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ORIGINAL ARTICLE • SCOLIOSIS - CONGENITAL

# Reliability analysis of Cobb angle measurements of congenital scoliosis using X-ray and 3D-CT images

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**Abstract**

*Purpose* Therapeutic decisions for congenital scoliosis rely on Cobb angle measurements on consecutive radiographs. There have been no studies documenting the variability of measuring the Cobb angle using 3D-CT images in children with congenital scoliosis. The purpose of this study was to compare the reliability and measurement errors using X-ray images and those utilizing 3D-CT images.

*Materials and methods* The X-ray and 3D-CT images of 20 patients diagnosed with congenital scoliosis were used to assess the reliability of the digital 3D-CT images for the measurement of the Cobb angle. Thirteen observers performed the measurements, and each image was analyzed by each observer twice with a minimum interval of 1 week between measurements. The analysis of intraobserver variation was expressed as the mean absolute difference (MAD) and standard deviation (SD) between measurements and the intraclass correlation coefficient (IaCC) of the measurements. In addition, the interobserver variation was expressed as the MAD and interclass correlation coefficient (IeCC).

*Results* The average MAD and SD was 4.5° and 3.2° by the X-ray method and 3.7° and 2.6° by the 3D-CT method. The intraobserver and interobserver intraclass ICCs were excellent in both methods (X-ray: IaCC 0.835–0.994 IeCC 0.847, 3D-CT: IaCC 0.819–0.996 IeCC 0.893). There was no significant MAD difference between X-ray and 3D-CT images in measuring each type of congenital scoliosis by each observer.

*Conclusions* Results of Cobb angle measurements in patients with congenital scoliosis using X-ray images in the frontal plane could be reproduced with almost the same measurement variance (3°–4° measurement error) using 3D-CT images. This suggests that X-ray images are clinically useful for assessing any type of congenital scoliosis

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about measuring the Cobb angle alone. However, since 3D-CT can provide more detailed images of the anterior and posterior components of malformed vertebrae, the volume of information that can be obtained by evaluating them has contributed greatly to the development of strategies for the surgical treatment of congenital scoliosis.

**Keywords** Congenital scoliosis · Cobb angle · Measurement reliability · Intraobserver · Interobserver · X-ray · Computed tomography · Children

## Introduction

The measurement of the Cobb angle is one of the most important parameters when assessing curve severity, and the risk of curve progression in scoliosis patients and measurement on radiographic films is recognized as the gold standard. However, the rapid development of digital technology and software has made it possible to measure the Cobb angle without any film, and this has become a widely accepted method of measurement. Several studies have attempted to assess the intra- and interobserver reliability of Cobb angle measurements using manual techniques with X-ray films or computer software [1–9]. Many of these studies have reported the measurement variability in idiopathic scoliosis; only two report measurement variability in congenital scoliosis [10, 11]. Facanha-Filho and Winter reported that a skilled observer can measure curves in congenital scoliosis with much greater accuracy than previously reported [10]. Measurement of the Cobb angle for congenital scoliosis, especially the mixed failure type, using X-ray images, is still difficult because the deformity is so complicated that it is not easy to define the appropriate end plates of the vertebra to measure the Cobb angle. Moreover, there has been no study of measurement variability in children with congenital scoliosis using 3D-CT images. The purpose of this study is to compare the reliability and measurement errors using X-ray images and those utilizing 3D-CT images for congenital scoliosis.

## Materials and methods

This retrospective study reviewed previously obtained X-ray images (in supine) and 3D-CT images of 20 patients (11 males and nine females) with congenital scoliosis, of which seven were the formation failure type, six were the segmentation failure type, and seven the mixed failure type. Each observer (13 spine surgeons) measured the angle of the major curve of the X-ray and 3D-CT images using available software at their institutions at two different times in random sequence. Each observer identified the proximal and distal end plates independently at each measurement. The first author selected the 3D-CT images to be used for measurements. Observers could repeat their measurements of the images a week after the first measurement. Each observer measured the angle digitally. The secretary of the Chest Wall and Spinal Deformity Study Group randomly numbered the X-ray and CT images from 1 to 40 for the first round of measurements. The same images were again randomly numbered for the second round, to avoid any bias. Observers were blinded to each patient's age, sex, and clinical condition. The digital procedure was conducted by marking the digital X-ray and 3D-CT images with the mouse with a dot at each end of the superior plate of the first vertebra and a dot at each end of the inferior plate of the last vertebra of the major curvature to assess the magnitude (Fig. 1). Each observer used the available software in their institute.

### Statistical analysis

The reliability and variability of Cobb angle measurements using X-ray and 3D-CT images were assessed by comparing intra- and interobserver differences. The analysis of intraobserver variation, individually calculated for each observer, was expressed as the mean absolute difference (MAD) and the standard deviation (SD) between measurements, and the intraclass correlation coefficient (IaCC) of the measurements taken during the two assessments performed by each observer. In addition, the interclass correlation coefficients (IeCC) of the measurements taken during the assessments were performed by the 13 observers in the same manner. The confidence interval of intra- and interclass correlation coefficients for both analyses was calculated to a level of significance of 95 %. Paired $t$ test was used to assess the difference between the variability of X-ray versus 3D-CT images. The data were analyzed using the SPSS® 19.0 software (SPSS Inc. Chicago, Illinois, USA). A $P$ value $<0.05$ was considered to be significant.

## Results

There were a total of 1040 Cobb measurements (20 X-ray images and 20 3D-CT images by 13 observers making two measurements each). The average MAD and SD using X-ray images was 4.5° (1.6°–7.8°) and 3.2° (1.1°–5.5°), respectively. The average MAD and SD using 3D-CT image was 3.7° (1.6°–8.6°) and 2.6° (1.2°–6.0°), respectively. The measurement error of the Cobb angle was significantly reduced using 3D-CT images in four of the 13

**Table 1** Parameters between X-ray and 3D-CT methods

| | MAD/X-ray (°) | MAD/3D-CT (°) | SD/X-ray (°) | SD/3D-CT (°) | *P* value |
|---|---|---|---|---|---|
| Observer | | | | | |
| Observer 1 | 5.0 | 3.2 | 3.5 | 2.2 | 0.098 |
| Observer 2 | 4.6 | 4.7 | 3.3 | 3.3 | 0.962 |
| Observer 3 | 3.6 | 3.4 | 2.5 | 2.4 | 0.805 |
| Observer 4 | 1.6 | 1.8 | 1.1 | 1.2 | 0.707 |
| Observer 5 | 7.8 | 8.6 | 5.5 | 6.0 | 0.566 |
| Observer 6 | 6.1 | 7.4 | 4.3 | 5.2 | 0.177 |
| Observer 7 | 4.2 | 2.8 | 2.9 | 1.9 | 0.362 |
| Observer 8 | 5.3 | 2.7 | 3.7 | 1.9 | 0.007 |
| Observer 9 | 4.1 | 3.2 | 2.9 | 2.3 | 0.438 |
| Observer 10 | 5.4 | 2.9 | 3.8 | 2.1 | 0.002 |
| Observer 11 | 3.8 | 2.1 | 2.7 | 1.5 | 0.005 |
| Observer 12 | 2.9 | 1.6 | 2.3 | 1.5 | 0.040 |
| Observer 13 | 3.6 | 3.3 | 2.6 | 2.3 | 0.684 |

*MAD* mean absolute difference, *SD* standard deviation

**Table 2** Intraobserver analysis between X-ray and 3D-CT

| | X-ray | | 3D-CT | |
|---|---|---|---|---|
| | IaCC | CI of IaCC | IaCC | CI of IaCC |
| Observer | | | | |
| Observer 1 | 0.941 | 0.861–0.976 | 0.969 | 0.924–0.987 |
| Observer 2 | 0.957 | 0.896–0.983 | 0.965 | 0.915–0.986 |
| Observer 3 | 0.965 | 0.916–0.986 | 0.978 | 0.945–0.991 |
| Observer 4 | 0.994 | 0.985–0.998 | 0.996 | 0.991–0.999 |
| Observer 5 | 0.835 | 0.675–0.940 | 0.819 | 0.604–0.924 |
| Observer 6 | 0.913 | 0.797–0.964 | 0.86 | 0.685–0.942 |
| Observer 7 | 0.926 | 0.827–0.970 | 0.987 | 0.967–0.995 |
| Observer 8 | 0.934 | 0.845–0.973 | 0.985 | 0.963–0.994 |
| Observer 9 | 0.939 | 0.856–0.975 | 0.979 | 0.948–0.992 |
| Observer 10 | 0.934 | 0.843–0.973 | 0.985 | 0.964–0.994 |
| Observer 11 | 0.982 | 0.955–0.993 | 0.994 | 0.984–0.997 |
| Observer 12 | 0.971 | 0.931–0.989 | 0.996 | 0.991–0.999 |
| Observer 13 | 0.968 | 0.923–0.987 | 0.976 | 0.942–0.990 |

*IaCC* intraclass correlation coefficient, *CI* confidence interval

observers (Table 1). The IaCCs obtained by both methods are presented in Table 2. The results show that the average IaCC of the X-ray method is 0.943, and the average IaCC of the 3D-CT method is 0.961. The intraobserver reliability was excellent in each group. The interobserver reliability was excellent with an IeCC value of 0.847 with a 95 % CI between 0.735 and 0.927 in X-ray images and 0.893 with a 95 % CI between 0.814 and 0.949 in 3D-CT images (Table 3). There was no significant difference in MAD between X-ray and 3D-CT images in measuring each type of congenital scoliosis by each observer (Table 4).

**Table 3** Statistical parameters of interobserver analysis between X-ray and 3D methods

| | X-ray | 3D-CT |
|---|---|---|
| IeCC | 0.847 | 0.893 |
| CI of IeCC | 0.735–0.927 | 0.814–0.949 |

*IeCC* interclass correlation coefficient, *CI* confidence interval

**Table 4** Parameters between X-ray and 3D-CT methods associated with failure type of congenital scoliosis

| Type of failure | MAD/X-ray (°) | MAD/3D-CT (°) | *P* value |
|---|---|---|---|
| Formation failure | 4.4 | 3.1 | 0.07 |
| Segmentation failure | 3.6 | 3.0 | 0.48 |
| Mixed failure | 5.2 | 4.9 | 0.74 |

## Discussion

Clinical measurement of Cobb's angle is important for the assessment of the severity of scoliosis and for predicting the progression of the curvature. Many intraobserver and interobserver studies have examined the variability of measurement of the curvature done manually or digitally. These measurement errors range from 2.4°–8.8°, with 5° an acceptable value for the manual method [1, 3–9, 12–14]. However, these studies were all associated with idiopathic scoliosis; only two studies of measurement variability in congenital scoliosis have been reported. Loder et al. reported an interobserver variance of 11.8° and an intraobserver variance of 9.6° when using the Cobb method in congenital scoliosis. They also described the difficulty in correctly measuring the Cobb angle of the curvature in congenital scoliosis and its reproducibility [11]. On the other hand, Facanha-Filho and Winter et al. [10] reported that a skilled observer can measure two radiographs at the same time with an accuracy of ±3° 95 % of the time.

Although scoliosis is a three-dimensional deformity, two-dimensional images from plain radiographic films have been adopted to assess the severity of the deformity. In addition, congenital scoliosis, especially the mixed failure type, is so complicated that it is quite difficult to determine the endplates of the vertebrae to measure the Cobb angle due to the absence of visible landmarks on two-dimensional plain X-ray films. The hypothesis is that the Cobb angle in congenital scoliosis could be measured more accurately by 3D-CT images rather than with X-ray images because 3D-CT can better depict the details of the scoliosis. A preliminary study evaluated the reliability of the measurements taken of the Cobb angle in 25 idiopathic scoliosis patients by three spine surgeons using X-ray and 3D-CT images. The results showed that both IaCCs were high (IaCC: Ave. 0.94 in X-ray, Ave. 0.97 in 3D-CT, IeCC: 0.97 in X-ray, 0.96 in 3D-CT) and that the measurement of Cobb angle for idiopathic scoliosis using 3D-CT images was as reproducible as that with X-ray images (data not shown). The study hypothesized that it was more reasonable to measure the Cobb angle in congenital scoliosis using 3D-CT images than with X-ray images because in congenital scoliosis, it is more difficult to define the endplates of the vertebrae. However, the IaCC and IeCC values estimated in this study indicated excellent reproducible intraobserver and interobserver reliability for the Cobb angle measurement using both methods, although the 3D-CT method showed relatively higher reliability (IaCC: Ave. 0.943 in X-ray, Ave. 0.96 in 3D-CT, IeCC: 0.847 in X-ray, 0.893 in 3D-CT). All observers except one demonstrated high intraobserver error reliability (>0.9) using the X-ray method. It can be concluded that the Cobb angle measurement of X-rays in the frontal plane could approximate the 3D-CT method in measuring the curve of congenital scoliosis. We predicted that the X-ray method might show greater measurement errors in assessing the magnitude of curvatures of congenital scoliosis, particularly the mixed type; however, there was no significant difference in MAD between X-ray and 3D-CT images. Based on these results, spine surgeons could possibly measure the Cobb angle of any type of congenital scoliosis using X-ray images, although 3D-CT images could display a much more detailed anatomical structure of the spinal column of congenital scoliosis. However, no matter how high the quality of radiographic images is, there may be a measurement variance of 3°–4°, attributable to human error.

Several limitations of the current study must be acknowledged. First, the patient sample size was small, so the study may be too underpowered to statistically evaluate

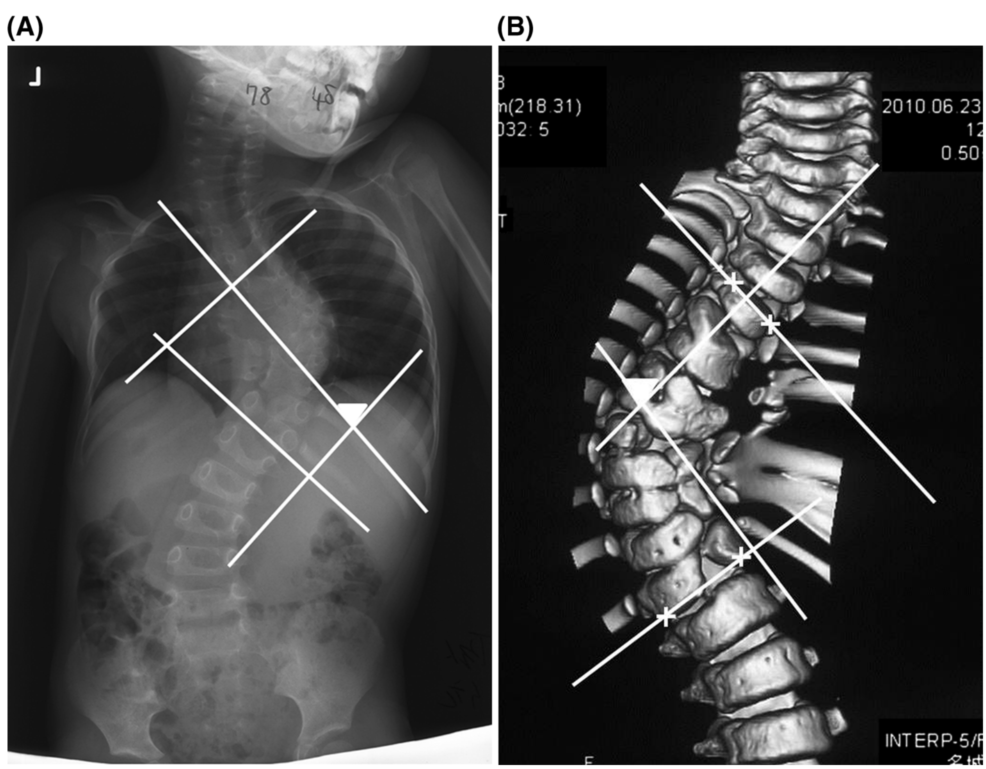


**Fig. 1** Measurements taken using the X-ray images (**a**) and 3D-CT images (**b**)

the difference between both methods. Second, this study used supine position X-ray and 3D-CT images, and this may not reflect the real conditions in routine practice, because standing radiographs are usually used to measure and evaluate the Cobb angle of scoliosis. Third, the observers in the current study included only professional spine surgeons, not general pediatric orthopedic surgeons, general orthopedic surgeons, or residents and fellows. The present study could not demonstrate whether Cobb angle measurement using 3D-CT images was easier for the non-specialists than plain X-rays. Fourth, the software to measure the Cobb angle was not standardized. Although there still might be measurement errors due to the use of different type of software, it may be minimal, as the IeCC was fairly high. Therefore, this study was important because it proved that X-ray images were useful in assessing the Cobb angle in patients with congenital scoliosis. Although X-ray images could assess the Cobb angle accurately in congenitally deformed vertebrae, the more detailed images of the anterior and posterior components of the malformed vertebrae and their relationship with adjacent vertebrae by 3D-CT images have contributed greatly to the development of strategies for the surgical treatment of congenital scoliosis.

## Conclusion

Cobb angle measurement using 3D-CT images has proved to be reliable in helping spine surgeons in patients with congenital scoliosis. On the other hand, it can also be concluded that Cobb angle measurements in patients with congenital scoliosis using X-ray images in the frontal plane produced similar measurement variances (3–4° measurement error) as 3D-CT images, suggesting that plain X-rays are clinically useful for assessing curves in congenital scoliosis. However, since 3D-CT can provide more detailed images of the anterior and posterior components of malformed vertebrae, the volume of information that can be obtained by evaluating them has contributed greatly to the development of strategies for the surgical treatment of congenital scoliosis.

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**Compliance with ethical standards**

**Conflict of interest** The authors have no financial conflicts of interest.

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