Spine Deformity
www.spine-deformity.org

Spine Deformity 3 (2015) 151−158

Intra- and Inter-rater Reliability of Coronal Curvature Measurement for Adolescent Idiopathic Scoliosis Using Ultrasonic Imaging Method—A Pilot Study

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Received 7 March 2014; revised 15 August 2014; accepted 25 August 2014

Abstract

Study Design: Retrospective reliability study of the coronal curvature measurement on ultrasound (US) imaging in adolescent idiopathic scoliosis (AIS).
Objectives: To determine the intra- and inter-rater reliability and validity of the coronal curvature measurements obtained from US images.
Summary of Background Data: Cobb angle measurements on radiographs are the usual method to diagnose and monitor the progression of scoliosis. Repeated ionizing radiation exposure is a frequent concern of patients and their families. Use of US imaging method to measure coronal curvature in children who have idiopathic scoliosis has not been clinically validated.
Methods: The researchers scanned 26 subjects using a medical 3-dimensional US system. Spinal radiographs were obtained on the same day from the local scoliosis clinic. Three raters used the center of lamina method to measure the coronal curvature on the US images twice 1 week apart. The raters also measured the Cobb angle on the radiographs twice. Intra- and inter-rater reliability of the coronal curvature measurement from the US images was analyzed using intra-class correlation coefficients. The correlation coefficient of the US coronal curvature measurements was compared with the Cobb angles.
Results: The intra-class correlation coefficient (2,1) values of intra- and inter-rater reliability on the US method were greater than 0.80. Standard error of measurement on both of the intra- and inter-rater US methods was less than 2.8°. The correlation coefficient between the US and radiographic methods ranged between 0.78 and 0.84 among 3 raters.
Conclusions: The US method illustrated substantial intra- and inter-rater reliability. The measurement difference between radiography and the US method was within the range of clinically acceptable error (5°). The US method may be considered a radiation-free alternative to assess children with scoliosis of mild to moderate severity.

Keywords: AIS; Coronal curvature; Ultrasound imaging; COL method; Cobb angle

Introduction

Adolescent idiopathic scoliosis (AIS) is a 3-dimensional (3D) deformity of the spine characterized by lateral curvature of the spine and vertebral rotation. It occurs in approximately 3% of adolescents and is especially prominent in females [1]. The Cobb angle [2] measured on standing posterior-anterior radiographs is the reference standard to diagnose and monitor AIS. It also has an important role in

Author disclosures: RZ (none); ACYC (none); WC (none); DLH (none); LHL (none); DH (none); MM (none); JM (none); SS (none); EL (none).

This work was supported by the Women's and Children's Health Research Institute and the Edmonton Orthopaedic Research Society.

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2212-134X/$ - see front matter © 2015 Scoliosis Research Society.
http://dx.doi.org/10.1016/j.jspd.2014.08.008

determining curve progression, treatment options, and assessment of treatment outcome [3-5]. Some studies [6,7] have focused on the intra- and inter-rater reliability of the Cobb angle measurement. It has been reported that measurement errors of the Cobb method based on radiographs are within the range of 3° to 7° [6,7], and usually 5° is considered as a clinically acceptable error as well as the threshold of determining curve progression [2,8].

Although the Cobb method is the most widely used technique in a scoliosis clinic, exposure to ionizing radiation is a significant concern for both patients and their families. These children may require multiple radiographs annually during long-term follow-up, which has been reported to increase risk of breast cancer in female patients [9,10]. Therefore, alternative methods have been investigated to decrease or overcome the potential harm of radiation.

Among many imaging modalities, ultrasound (US) imaging is a promising radiation-free method for scoliosis studies [11-24]. Suzuki et al. [11] identified the spinous processes and laminae on each of the vertebra on US spinal images. They reported that these 2 anatomic landmarks parameters could be used to quantify axial vertebral rotation, which was correlated with the Cobb angle. Furness et al. [12] attempted to use US imaging to identify lumbar intervertebral spaces for anesthetic techniques; they reported that 71% of the lumbar intervertebral spaces were identified correctly. Burwell et al. [13-17] applied US to measure axial vertebral rotation and rib rotation in prone positions. They also reported that repositioning the patient significantly altered measurements. One reasons was that the applied US machine did not have the sensor to track the position and orientation of the transducer. The prone position may also affect spinal deformity measurements.

For the direct measurement of spinal curvature, Li et al. [18,19] used US imaging to determine the optimal location of pressure pads in spinal braces during the brace-fitting process. Instead of using the Cobb angle to quantify the severity of scoliosis, they used the spinous process angle, which they reported was highly correlated with the Cobb angle ($R = 0.98$; $p < .01$) [19]. As a result, 62% of patients (13 of 21 patients) in that study benefited from US assistance. In the US spinal images, the end plates of each vertebra are difficult to identify owing to the acoustic shadowing of posterior structures. Chen et al. [20,21] conducted multiple studies to determine alternative vertebral landmarks that could be used to measure the angle of the tilted vertebrae on the coronal plane [20,21]. They reported that the center of laminar (COL) measurement method on US images was highly correlated with the Cobb angle from radiographs. A pilot study with 5 AIS subjects was performed. The mean absolute difference (MAD) and standard deviation (SD) of measurements between the US and the corresponding radiographs were 0.7 ± 0.5. Cheung et al. [23] developed a freehand 3D US imaging system to assess scoliosis. Based on a series of B-mode ultrasound images (the spatial information and visible vertebral landmarks, ie, spinous process, transverse articular process, and/or superior process), they were able to form a 3D spine model. Their 3D spine model was then projected onto a 2D coronal plane to measure the Cobb angle. The study was validated on a spine phantom with 16 severity configurations. A strong correlation ($R^2 = 0.76$) between the Cobb angle measurements of the radiographic images and US system was obtained, and the intra- and interobserver correlations were 0.99 and 0.89, respectively. Recently, Ungi et al. [24] used the same US system as that of the current authors to measure spinal curvature by using transverse processes as vertebral landmarks. They reported that the MAD ± SD of the differences between the curvature measurements on adult and pediatric spines from the US and the phantoms were 1.27° ± 0.84° and 0.96° ± 0.87°, respectively.

As seen from the literature, although in vitro US measurements have been investigated, in vivo US measurements of spinal deformity have not been fully validated. Therefore, the objectives of this study were to compare the reliability and determine the validity of coronal curvature as measured from standing US images against those measured from standing radiographs on pediatric subjects who have AIS.

Methods

Clinical subjects

The researchers recruited 26 adolescent (22 female and 4 male; mean age, 13.9 ± 2.1 years) who met the following inclusion criteria for the reliability study: 1) they were diagnosed with AIS; 2) they had no prior surgical treatment; 3) they had out-of-brace radiographs on the study day; and 4) the major curve was in the range of 10° to 45°. The time frame of the study was between August and October, 2013. The local health research ethics board granted ethics approval and all participating subjects signed a written consent before being enrolled into the study.

Data acquisition

During the scoliosis clinic visit, each subject was first examined with a posterior-anterior standing radiograph and had a US scan performed within an hour. All US scans were acquired by the same pair of technicians. The US scan was obtained using the SonixTABLET system equipped with 128-element C5-2/60 GPS transducer and the SonixGPS system (Analogic Ultrasound - BK Medical, Peabody, Massachusetts, USA). The applied scan frequency was 2.5 MHz and the penetration imaging depth was set at 6 cm. The gain was set to 10% with linear time gain compensation. The full spine range from C7 to L5 was scanned with the subject in a standing position. Acquisition time was less than 1 minute. Figure 1 shows the subject being scanned using the US device. After scanning, the acquired data were