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ORIGINAL ARTICLE

Cobb angle measurement with a conventional convex echography probe and a smartphone

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Abstract

Background context Serial X-rays are needed during the follow-up of adolescent idiopathic scoliosis. They are done every 6 or 3 months in cases of high risk of progression. Thanks to the advances in ultrasound techniques, deformity measurement systems free from ionizing radiations have been validated, although spinal surgeons did not use them routinely due to the need of special software.

Objective The aim of our work is to assess the reproducibility and correlation of an ultrasound measuring system based on the positioning of the transverse processes.

Study design Prospective, single center, randomized, triple blinded.

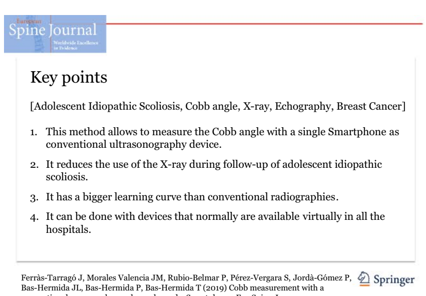
Methods Two independent researchers trained in ultrasound examined the spinal deformities of 31 children. The measurements were compared against those performed with an X-ray by three scoliosis expert surgeons. Statistics were performed by an independent researcher. Parametric methods were used.

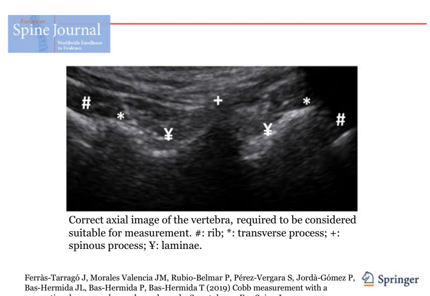
Results We found a 95% [(0.91–0.97) $p < 2.2e^{-16}$] correlation between the degree of scoliosis measured with the proposed ultrasound system and the 30 cm × 90 cm X-rays in standing position. There was an intra-observer reliability of 97% [r-squared = 0.97; CI 95% (0.95–0.98) $p < 2.2e^{-16}$] and an inter-observer reliability of 95% [r-squared = 0.95; CI 95% (0.90–0.97) $p < 2.2e^{-16}$].

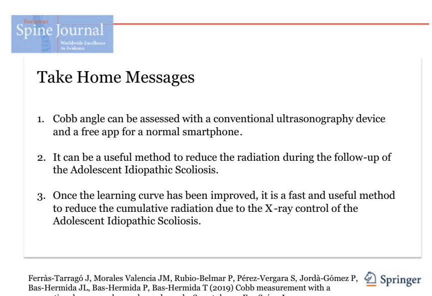
Conclusions An approximation of the Cobb angle measure is possible with ultrasound by using the transverse processes as reference. This is a very rapid and simple system for assessing the principal spinal deformity measure in young people, although it does not allow estimating the associated axial or sagittal rotation.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Adolescent idiopathic scoliosis · Cobb angle · X-ray · Echography · Breast cancer

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Extended author information available on the last page of the article

Introduction

Adolescent idiopathic scoliosis (AIS) is a progressive three-dimensional spinal deformity with prevalence in 0.47–5.2% of the population and is up to three times more frequent in women than in men [1, 2]. It occurs between the ages of 11 and 18 years and accounts for 90% of idiopathic scoliosis in children [2].

The Cobb angle is the most important factor in the classification of the deformity and in the selection of treatment [3–5]. It is also the fundamental element in the classification of the major curve according to Lenke in AIS and SRS-Schwab in adult scoliosis, whose classification system and recommendations are the most widely used today [6, 7]. When the surgical criteria are established, it is essential to take into account other parameters such as shoulder height, dynamic radiographs, the central sacral vertical line (CSVL), and the sagittal alignment [8]. However, there is no obligation to monitor these parameters during follow-up, since a curve is considered progressive when it increases 5° [9, 10].

Due to the pathology's progression, it is necessary to perform 30 cm × 90 cm serial radiographs to control deformity every 6–12 months depending on the severity of the deformity, since an advancement of this condition may require a change in treatment from expectant to conservative or surgical [11]. An accelerated growth phase occurs at the age of 11 in girls and 13 in boys, which may require an increase in radiographic controls and is indicated as well in curves of more than 20° in skeletally immature patients (Risser 0–1) [12]. Radiographic controls should be maintained until skeletal maturity is reached, which implies a large amount of accumulated radiation that has been shown to increase cancer mortality in women [13]. In addition, radiographic studies increase the cost of patient care both in the cost of radiographic studies and in the increase in the required spinal consultations.

Due to the risks associated with ionizing radiation and the obligatory nature of radiographic follow-ups, the search for alternative systems for measuring the Cobb angle at follow-up of these patients has been encouraged [14]. This would therefore allow for a better spacing of radiographic controls and a reduction in cumulative radiation, among which the minimum radiation protocols (EOS) [15, 16], the ultrasound assessment models of spinal coronal deformity using specific software [17], and the posterior three-dimensional reconstruction models based on ultrasound [18] are highlighted. Devices such as 3D image topography based on photographic techniques and sensors [19] or percutaneous assessment of the spinous processes [20] have not proven to be useful, leaving ultrasound as the most promising tool at the present time.

The main problem with ultrasound is that it is not able to assess the inclination of the vertebral body, due to the acoustic shadow produced by the posterior column of the spine. Chen et al. [21] described the vertebral posterior references seen through ultrasound and highlighted the importance of the spinous processes, the laminae, and the apophysis or transverse processes. Later, the parallelism that exists between posterior structures of the spine and the vertebral body was demonstrated, with the transverse processes showing a greater correlation [22]. The spinous processes are perpendicular to the vertebral body in healthy patients, but in patients with scoliosis these suffer an alteration in their normal morphology, due to the forces of tension to which they are subjected during the three-dimensional rotation of the vertebral body. This phenomenon does not occur in the laminae, which move together with the body [22].

Alternative processes to the radiographic ones for the calculation of the Cobb angle based on the capturing of later images of the vertebrae and their volumetric reconstruction have been described, but no system that allows the measurement of the Cobb angle with a conventional ultrasound device has been outlined. The main reason for this is that the Cobb angle involves the assessment of the coronal deformity of one vertebra with respect to another that is too far away to be captured in the same conventional ultrasound image. Therefore, the devices that have been designed are based on the reconstruction from multiple ultrasound images, which require special equipment and software. All this makes the technique more expensive and limits the accessibility of most centers, thereby reducing its applicability. Our goal is to develop and validate a Cobb angle measurement system using a conventional ultrasound device and a conventional smartphone, without the need for specific devices.

Materials and methods

Statistical method

In this cross-sectional study, after selecting patients who met the inclusion criteria ($n = 97$), randomization was achieved through the use of a random number system until the estimated needed number of patients was obtained ($n = 35$), in order to standardize the type of the curve and to avoid selection bias. The inclusion criteria were: patients between 10 and 18 years diagnosed with AIS, presenting curves, 1 month before the ultrasonographic measurement, lower than 45°, and who could autonomously maintain a standing position. In this way, we ensure that there was no significant progression in the curve between the X-ray and ultrasonographic measurements.

The required sample size was calculated for a statistical significance level of 0.05 and a beta error of 0.2, with an expected patient loss of 15% and a *d* value of 0.2, to analyze the agreement percentage between the observers (Cohen's kappa analysis).

The degree of concordance between the radiographic and ultrasound (Mindray DC-70 Exp. ultrasonographic device; Samsung S8 Smartphone device; app Level of Google Commerce Ltd) measurements was analyzed using the Cohen kappa correlation test. Agreement between the measurements of the two investigators (JFT and PJG) occurred when the measure of the angle on the ultrasound showed an error of 5°, since this is the clinically relevant error according to the literature [10]. The relationship between the Cobb angle and the angle obtained by the ultrasound technique described was analyzed, using a Pearson correlation system (R Foundation for Statistical Computing 3.3.1, 2016).

The Cohen kappa test was preferred to analyze the agreement [23], and it was assumed to be almost perfect when it was higher than 90% [24].

The ultrasound measurement was blinded for radiographic measurement, and vice versa. X-ray measurement was considered the mean between three measures by independent spine surgeons. The statistical results were analyzed by a triple-blinded independent researcher.

The study was approved by the Medical Ethics Committee of the institution.

Ultrasound measurement method

The objective of the method is to obtain an ultrasound image that contains both transverse processes. In a healthy patient, this image is achieved by placing the transducer perpendicular to the longitudinal axis of the spine, since it is in the same direction as the vertebral body, the laminae, and the transverse processes (Fig. 1). When the ultrasound is not perfectly parallel to the laminae and the vertebral body, only one of the two transverse processes can be observed (Fig. 2).

An apparatus was made to be able to attach a smartphone to the ultrasound transducer, and a 0° balance reading was taken prior to the ultrasound measurement. That way when the ultrasound was placed completely perpendicular to the longitudinal axis of the spine, the inclinometer would read 0°. Thus, when the ultrasound transducer was rotated clockwise/counterclockwise, the degrees of inclination being applied were visible. Hence, in a normal vertebra, the obtaining of the image described was achieved without having to rotate the ultrasound transducer, and the transducer inclination was 0°. When a rotation occurs in the coronal plane, the tilting of the transducer to obtain the image described is necessary, and the degrees necessary to tilt it are equal to the degrees of inclination that a vertebra presents in relation to the horizontal.

This process was carried out for upper and lower end vertebrae previously examined during the first ultrasound visit. Each presented a degree of inclination in an opposite direction, so to obtain the image described the transducer had to be tilted clockwise in one and counterclockwise in the other. By adding the absolute values of the degrees with respect to the horizontal of both vertebrae, the total inclination of one vertebra in relation to the other was obtained, which is a measurement comparable to the Cobb angle (Fig. 3).

Fig. 1 Reference image that must be obtained to measure the Cobb angle. #: rib; *: transverse process; ¥: lamina; +: spinous process

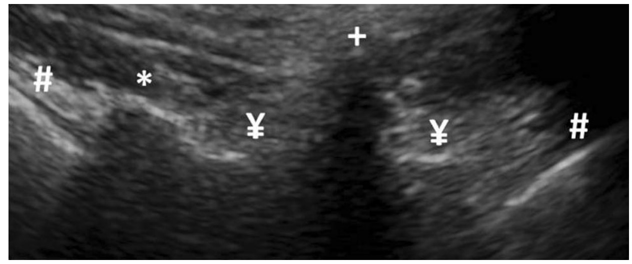

Fig. 2 In this picture, the right transverse process is not seen, and it must be improved before measuring the Cobb angle

Results

The agreement between radiography measurement and ultrasound measurement was very high [Cohen's kappa = 0.93; CI 95% (0.86–0.97 $p = 0.023$].

The ultrasound measurement was strongly correlated with the radiographic measurement [r-squared = 0.957; CI 95% (0.91–0.97) $p < 2.2e^{-16}$] (Fig. 4). The intra-observer reliability was very high [r-squared = 0.97; CI 95% (0.95–0.98) $p < 2.2e^{-16}$] (Fig. 5). The inter-observer reproducibility was high [r-squared = 0.95; CI 95% (0.90–0.97) $p < 2.2e^{-16}$] (Fig. 6). There was a very little disagreement between the PI and the Co-I. We did not have any difference superior to 5° between the first and the second measure of the PI. The mean age was 14, 87 years (SD = 2.17) with a normal distribution (Shapiro–Wilk $p = 0.1$). The mean Cobb angle in the echography group was 25.83 (SD = 9.84) with a normal distribution (Shapiro–Wilk $p = 0.48$), and in the radiography

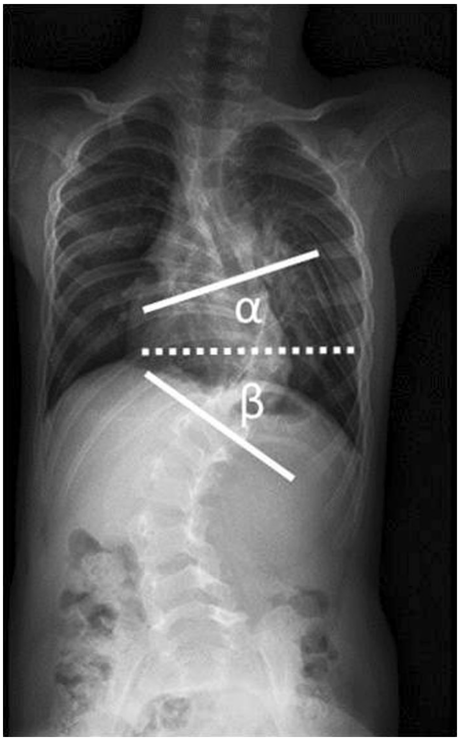

Fig. 3 The Cobb angle is the absolute value of the sum of the inclination of the upper end vertebra and the lower end vertebra regarding the ground level

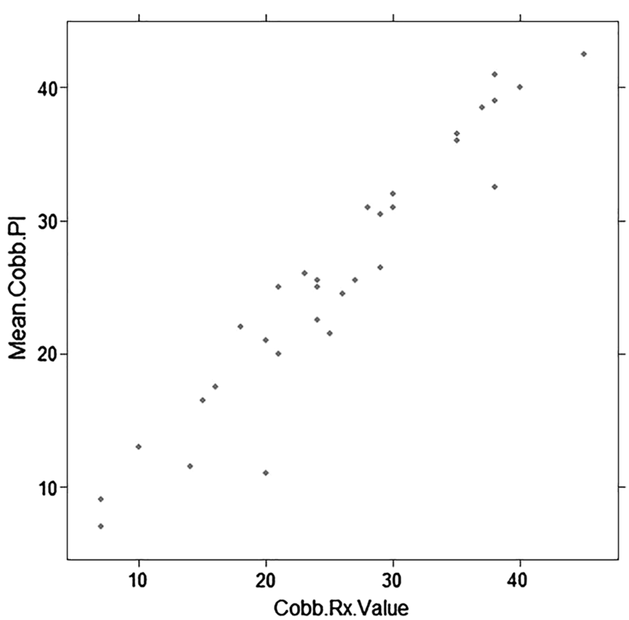

Fig. 4 Agreement between X-ray and ultrasonography measurements of the Cobb angle

group, it was 25.61 (SD = 9.78) with a normal distribution (Shapiro–Wilk $p = 0.75$). For this reason, parametric statistical tests were used.

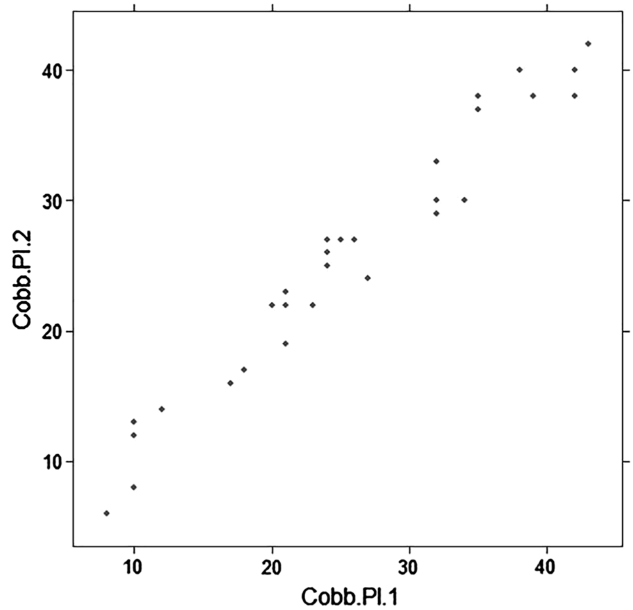

Fig. 5 Intraobserver reliability

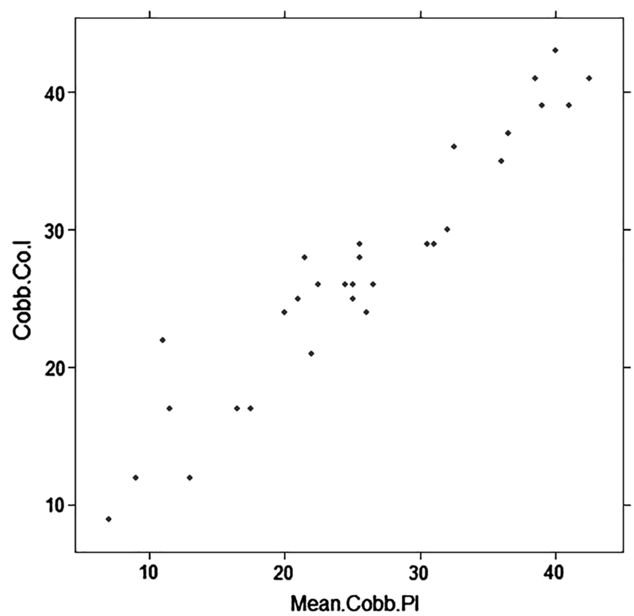

Fig. 6 Interobserver reliability

The study ended when the necessary number of predefined patients was obtained in the study ($n = 31$). Eighty-seven percent were women and 13% were men. There was a total loss of four patients after randomization that did not come to the hospital to be measured with the ultrasonographic method for personal reasons.

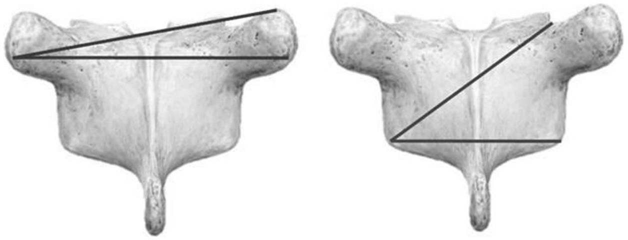

Fig. 7 The transverse processes are more reliable than the laminae to assess the inclination of the vertebra with the Center of Lamina (COL) theorem

Discussion

This Cobb angle is the frame of reference used during therapeutic decision making at present and is the parameter most measured during the follow-up. Although the definitive treatment does not depend solely on the Cobb angle, the progression of the deformity in the axial and sagittal planes without alterations in the coronal plane is rare in AIS. Therefore, the absence of changes in the coronal deformity is a good element to use to be able to monitor the deformity in the rest of planes [25–27].

It is not possible to capture an image of the two end vertebrae with a normal ultrasound image. Therefore, in order to obtain the relative coronal inclination of one vertebra in relation to the other, a common reference point must be established. This study uses the horizontal as a pivot point, since by means of a conventional digital inclinometer the inclination of a conventional ultrasound transducer in relation to this horizontal can be obtained.

When observing an ultrasound image that contains both transverse processes in the thoracic vertebrae, or both transverse apophyses in the lumbar vertebrae, a view of an axial section of the vertebra is obtained, and our ultrasound needs to be parallel to the vertebral body to get it. Thus, to obtain a similar image in a vertebra with inclination in the coronal plane, we must tilt our ultrasound transducer the same number of degrees that the vertebra presents, while the inclinometer or the smartphone indicates the measurement in degrees. By performing this maneuver in both vertebrae, the inclination of each of the vertebrae in relation to the horizontal is ascertained, and by adding their absolute values, the relative inclination of both end vertebrae is reached, which is comparable to the Cobb angle.

To be able to carry out this process, it is essential to first obtain a control X-ray of the end vertebrae. Once the end vertebrae are defined with X-ray, we locate the last rib. This rib will finish medially next to T12 transverse process. Then, we can locate our end vertebra counting backward or forward locating the transverse processes of the upper and lower vertebrae.

Fig. 8 Clinical scenario of the method application

It is possible to perform the same procedure without previous radiography as a screening system, but it requires more time since the assessment of the inclination of all the vertebrae must be carried out beforehand and this procedure is both expensive and slow.

The success of measuring correctly is based on obtaining a good ultrasound image that allows a view of both transverse processes. The reason for using this anatomical reference and not the laminae, as described in other studies, is that they are narrower and more lateral elements. Therefore, the tangent formed between the lowest point and the highest point of the transverse processes is smaller than that formed in laminae, especially at the level of the thoracic vertebrae. The smaller the tangent of this angle, the lower the risk of error, which would occur when obtaining an image of the two transverse processes, but where the lower limit of one and the upper limit of the other are observed (Fig. 7).

This method has a reduced reliability with curves greater than 45°, since a severe deformity in the axial plane favors the anterior displacement of the transverse processes, which limits ultrasound access and makes it difficult to obtain the necessary image to verify the correct position of the transducer. Even so, when the curve exceeds 45°, it is necessary to evaluate other parameters more carefully such as axial rotation and sagittal balance, for which radiography is essential. Therefore, in the case of identifying a progression in the deformity that approaches the limits that would indicate a change in therapeutic treatment, it would be convenient to perform a conventional radiographic study in order to measure other modifiers that would allow for the optimization of the surgical indication.

Still, this system allows for a significant reduction ionizing radiation in the follow-up of non-surgical AIS curves, which ensures good reproducibility and reliability of the results. Also this system maintains intra-observer and inter-observer variability similar to that obtained with the radiographic measurements of our study, which coincides with the bibliography [17, 25].

One of the main problems, however, of this method is the learning curve of the ultrasonography. It is necessary to measure the angle just when the perfect axial image is obtained; otherwise, it could be wrong. Also, although studies have shown that free smartphones apps have a great sensibility to measure inclination [28], more studies are needed to verify our method with specific apps (Fig. 8). In addition, the patient needs to be very collaborative to perform the measurement properly, and the doctor must verify clinically that the patient is properly standing when the measure is taken in order to avoid postural changes that modify the real Cobb angle value.

Finally, it must be assumed that the end vertebra can change during the follow-up. To avoid this error, we recommend studying the concomitant vertebrae to the previously known end vertebra. If the end vertebra has changed, the upper or the lower vertebrae closer to the end vertebra must be more tilted than the previous end vertebra. In that case, the most tilted vertebra must be assumed to be the new end vertebra.

To sum up, this system reduces the ionizing radiation during the follow-up of children with adolescent idiopathic scoliosis without a conventional ultrasound device and a smartphone app. A conventional ultrasound device is readily available in virtually all hospitals, and although they are not normally in the doctor's box, they are easily available in the hospital, and most doctors have smartphones that are compatible with a digital inclinometer. Hence, the proposal of this low-radiation system as highly applicable for clinical use for measuring the Cobb angle in incipient AIS.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Kamtsiuris P, Atzpodien K, Ellert U, Schlack R, Schlaud M (2007) Prevalence of somatic diseases in German children and adolescents. Results of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS). Bundesgesundheitsblatt Gesundh Gesundh 50(5–6):686–700
2. Konieczny MR, Senyurt H, Krauspe R (2013) Epidemiology of adolescent idiopathic scoliosis. J Child Orthop 7(1):3–9
3. Negrini S, Donzelli S, Aulisa AG, Czaprowski D, Schreiber S, de Mauroy JC et al (2018) 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis Spinal Disord 13:3
4. Uno H, Wei L-J, Hughes M (2014) Effects of bracing in adolescents with idiopathic scoliosis. N Engl J Med 370(7):680
5. Negrini S, Negrini F, Fusco C, Zaina F (2011) Idiopathic scoliosis patients with curves more than 45 Cobb degrees refusing surgery can be effectively treated through bracing with curve improvements. Spine J 11(5):369–380
6. Lenke LG (2005) Lenke classification system of adolescent idiopathic scoliosis: treatment recommendations. Instr Course Lect 54:537–542
7. Terran J, Schwab F, Shaffrey CI, Smith JS, Devos P, Ames CP et al (2013) The SRS-Schwab adult spinal deformity classification: assessment and clinical correlations based on a prospective operative and nonoperative cohort. Neurosurgery 73(4):559–568
8. Trobisch PD, Ducoffe AR, Lonner BS, Errico TJ (2013) Choosing fusion levels in adolescent idiopathic scoliosis. J Am Acad Orthop Surg 21(9):519–528
9. El-Hawary R, Chukwunyerenwa C (2014) Update on evaluation and treatment of scoliosis. Pediatr Clin N Am 61(6):1223–1241
10. Lonstein JE, Carlson JM (1984) The prediction of curve progression in untreated idiopathic scoliosis during growth. J Bone Joint Surg Am 66(7):1061–1071
11. Knott P, Pappo E, Cameron M, Demauroy J, Rivard C, Kotwicki T et al (2014) SOSORT 2012 consensus paper: reducing X-ray exposure in pediatric patients with scoliosis. Scoliosis 9:4
12. Jada A, Mackel CE, Hwang SW, Samdani AF, Stephen JH, Bennett JT et al (2017) Evaluation and management of adolescent idiopathic scoliosis: a review. Neurosurg Focus 43(4):E2
13. Law M, Ma W-K, Lau D, Chan E, Yip L, Lam W (2016) Cumulative radiation exposure and associated cancer risk estimates for scoliosis patients: impact of repetitive full spine radiography. Eur J Radiol 85(3):625–628
14. Presciutti SM, Karukanda T, Lee M (2014) Management decisions for adolescent idiopathic scoliosis significantly affect patient radiation exposure. Spine J 14(9):1984–1990
15. Newton PO, Khandwala Y, Bartley CE, Reighard FG, Bastrom TP, Yaszay B (2016) New EOS imaging protocol allows a substantial reduction in radiation exposure for scoliosis patients. Spine Deform 4(2):138–144
16. Morel B, Moueddeb S, Blondiaux E, Richard S, Bachy M, Vialle R et al (2018) Dose, image quality and spine modeling assessment of biplanar EOS micro-dose radiographs for the follow-up of in-brace adolescent idiopathic scoliosis patients. Eur Spine J 27(5):1082–1088
17. Khodaei M, Hill D, Zheng R, Le LH, Lou EHM (2018) Intra- and inter-rater reliability of spinal flexibility measurements using ultrasonic (US) images for non-surgical candidates with adolescent idiopathic scoliosis: a pilot study. Eur Spine J 27:2156–2164
18. Zheng Y-P, Lee TT-Y, Lai KK-L, Yip BH-K, Zhou G-Q, Jiang W-W et al (2016) A reliability and validity study for Scolioscan: a radiation-free scoliosis assessment system using 3D ultrasound imaging. Scoliosis Spinal Disord 11:13
19. Oxborrow NJ (2000) Assessing the child with scoliosis: the role of surface topography. Arch Dis Child 83(5):453–455
20. Knott P, Mardjetko S, Nance D, Dunn M (2006) Electromagnetic topographical technique of curve evaluation for adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 31(24):E911–E915 **(discussion E916)**

21. Chen W, Le LH, Lou EHM (2012) Ultrasound imaging of spinal vertebrae to study scoliosis. Open J Acoust 2(3):95–103
22. Homans J (2018) How do different ultrasound measurements of the scoliotic spine relate to the Cobb angle? A CT based study? In: Global spine congress
23. Fleiss L, Cohen J (1973) The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. Educ Psychol Meas 33:613
24. McHugh ML (2012) Interrater reliability: the kappa statistic. Biochem Med 22(3):276–282
25. Villemure I, Aubin CE, Grimard G, Dansereau J, Labelle H (2001) Progression of vertebral and spinal three-dimensional deformities in adolescent idiopathic scoliosis: a longitudinal study. Spine (Phila Pa 1976) 26(20):2244–2250
26. White AA 3rd (1971) Kinematics of the normal spine as related to scoliosis. J Biomech 4(5):405–411
27. Morrison DG, Chan A, Hill D, Parent EC, Lou EHM (2015) Correlation between Cobb angle, spinous process angle (SPA) and apical vertebrae rotation (AVR) on posteroanterior radiographs in adolescent idiopathic scoliosis (AIS). Eur Spine J 24(2):306–312
28. Naziri Q, Detolla J, Hayes W, Burekhovich S, Merola A, Akamnanu C et al (2018) A systematic review of all smart phone applications specifically aimed for use as a scoliosis screening tool. J Long Term Eff Med Implants 28(1):25–30

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