnetic resonance imaging machine.

TABLE 1. Patient Demographics

Patient	Sex	Age	Major Cobb	Minor Cobb	Kyphosis
1	F	14	46	44	32
2	F	17	37	18	25
3	F	15	37	25	33
4	F	14	42	34	30
5	F	14	56	47	14
6	M	15	50	35	8
7	M	16	28	23	32
8	F	12	28	16	34
9	F	15	46	30	26
10	M	13	20	18	13
11	F	13	14		47
12	F	14	19	18	2
13	M	14	27	18	11
14	F	13	71	39	17
15	M	17	11	7	38
16	F	14	52	37	17
17	M	13	21	18	19
18	F	14	10		20
19	F	17	21	19	32
20	M	18	33	13	20
21	F	17	40	24	22
22	M	14	14	8	30
23	F	14	17	8	23
24	M	13	6	2	16
25	F	15	11	9	26

access to the data with patient identifiers. Each subject was assigned a unique number in consecutive order, not derived from any patient identifiers. Images were stored as JPEG files. The average file size was 500 KB and 300 KB for radiographs and uMR images, respectively.

Data Analysis

Statistics were performed using SPSS version 17.0 software (SPSS, Inc., Armonk, NY). Pearson correlations were used to compare the following measurements between the 2 different imaging modalities: major Cobb angles, minor Cobb angles, and T5–T12 kyphosis. Intraclass correlation coefficients, using a 2-way model with consistency of single measures, were calculated for interrater and intrarater analysis of both imaging modalities for the following measurements: major Cobb angles, minor Cobb angles, T5–T12 kyphosis, and vertebral rotation.

TABLE 2. Patient Demographic Summary

Number of Patients	N = 25 (9 M, 16 F)
Mean age (range)	14.6 yr (12–18)
Mean major curve magnitude (range)	30.3° (6–70)
Mean T5–12 kyphosis (range)	23.2° (2–47)
Mean axial rotation (range)	18.5° (3.5–35.9)

RESULTS

Patient Demographics

Twenty-five consecutively enrolled patients, 9 males and 16 females, with a mean age of 14.6 (range, 12–18) were seen in clinic for evaluation of AIS. The average major curve magnitude was 30.3° (range, 6°–71°). The average T5–T12 kyphosis magnitude was 23.2° (range, 2°–47°). The average vertebral rotation was 18.5° (range, 3.5°–35.9°) (Tables 1 and 2).

Correlations

The correlation between all plain film radiography and uMRI measurements were outstanding (P = 0.01); major Cobb angles (R = 0.901), minor Cobb angles (R = 0.838), and kyphosis (R = 0.943). The interrater reliabilities for all radiographical and uMRI measurements of major Cobb angles (R = 0.959, 0.896, respectively), minor Cobb angles (R = 0.951, 0.857, respectively), kyphosis (R = 0.960, 0.989), and vertebral rotation (R = 0.945) were outstanding. The intrarater reliability for all radiographical and MRI measurements of major Cobb angles (R = 0.966, 0.966, respectively), minor Cobb angles (R = 0.945, 0.943, respectively), kyphosis (R = 0.881, 0.985, respectively), and vertebral rotation (R = 0.992) were also outstanding (Table 3).

DISCUSSION

There is growing concern regarding the radiation exposure received by children and adolescents for diagnosis and monitoring of scoliosis. The carcinogenic risk of radiation exposure can be modified by several factors. These factors include: amount of exposure, sex (females have found to be more sensitive than males to radiation of the thyroid); age at exposure (younger children are more susceptible to radiation effects than older children); and attained age (given more time to appear, the incidence of cancer increases).[14] The majority of patients experiencing AIS are young females and repeated radiography is needed to monitor progression of the disease. Considering this information, the rise in concern is justified and a radiation-free alternative or substitute for traditional radiographical monitoring should be investigated.

This study investigates the utility of uMRI. When looking at a new technology from a clinical perspective, accuracy and precision are 2 extremely important requirements. Accuracy,

TABLE 3. Correlation and Reliability Values

uMRI/x-ray Correlation*							
Cobb major	0.901						
Cobb minor	0.838						
Kyphosis	0.943						
Inter-rater reliability (intraclass correlation coefficients)							
X-ray Cobb major	0.959	uMRI Cobb major	0.896	X-ray Kyphosis	0.96	uMRI rotation	0.945
X-ray Cobb minor	0.951	uMRI Cobb minor	0.857	uMRI kyphosis	0.989		
Intrarater reliability (intraclass correlation coefficients)							
X-ray Cobb major	0.966	MR Cobb major	0.966	MR axial	0.992		
X-ray Cobb minor	0.945	MR Cobb minor	0.943				
X-ray kyphosis	0.881	MR kyphosis	0.985				

**P = 0.01, Pearson correlation.*

uMRI indicates positional magnetic resonance imaging.

in this case, refers to the comparison of measurements performed using uMRI to measurements using the "gold standard," standing plain film radiography. Precision refers to the reliability of measurements made using uMRI; for both, repeated measurements by the same physician, and measurements made by different physicians. Dynamic upright positional MRI was found to have outstanding correlation with radiography for the following measurements: major Cobb angles, minor Cobb angles, and T5–T12 kyphosis. Additionally, uMRI had outstanding intrarater and interrater reliability for the following measurements: major Cobb angles, minor Cobb angles, T5–T12 kyphosis, and vertebral rotation. This supports the utility of uMRI as an alternative to the current "gold standard."

MRI technology allows for evaluation of radiological information not available on traditional plain film radiographs. It is possible to view and assess axial plane images (Figure 2). Vertebral rotation of a scoliotic curve can then be visualized and measured. The vertebral rotation measurements had outstanding reliability; however, comparison with a radiographical equivalent was not attempted. Additionally, the advancement of MRI technology to allow upright positional imaging confers the value of visualizing the patient's deformity in its true environment. The change in structure and positioning seen on typical supine MR images is eliminated. Traditional supine MRI is also time consuming (30–45 min per scan) and expensive ($1500+ depending on the institution or facility). The uMRI is done in less than 7 minutes and for fewer than $200. This can be compared with the cost of obtaining a radiograph, approximately $165 for standing PA/lateral radiographs.

Despite the benefits and encouraging results, there are several limitations to this study and uMRI in general. Although all the correlations were statistically significant, only 2 researchers evaluated the images, made measurements, and were compared. Ideally, and possibly in future analyses, there would be 4 to 5 physicians performing the evaluations, thus confirming and reiterating the reliability. This study was possible because imaging center was a commutable distance from the investigator's office; however, the current availability

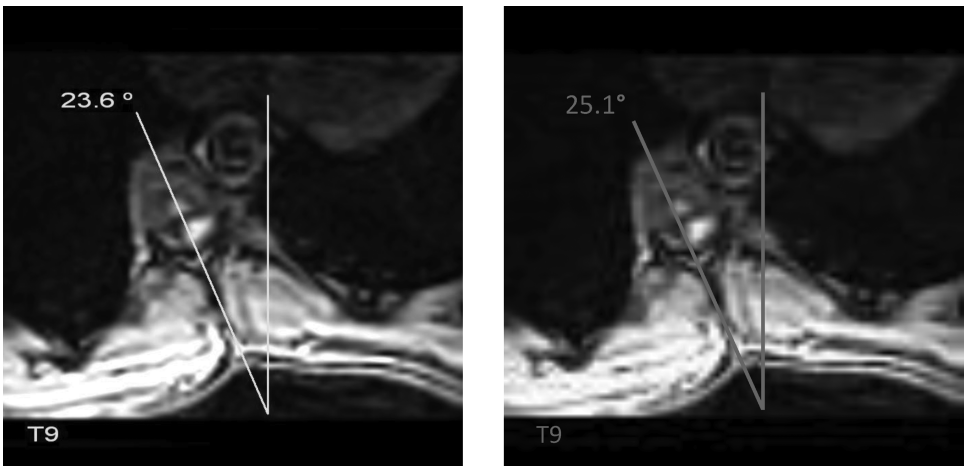

Figure 2. Axial images.

of uMRI machines is low. The availability of the machine is expected to increase exponentially in coming years, especially once their utility is recognized and competition drives their price down. The current cost is similar to traditional MRI machines, approximately 1.5 million, but increased supply will make the machines more accessible and even less expensive.

Several patient specific factors are also a limitation to the use of uMRI. The presence of nonremovable metallic implants and inability to remain relatively motionless for several minutes continuously are absolute and relative contraindications, respectively, to uMRI. Our patient recruitment took place in a preoperative clinic and there were no patients excluded for metallic implants. Several uMRI were repeated due to patient movement; however, there were no patients excluded from the study secondary to inability to remain motionless for the 3.5-minute intervals needed to acquire the scan. A condition resulting in inability to remain motionless would prevent a patient from being eligible for uMRI.

The results of this study are the first to demonstrate that uMRI is capable of producing reliable coronal and sagittal plane measurements that highly correlate with traditional plain film radiographical measurements. In addition, the reconstruction capabilities of MRI allow for axial views of the vertebrae for rotational measurement. The uMRI allows for upright, physiological positioning that provides a more accurate assessment of the patient's deformity. At less than 7 minutes per scan, the time constraints existent with traditional MRI are obviated. In the future, these scans are anticipated to be more readily available, making it a more feasible option for patients as well as driving down the already low cost of $200 per scan. Furthermore, the utility of the scan may be enhanced once uMRI is capable of providing truncal/rib cage deformity visualization and analysis. Dynamic upright positional MRI is a valuable, radiation-free alternative for diagnostic evaluation in AIS.

➢ Key Points

- ❑ Concerns about the oncological potential from cumulative doses of ionizing radiation in children and adolescents being monitored for AIS initiated a search for radiation-free diagnostic imaging modalities, including MRI.
- ❑ Our results show that uMRI is capable of producing coronal and sagittal plane measurements that highly correlate with traditional plain film radiographical measurements, while also allowing for evaluation of vertebral rotation.
- ❑ Radiation-free uMRI evaluation for AIS is performed safely, quickly, and may be an alternative for ionizing imaging techniques.

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