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CASE SERIES

Intra- and inter-rater reliabilities and differences of kyphotic angle measurements on ultrasound images versus radiographs for children with adolescent idiopathic scoliosis: a preliminary study

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Abstract

Purpose To develop a new method based on 3D ultrasound information to measure the kyphotic angle (KA) on ultrasound (US) images in adolescents with idiopathic scoliosis (AIS) and to evaluate the intra-rater and inter-rater reliabilities and accuracy of the US measurements.

Methods Twenty subjects with AIS (17F, 3 M, aged 13.7 ± 2.2 years old) were recruited. One 20 + years experienced rater (R3) measured the KA on radiographs twice using the Cobb method. Two raters (R1, R2), both have at least 1-year experience measured US images twice using the new spinous processes method. The intraclass correlation coefficients (ICC[2,1]) of the intra-rater and inter-rater reliabilities of US KA measurements were calculated. An equation based on US KA measurements to calculate the radiographic KA was generated.

Results The intra-rater reliability ICC[2,1] (R3) of the X-ray measurement was 0.92 and US KA measurements for R1 and R2 were 0.94 and 0.95, respectively. The inter-rater reliability ICC[2,1] for R1 versus R2 were 0.85 and 0.86, respectively. The mean absolute differences (MAD) of US versus radiography measurements were 4.2 ± 3.0° (R1 vs R3) and 5.0 ± 4.1° (R2 vs R3), respectively. The radiographic equivalent KA = 0.82 × US KA – 5.6°. When using this equation, the overall MAD between US and radiographic KA was 2.9 ± 1.6°.

Conclusions The ultrasound spinous process method was reliable to measure the KA. Although there was a systematic bias on the US measurements, after the correction, the MAD of the US and radiographic KA was 2.9 ± 1.6°. Using US allows clinicians to monitor KA without exposing children to ionizing radiation.

Keywords Adolescent idiopathic scoliosis · Ultrasound · Kyphotic Angle · Reliability · Accuracy

Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional (3D) spinal condition characterized by lateral curvature and vertebral rotation. It has no known cause and primarily affects girls aged 10–18 years old. The current gold standard to diagnose and monitor AIS is to measure the Cobb angle on standing posteroanterior (PA) radiographs [1]. Currently, the clinically accepted error for the Cobb angle measurement is 5° and the definition of curve progression is indicated by increments of 6° [2] on the Cobb angle. According to the Scoliosis Research Society, the recommended treatments are observation, orthotic treatment (bracing), and surgery [2–4], and most of the scoliosis centers use the value of the Cobb angle to make treatment recommendations. However, treatment decision based solely on the Cobb angle measured on PA radiographs may fail to account for the 3D nature of AIS,

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an issue which is only recently being addressed according to the International Scientific Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) guidelines. According to SRS recommendation, patients who have hyperkyphosis or hypokyphosis should continue be monitored. In addition, SOSORT also recommends using physiotherapy techniques or bracing to treat thoracic hyperkyphosis [5].

Scoliotic and kyphotic angles are generally measured from standing radiographs. There are only few studies have addressed the reliability and repeatability of KA measurements. This is due to the inconsistencies in vertebral selection, making comparisons between measurements difficult. Among all the KA measurement approaches, there were studies using the Cobb method to measure the superior endplate of T1 and inferior endplate of T12 [6–12]. A study by Carman et al. measuring KA found that an 11° difference in KA was accepted to rule out measurement error with 95% confidence [9]. Ohrt-Nissen et al. found an intra-rater reproducibility of 9° and inter-rater reliability of 13° [12].

However, the frequency of taking lateral (LAT) radiographs exposes children with AIS to higher ionizing radiation than PA radiographs, which increases lifetime cancer risk [13]. Even though the EOS Imaging machine is recently available in many scoliosis centers and the ionizing radiation dosage is reduced, the clarity of identifying the endplates of vertebrae at the upper thoracic region is still a challenge. Ultrasound (US) imaging is a radiation-free alternative that has been used to successfully measure the Cobb angle and the axial vertebral rotation (AVR) on standing PA and transverse views [14–19], respectively. The elimination of radiation in monitoring scoliosis is particularly appealing to the patients and their families. As a single US scan of the spine can provide information on all three planes: PA (Cobb), transverse (AVR) and lateral (KA), it may help to measure the KA more reliably. Recently, Lee et al. also used US to measure the sagittal curvature. However, their method only used the sagittal information. Similar to the US PA view, the endplates of vertebrae are invisible in the lateral view, and so an alternate method to measure sagittal deformity must be developed. The objectives of this study were to (1) present a new method to measure KA based on 3D US images, (2) determine the intra-rater and inter-rater reliabilities of the KA measurement, and (3) determine the inter-method accuracy in comparison to the Cobb method measured from radiographs.

Methods

Clinical subjects

Twenty subjects (17F, 3 M, aged 13.7 ± 2.2 years old, range 10–17 years old) were recruited in this study from a local scoliosis clinic. The inclusion criteria were subjects who were (1) diagnosed with AIS, (2) Cobb angle ≤ 50°, (3) required out of brace PA and sagittal radiographs, and (4) had no prior surgical treatment. The Cobb angle of ≤ 50° was chosen, which can eliminate patients who have large axial vertebral rotation, to make sure laminae are visible on the ultrasound images. Ethics approval was obtained from the local health research ethics board and written consents were obtained from all subjects prior to data acquisition.

Data acquisition

Standing out of brace PA and LAT radiographs and an US scan were obtained from each subject on the same day, with the US scan following the radiographs within 1 h. The PA and LAT radiographs were acquired simultaneously using the EOS system (EOS Imaging, Paris, France) with subjects standing in a standard posture: subjects look forward without tilting their heads and their hands placed on the front chamber wall of the EOS system. Both hands were placed approximately at the chest height. US images were acquired using the Sonix TABLET medical US system equipped with a 128-element C5-2/60 GPS convex transducer (Analogic Ultrasound—BK Medical, Peabody, Massachusetts, USA). This system recorded the orientation and location of the transducer to capture the 3D information of the spine. Prior to scanning, the spinous processes of C7, L5 and all vertebrae in between were palpated, identified, and marked on the skin. Ultrasound gel was applied to the skin and the surface of the ultrasound probe. The two points, C7 and L5, determined the region of the spine to be scanned. Each US scan started at the C7 vertebra and terminated at L5, with the transducer positioned perpendicular to the subject's back and moved at a constant rate along the path of the curve. Each US scan acquisition lasted for less than 1 min. During the scan, each subject was positioned in the middle of a wooden frame to standardize their posture and to minimize movement. The subject's standing posture was similar to that used in the EOS (radiograph) chamber with the hands placed at chest height and holding the wooden pole of the standing frame. The hips and the shoulder were also positioned in the same plane in a neutral standing position to minimize movement of the subject during the scan. The US data, which consisted of signal strength and position information, were processed with an in-house developed program, Medical Imaging Analysis System (MIAS). Combining a stack of ultrasound B-mode images with position and orientation, 2D images in three-different views, coronal, transverse and sagittal plane, were displayed automatically as shown in Fig. 1a–c. The US operator has 3 years of experience to acquire good US spinal images. This software allows users to zoom in and out the image, adjust the contract and brightness.

Raters

Two raters (R1 and R2) performed ultrasound KA measurements. R1 and R2 had 2 years and 1 year of experience measuring KA on US LAT images, respectively. R3 who had over 20 years of experience on radiographs measurement measured the KA on the corresponding radiographs. Prior to the study, both R1 and R2 measured an extra 10 LAT US images from previous patients' records as a training set to obtain a mutual measurement agreement. These ten measurements were not used for analysis.

Data measurements

The KA on both radiographs and US images were measured using the MIAS program. All raters were blinded to the clinical information and measured twice on the assigned images. R3 measured the KA from the radiographs while R1 and R2 measured the KA from the US images. The radiographs and US images were randomly coded with numbers. The second US measurement (M2) was measured 1-week apart from the first measurement (M1) to minimize recall bias. On LAT radiographs, the Cobb method was applied. During the measurements, all raters were permitted to adjust contrast, brightness and magnification. For the radiography measurement, two lines were then drawn parallel to the top endplate of T1 and bottom endplate of T12, and the MIAS program would display the value automatically.

On US images, the centres of lamina (COL) of T1–T3 and T10–T12 vertebrae are first identified on the PA view (Fig. 1a). The six spinous process (SP) was then identified in the transverse view (Fig. 1b) which was more precise than the PA view. The SP would automatically display in the sagittal view, where its location could be fine-tuned (Fig. 1c). The identification of T3 and T10 were only used to confirm the trend of the spinal curve. The MIAS program also automatically displayed the KA calculated using the intersection of a line connecting the SP of T1 and T2 and another line connecting the SP of T11 and T12. The program calculated the acute angle formed by the intersection of these two lines, which was taken to the proxy KA.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics v23 software (IBM, Armonk, New York, USA). The mean and standard deviation (SD) of the KA measurements on both radiographs and US images from all three raters were reported. The intra- and inter-rater reliabilities of the US KA measurements were calculated using the intraclass correlation coefficient [ICC(2,1)] with a two-way random model and absolute agreement with a confidence interval of 95%. The inter-rater reliability was determined by comparing the measurements made by both raters (R1 and R2) with two different measurements (M1, M2). The accuracy of the US measurements was analyzed by comparing the radiographic measurements with US measurements. The ICC value was considered excellent (≥ 0.90), good (0.75–0.90), moderate (0.5–0.75), or poor (< 0.5) reliability based on Koo's report [20]. The mean absolute difference (MAD) and standard error of the mean (SEM) [21] were determined for the intra-rater, inter-rater and inter-method analyses. The inter-method of inter-rater comparison was calculated to report the measurement differences. Bland–Altman analyses

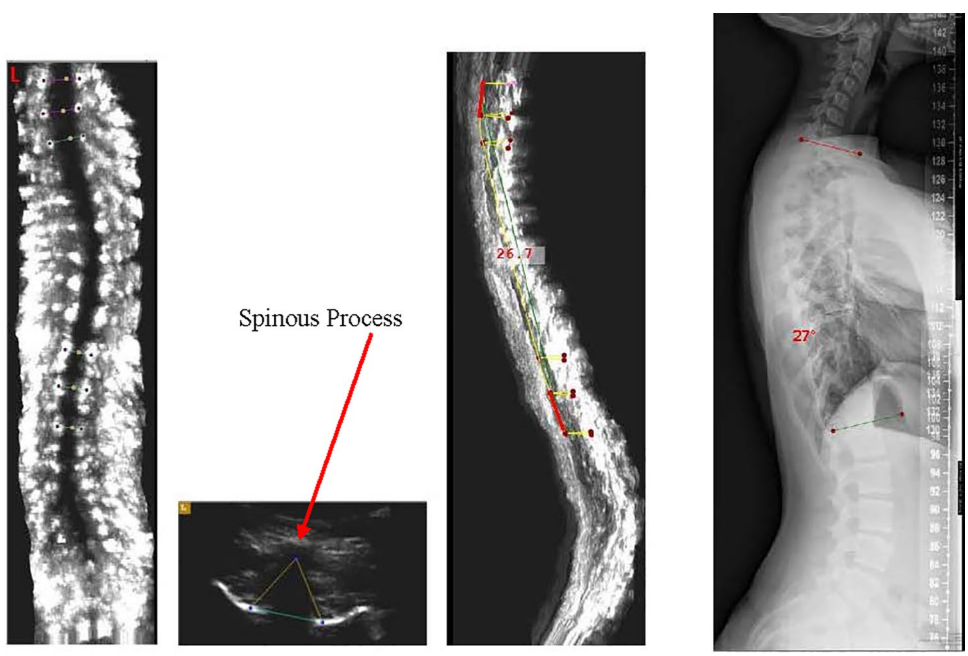

Fig. 1 **a** An ultrasound image showing a coronal PA view of spine with T1–T3 and T10–T12 identified on the image, **b** an US transverse view of T1 with the laminas identified and joined using a line and the midpoint of the line as the spinous process, **c** US sagittal view of spine and the kyphotic angle measured 27° using the slope of a line joining spinous process of T1 and T2 of top to T11 and T12 of bottom, **d** the sagittal view X-ray of the spine correspond to the same patient and the kyphotic angle measured using the Cobb method as 27°

Table 1 KA measurement means, standard deviations, and range on radiographs and US images ($n=20$)

	M1 (°)	M2 (°)
R1 (US)	40 ± 10 (22–56)	37 ± 12 (11–58)
R2 (US)	41 ± 11 (18–59)	39 ± 13 (17–60)
R3 (Radiograph)	38 ± 10 (16–56)	36 ± 12 (17–55)

R rater, *M* measurements

Table 2 The intra-rater reliability of the US KA measurements ($n=20$)

	MAD ± SD (°)	SEM (°)	ICC[1, 2]
R1 (US)	3.1 ± 1.7	0.4	0.94
R2 (US)	3.2 ± 2.3	0.5	0.95
R3 (Radiograph)	3.0 ± 2.2	0.5	0.92

R Rater, *MAD* mean absolute difference, *SD* standard deviation, *SEM* standard error of the mean, *ICC* intraclass correlation coefficient

were also performed. An equation between the US KA and the radiographic KA value was generated based on all rater 1 and 2 US measurements.

Results

Among the 20 subjects, 10 subjects were under observation and they were in their initial visits. Another ten subjects were under brace treatment and they were in those clinics that their braces were first prescribed. The major Cobb angle of the subjects ranged from 13° to 41° (25° ± 8°) and KA from radiography ranged from 16° to 56° (38° ± 10°). A total of 20 KAs were measured on both radiographs and US images. Table 1 summarizes the mean, standard deviation, and the range of the KA measurements by each rater (R1, R2, R3). Table 2 shows the MAD ± SD, SEM and the intra-rater reliability (ICC[1,2]) of the KA measurements of R1, R2 and R3. All 3 raters have excellent reliability (ICC[1,2] ≥ 0.92). Table 3 compares the inter-rater reliability on both US KA measurements (R1 vs R2). The ICC values showed good reliability (> 0.85), and there was no statistically significant difference on the measurements ($P < 0.05$). Table 4 shows the inter-method comparison between R1 vs R3 and R2 vs R3. The results from both US raters R1 and R2 at different measurement sessions M1 and M2 compared with the radiography rater R3 at the first measurement session M1 showed similar as all the SEM values were under 1.7° and the ICC[1, 2] values were > 0.84.

Figure 2 shows a comparison between the R1 and R2 M2 (US measurements) vs. R3 M1 (radiographic measurement). Both R1 and R2 showed the US KA always overestimated.

Table 3 The inter-rater reliability for KA measurements on both US and radiographs ($n=20$)

Image Modality	MAD ± SD (°)	SEM (°)	ICC[1, 2]
R1 vs R2—M1 US	4.2 ± 4.6	1.8	0.85
R1 vs R2—M2 US	4.8 ± 4.2	1.6	0.86

Table 4 The inter-method comparison and reliability of the KA measurements from both raters (n = 20)

Variable	MAD ± SD (°)	SEM (°)	ICC[1, 2]
R1 M1 vs R3 M1	4.2 ± 3.0	1.1	0.87
R1 M2 vs R3 M1	3.9 ± 2.9	0.9	0.90
R2 M1 vs R3 M1	5.0 ± 4.1	1.7	0.84
R2 M2 vs R3 M1	4.1 ± 3.9	1.3	0.88

The variability was smaller when the KA values were larger. The US measurements of both raters were averaged and plotted against the average radiographic KA measurements by both raters. A linear equation of the radiographic KA = 0.82 × US KA – 5.60° was generated, which can be used to convert the US KA to its radiographic equivalent. When using this equation to assess the accuracy of the US measurements, the overall MAD between US and radiographic KA was 2.9 ± 1.6°.

Figure 3 shows the Bland–Altman analyses for R1 X-ray versus the second US measurement and the same repeated for R2. R1 demonstrates less bias than R2 between the two types of measurements, with a scatter that indicates moderate overestimation but all points within 1.96 standard deviations about the mean. R2 showed a systematic overestimation of larger values of KA than R1, confirming the results found in Fig. 2.

Discussion

To understand the 3D nature of scoliosis, the Cobb angle on the coronal view, the axial vertebral rotation on the transverse view, and the KA on the sagittal view should be measured at each clinic. However, due to the increase of cancer risk in taking an extra radiograph, most orthopedic surgeons decide not to take the LAT radiograph in the follow-up clinic unless patients complain about back pain. Although the low dose X-ray system (EOS) has become common, clinicians and parents are still concerned about the accumulated ionizing radiation. The US method has been introduced and it has been demonstrated that it can measure the Cobb angle and vertebral rotation reliably, but it has not been developed for kyphotic measurement using the 3D information. From the literature, Carman et al. reported that, without fixing the end

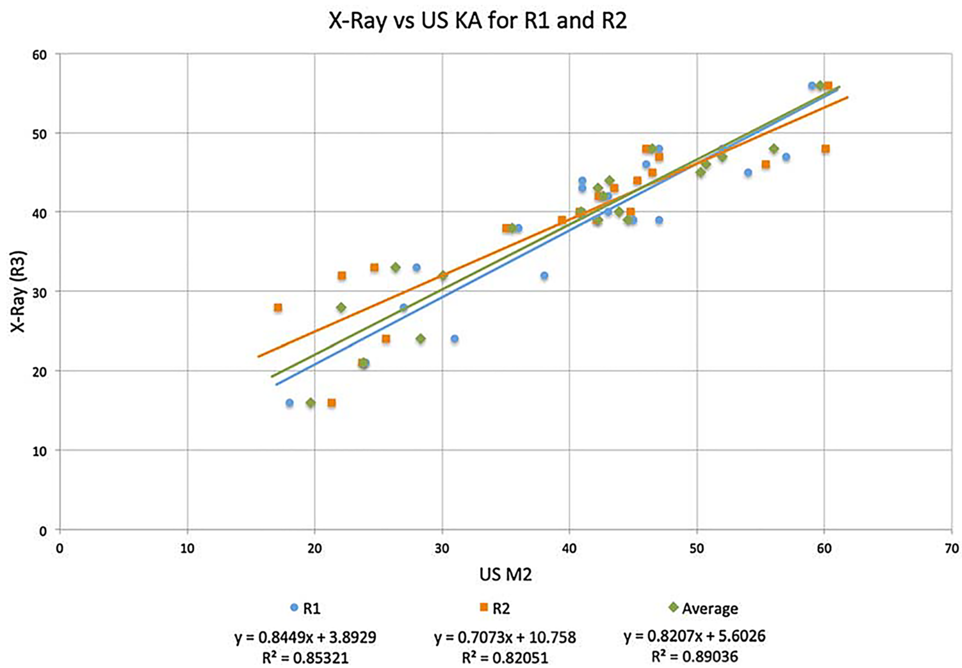

Fig. 2 Inter-method comparison between the radiographic measurements and US measurements from both raters (R1 and R2) and the average of both raters with R^2 indicating the correlation coefficient of each set of measurements

vertebrae to measure the KA, the measurement difference could be as large as an 11° difference in between consecutive measurements of the same subject [9]. Also, there is no standard clinically accepted error in KA measurements. The KA measurement differences between the inter-rater and the inter-method on both raters (Tables 3 and 4) ranged from 3.9° to 4.8°, which showed very little difference, indicating that kyphotic angle measurements from both radiographs and US images are similar.

A limitation in assessing the relevance of the data acquired in this study is the wide variety of methodology used in determining thoracic kyphosis (TK), including but not limited to a range of radiographic parameters (T1–T12, T2–T12, T5–T12, and non-fixed endplate methods), computer-assisted methods, and surface topography [5, 9, 12, 22, 23]. While the T1–T12 method is the most commonly reported, for both ease of comparison of the degree of kyphosis between subjects, and also for its relevance in capturing the entirety of the global TK. Of course, it has some radiograph-specific drawbacks such as the difficulty in visualizing the T1 vertebra on a conventional X-ray system due to the overlap of the shoulder girdle in some subjects [6–10, 12]. However, the LAT radiograph acquires from the EOS system does not have this difficulty, it is because the orthogonal direction of the radiographic beam and the image signal treatment. This limitation does not exist in US images, because the vertebral selection and the COL identification on both coronal and transverse planes are shown clearly. This makes T1 clearly visible in every US image, and this highlights a key strength of using US images for kyphotic measurements. Additionally, a study [24] has compared different methods based on plumbline measures, using correlation of plumbline distance, or based on video rasterstereography methods to measure kyphosis. These studies only provided fair to good results on reliability, but no direct measurements were reported.

In addition to the lack of consistency measurement method for TK, there are only two studies reported the standard intra-rater and inter-rater reliabilities of the KA measurement based on T1–T12 [11, 12]. Among the two studies [13, 14], Ilharreborde et al. [11] reported an average intra-operator difference of three experienced raters was 6° and an inter-operator reproducibility of 7°. The current study demonstrates similar results. Furthermore, Ilharreborde et al. already used 3D EOS system to capture the TK, which may have more reliable images. Ohrt-Nissen et al. [12] reported the intra-rater and inter-rater reliabilities 0.87 and 0.82, respectively. Our study reported similar or better results on both intra-rater and inter-rater reliabilities while using the US images.

Limitations of our study include (a) the US image quality, which may depend on the skill of the US operator and the length of acquisition time, (b) the identification of the lamina, which requires experience to identify COL on US images, (c) the limited raters of different training levels and d) the limited number of samples and the Cobb angle severity, which may affect the generated equation for mild and moderate curves only. However, the advantage of the US images is the ability to view the spinal images in all three-dimensional views (coronal, transverse, and sagittal). This eliminates the difficult of only observing on the sagittal view. Furthermore, as this is the only known study to measure KA directly from US images, the

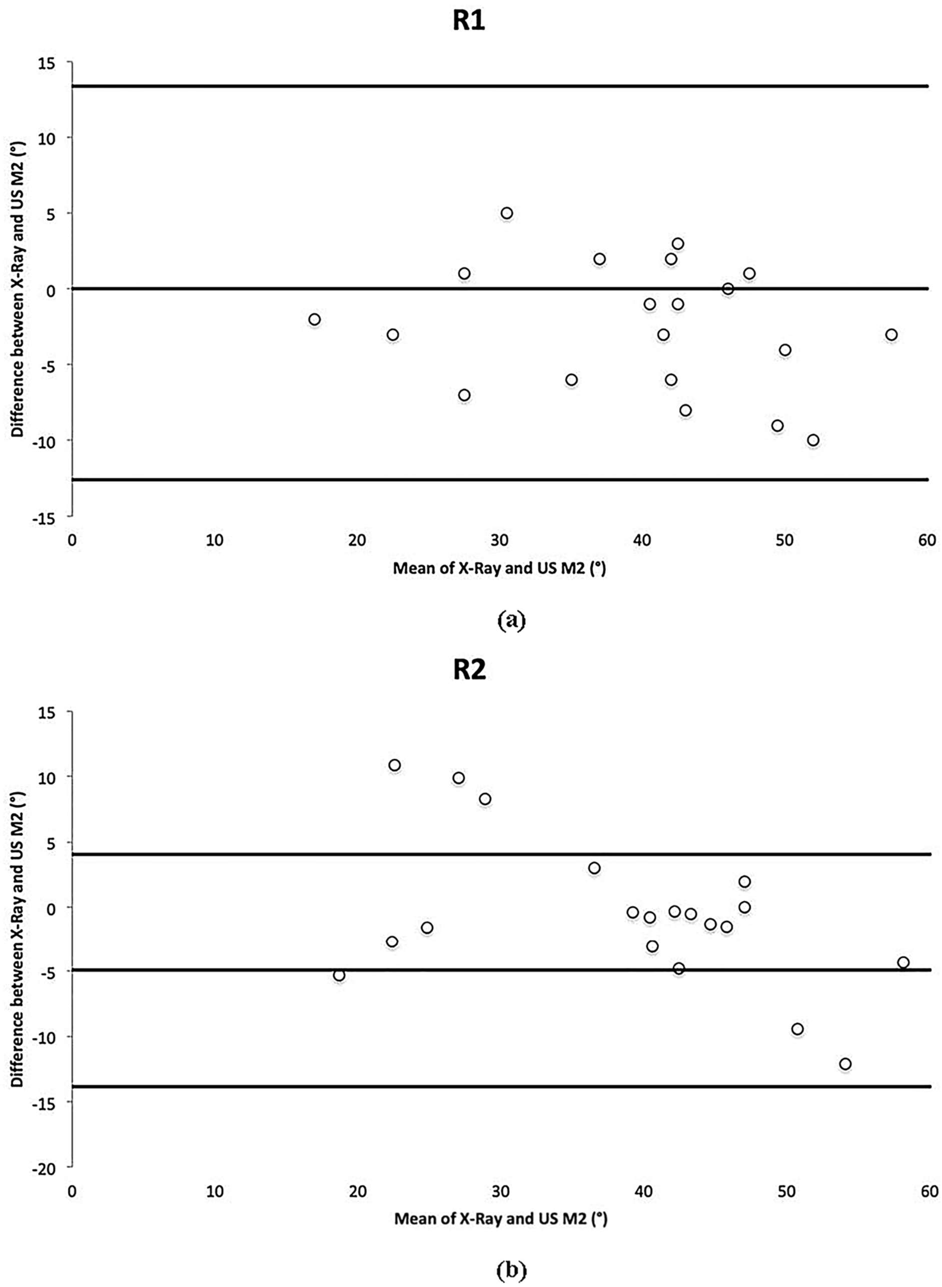

Fig. 3 The Bland–Altman plot of mean and ± 1.96 standard deviations of the mean of radiographic and US measurements versus the differences between the radiographic and US measurements for **a** Rater 1 and **b** Rater 2

reduction of exposing children to extra ionizing radiation can be made. In this study, the EOS micro-dose protocol is used in the follow-up clinic. The radiation dosage for a medium size of spine is 0.0513 mSv for EOS system, but it is 9.92 mSv for the conventional X-ray system.

Conclusions

The intra-rater and inter-rater reliabilities of the KA measurements on US images can be performed reliably and the measurement differences are within the clinical accepted range. Also, the average differences of the KA measurements between the US images and radiographs is 4°, which shows no significant difference on repeat KA measurements from radiographs. However, since the number of study cases is small, a larger clinical trial is needed to validate the US method can be applied to scoliosis clinics.

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Author contributions TS, MK, DH, EL: made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data; or the creation of new software used in the work. TS, MK, DH, EL: drafted the work or revised it critically for important intellectual content. MK, DH, EL: approved the version to be published. MK, DH, EL: agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Availability of data and materials Data will be available upon request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declared that there is no conflict of interest.

Ethics approval Ethics approval was granted by the University of Alberta Health Research Ethics Board.

Consent to participate All participants and their guardians signed the assents and parental consent forms prior to participation.

Consent for publication Patients signed informed consent regarding publishing their data and photographs.

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