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Clinical Study

Accuracy of photogrammetry for detecting adolescent idiopathic scoliosis progression

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Abstract

BACKGROUND: The gold standard method of monitoring the evolution of scoliosis has been serial standing, posteroanterior, full-length spine radiographs with curvature measurements using the Cobb method. However, over the course of follow-up, patients can receive high radiation doses. Various studies have shown that repeated exposure to radiation in children and adolescents can be harmful to their health.

PURPOSE: To determine the accuracy of photogrammetry in evaluating the progression of adolescent idiopathic scoliosis in comparison with radiography.

STUDY DESIGN: Diagnostic study.

PATIENT SAMPLE: Ninety adolescents subjected to radiographic follow-up of idiopathic scoliosis.

OUTCOME MEASURES: The angle of scoliotic curvature was measured using the Cobb radiographic method and photogrammetry. An increase of 5° or more between two radiographic exams was considered a progression of the curvature and was defined as the standard for calculations of sensitivity, specificity, predictive value, and accuracy of the photogrammetric method for measuring scoliosis progression.

METHODS: Patients were subjected to radiographic and photogrammetric exams concomitantly and were reevaluated after an average of 8.6 months. The exams were analyzed separately and independently by two examiners for progression of scoliosis.

RESULTS: The measurements of the curves at the beginning of the study were 39.5±16.7° and 39.5±14.3° for radiographic and photogrammetric exams, respectively (p=1.0). At the end of the study, the measurements of the curves were 40.2±16.2° and 41.3±15.1° for the radiographic and photogrammetric exams, respectively (p=.310). The photogrammetric method had an accuracy of 89% (Confidence interval [CI] 95%=82.5−95.5) for the detection of scoliosis progression, with a sensitivity of 94.4% (CI 95%=89.6−99.2), a specificity of 86.7% (CI 95%=79.7−93.7), a positive predictive value of 75.5% (CI 95%=66.6−84.4), a negative predictive value of 97.2% (CI 95%=93.8−100), and a Kappa index of 0.75 (CI 95%=66.1−83.9). The interclass correlation coefficient between the two methods was 0.74 (CI 95%=0.65−0.81; p=0).

CONCLUSIONS: The photogrammetric method showed good performance for detecting the progression of adolescent idiopathic scoliosis in comparison with the radiographic exam method.

Keywords: Diagnosis; Accuracy; Validity; Cobb method; Idiopathic scoliosis; Photogrammetry.

FDA device/drug status: Not applicable.

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Introduction

Scoliosis is the most common spinal disorder in children and adolescents [1]. Once the condition is identified, the majority of patients should be followed with periodic radiographic exams so that progressive types of scoliosis may be identified and treated early, thus preventing more serious cases. Fortunately, progression to severe forms is infrequent. Taking into consideration that the less serious cases of scoliosis are 10 times more common than the serious cases [2−4], many patients are unnecessarily subjected to elevated radiographic exposure. Doody et al. [5] reported 25 incidences of radiographic exposure at the end of follow-up of adolescent idiopathic scoliosis (AIS), with an average exposure of 10.8 cGy of ionizing radiation. Nearly 15% of patients in one study underwent 50 or more radiographic examinations and 17% received an estimated cumulative radiation dose of 20 cGy or greater [5]. Exposure to ionizing radiation of this degree during a high growth period, in which the skeleton is immature and there is intense development of internal organs, may be associated with breast cancer, leukemia, genetic alterations, cataracts, and other diseases [6−9].

In an effort to decrease the exposure to radiation during follow-up of adolescent idiopathic scoliosis, new methods to monitor the progression of scoliosis have been developed in recent years [10−14]. The method presented in this study consists of a spatial analysis of the back by means of graphic design software, utilizing the principles of photogrammetry [15−17]. In a preliminary study, the equivalence between this new method and radiographic examination was verified [18]. The objective of the present prospective study was to evaluate the accuracy of photogrammetry for detecting the progression of AIS in comparison to radiography.

Materials and methods

Design of the study

A prospective study was performed to evaluate the capacity of photogrammetry to detect the progression of adolescent idiopathic scoliosis, considering radiographic examination as the gold standard. The study was undertaken in a tertiary referral center for the treatment of deformities of the spine. The patients selected for the study were subjected concomitantly to radiographic and photogrammetric exams during two distinct periods by two independent examiners. The research project was approved by the Ethics Committee of the institution (inscription number CAAE 0592.0.203.000-10).

Patients

A pilot study was performed previously to test the protocols and instruments of the study and to obtain an average of the initial curves and their variability, in order to calculate the ideal sample size for the study. The final sample size was calculated to be 95 participants to achieve up to 3° of difference between the two methods with 95% confidence. The primary inclusion criterion was a diagnosis of adolescent idiopathic scoliosis, along with the indication for the radiographic monitoring of the deformity. Exclusion criteria included diagnosis of nonidiopathic scoliosis and previous surgery on the spine.

Ninety-six patients were initially consecutively recruited of a total of 398 patients seen. Ninety completed the two exams at two distinct periods and comprised the final sample for analysis. The principal characteristics of the sample group studied are described in Tables 1 and 2.

Collection of data

Full-length standing posteroanterior spine radiographs were obtained using an X-ray generator and digital radiography. The images were acquired for two incidences: digital capture and printing on plain film. Only the posteroanterior incidence was chosen for radiographic analysis. The scoliotic curvature was measured using the Cobb radiographic method by a single examiner. Immediately after the radiographic exam, the patient was sent to another single examiner to perform measurement of the scoliotic curve using the photogrammetric method, with a protocol described by Aroeira et al. [18]. This measurement was calculated as the sum of the deviation of each segment, denominated as angle Rn (R1, R2, R3, etc.) (Fig. 1). Angle Rn subtended the lines traced between the centers of the surface markers on the spinous process between two adjacent vertebrae,

Table 1
General characteristics of sample

Variable	(N=90) n	(%)
1—Gender:		
Female	83	(92.2)
Male	7	(7.8)
2—Somatotype:		
Ectomorphic	68	(75.6)
Mesomorphic	18	(20.0)
Endomorphic	4	(4.4)
3—Menarche:		
Absent	14	(15.6)
<1 year	20	(22.2)
1≥2 years	17	(18.9)
2≥3 years	10	(11.1)
3≥4v years	12	(13.3)
4≥5 years	2	(2.3)
>5 years	8	(8.9)
Male	7	(7.8)
4—BMI:		
<18.5	46	(51.1)
≥18.5	44	(48.9)
>24.9	2	(2.2)
≤24.9	88	(97.8)

BMI, Body mass index.

Table 2
Characteristics of patients according to age, weight, height, and BMI

Variable (N=90)	Mean	SD	Min	Q1	Median	Q3	Max
Age (years)	14.03	1.95	9.35	12.74	13.97	15.40	17.96
Weight (kg)	46.57	7.46	20.80	41.72	45.6	51.12	69.50
Height (m)	1.58	0.09	1.15	1.53	1.59	1.64	1.79
BMI (kg/m^2)	18.45	2.29	13.18	16.62	18.30	19.98	25.53

SD, Standard deviation; Min, Minimum; Q1, First quartile; Q3, Third quartile; Max, Maximum; kg, kilogram; m, meter; BMI, body mass index.

with the line of the vertical axis. The sum of these angle Rn measurements for each segment, between the superior limit vertebra and the apical vertebra, determined the final angle determined through photogrammetry and is called the "MR" angle in this study. Fig. 2 shows a typical case of a participant subjected to the two methods concomitantly.

Analysis of the data

The Wilcoxon test was used to compare the values of the curve measurements obtained by the photogrammetric and radiographic methods. The comparison between the values was studied through analysis of the Pearson "r" coefficient and through the interclass correlation coefficient (ICC).

An increase in the curve of 5° or more between two given radiographic exams characterized curve progression and was defined as the reference standard to calculate sensitivity, specificity, predictive values, and accuracy of the photogrammetric method to detect the progression of scoliosis.

To examine the trade-off between sensitivity and specificity when different photogrammetry cut-off points were used, receiver operating characteristic (ROC) curve analysis was used. ROC curve analysis also allowed the determi-

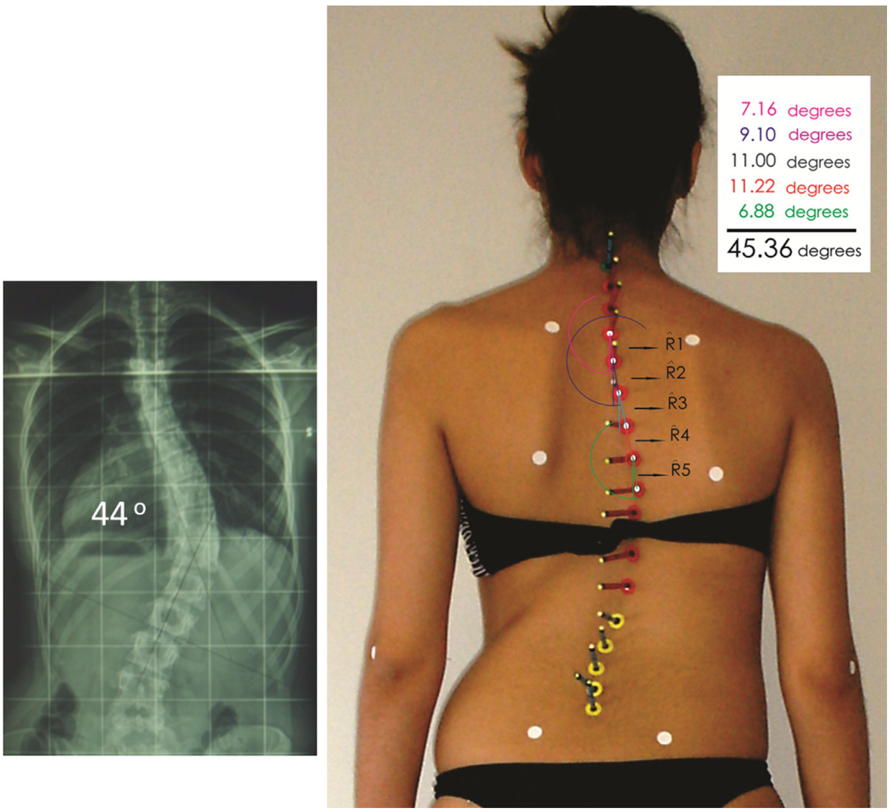

Fig. 1. Measurement of scoliotic curve through photogrammetry and radiography in a patient included in the study sample. Photogrammetric method: Step 1—measurement of Rn angles for each segment localized between the superior limit vertebra and the apical vertebra: R1=7.16°, R2=9.10°, R3=11°, R4=11.22°, R5=6.88°. Step 2—sum of Rn angles=final MR angle=45.36 degrees. Radiographic method: measurement of the Cobb angle was 44° for the same patient.

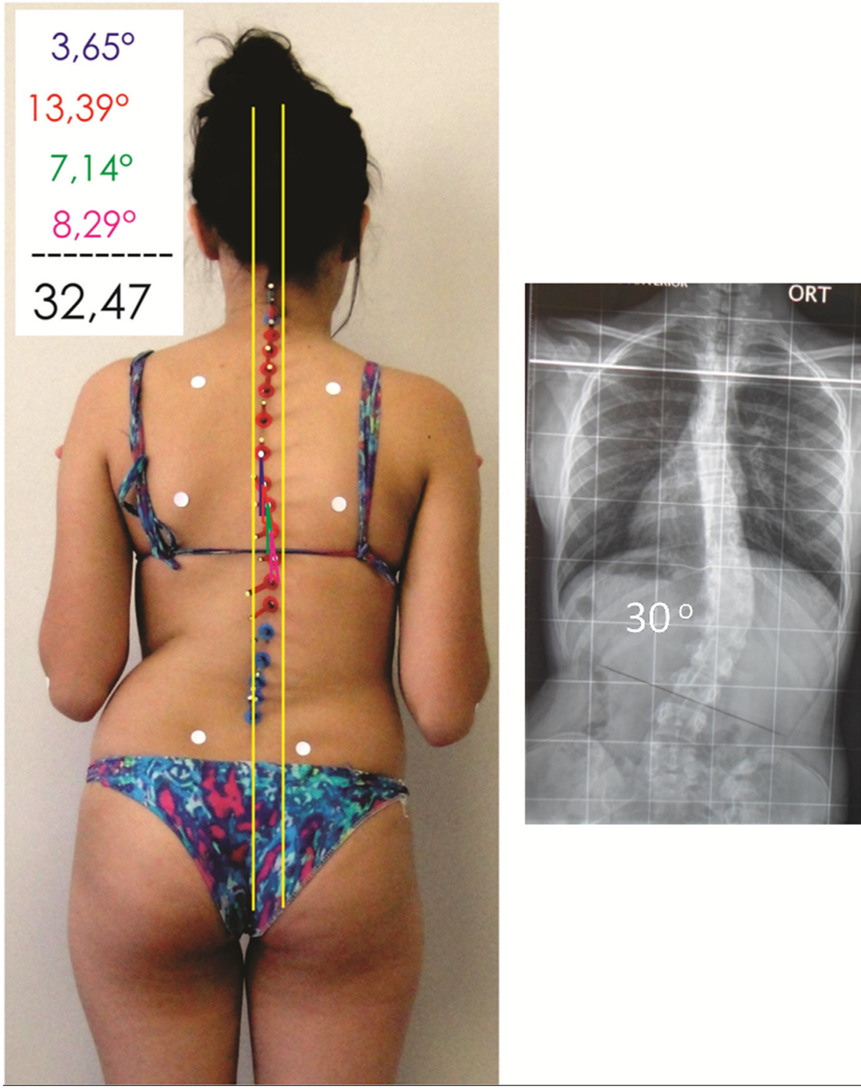

Fig. 2. Measurements of the curve in a typical case obtained through both photogrammetry and radiography. Photogrammetric method=32.47°. Cobb radiographic method=30°.

nation of the probability that a patient with scoliosis progression of more than 5° with the Cobb method would be correctly identified by photogrammetry. This analysis was conducted according to the trapezoid method described by Hanley and McNeil [19]. The auxiliary computational analysis resources used to calculate statistical tests were MINITAB and R.

Results

Among the 90 participants who completed two cycles of photogrammetric and radiographic exams, 29 had double curves, resulting in 119 curves for analysis. The average time between cycles of exams was 8.6 months (range of 4.6−24.4 months).

The average time spent to complete the radiographic method was 16 minutes (positioning, radiographic exposure, and curve measurement). The average time spent to complete the photogrammetric method was 28 minutes (surface marking, photographic exposure, and curve measurement).

Comparison between the photogrammetric method and the radiographic method

In the first cycle of exams, the average of the scoliotic curves was 39.5° for both methods (Table 3). Beyond the comparison of the curve averages obtained through both methods, the frequency of estimation errors of more than 5° in the photogrammetry method in comparison with radiography was also calculated. In the analysis of 119 curves (90 patients) obtained through the photogrammetric method, 21 curves (17.6%) showed differences of more than 5° in relation to radiography. Stratifying the frequency of misestimation of curves above and below the average (39.5°), we

Table 3
Comparison of the scoliotic curves between photogrammetric and radiographic measurements in both examination cycles

N=119* (90 participants)	Photogrammetry	Radiography	p value
Cycle 1			
Average	39.5	39.5	
SD	16.7	14.3	1.0
Cycle 2			
Average	40.2	41.3	
SD	16.2	15.1	0.310

SD, Standard deviation.
* Secondary curves included.

observed a frequency of misestimation of 6.45% (3 curves overestimated, 1 curve underestimated) for the curves below the average and 29.82% (17 curves) for the curves above the average. Of these 17 curves, 11 were overestimated, and 6 were underestimated compared with values obtained through radiography.

In the second cycle, the average of the curves was 40.2± 16.2° in the photogrammetric method and 41.3±15.1° in the radiographic method. There was no significant difference between the averages of the two methods (Table 3).

The scatter diagram for the curves measured with both methods demonstrates a clear positive linear relationship between the two methods, in both cycles of exams (Fig. 3).

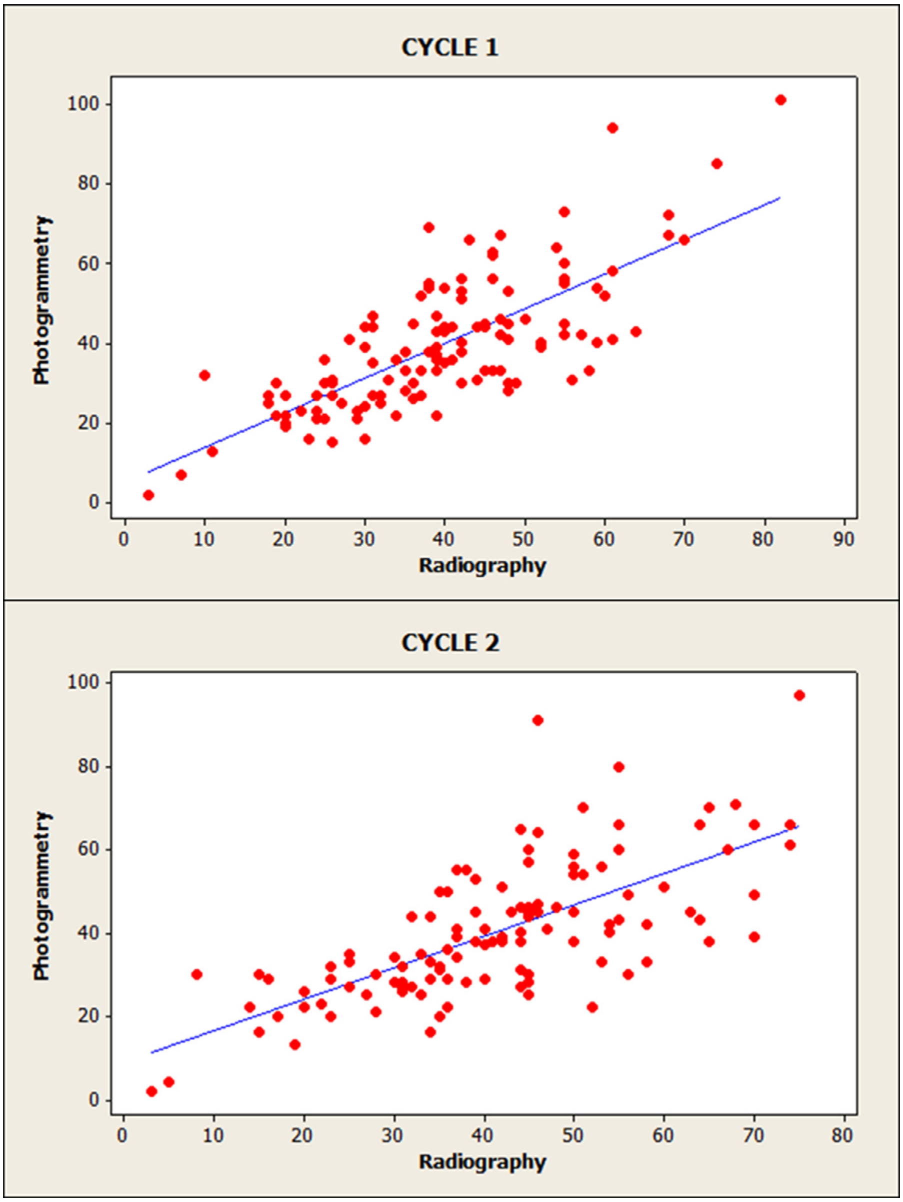

Fig. 3. Scatter diagram between the curves measured by photogrammetry and radiography in the two examination cycles. Pearson's coefficient was 0.74 in cycle 1 and 0.70 in cycle 2.

Table 4
Ability of photogrammetry to detect scoliosis progression according to several cut-off points using the Cobb angle progression as the gold standard*

Cutoff†	*Kappa*	Sens	Espec	PPV	NPV	NLR	PLR	Accuracy
1°	0.56	97.22	69.87	58.33	98.30	0.03	3.22	78.15
2°	0.69	97.22	80.72	68.62	98.52	0.03	5.04	85.71
3°	***0.75***	***94.44***	***86.74***	***75.55***	***97.29***	***0.06***	***7.12***	***89.07***
[CI 95%]	[66.1−83.9]	[89.6−99.2]	[79.7−93.7]	[66.6−84.4]	[93.8−1]	[NA]	[NA]	[82.5−95.5]
4°	0.76	83.33	92.77	83.33	92.77	0.17	11.54	89.91
5°	0.75	77.77	95.18	87.50	90.80	0.23	16.13	89.99
6°	0.74	72.22	97.59	92.85	89.01	0.28	30.09	89.91
7°	0.46	41.66	97.59	88.23	79.41	0.59	17.35	80.67
8°	0.37	33.33	97.59	85.71	77.14	0.68	13.88	78.15

Sens, Sensitivity; Espec, Specificity; PPV, Positive predictive value; NPV, Negative predictive value; NLR, Negative likelihood ratio; PLR, Positive likelihood ratio; NA, Not applicable.

* Scoliosis progression: defined as an increase of 5° or more between two radiographic examinations.

† Positive variation measured by photogrammetric between two examinations.

In the first cycle, the value of the Pearson coefficient was 0.74 (CI 95%= 0.65−0.81). In the second cycle, the value was 0.70 (CI 95%=0.59−0.78).

The ICC was identical to the Pearson coefficient at 0.74 (CI 95%=0.65−0.81) in the first cycle and 0.70 (CI 95%=0.59−0.78) in the second cycle, with a p=0 in both comparisons.

Results of photogrammetry in detecting scoliosis progression

The ability of photogrammetry to detect the progression of scoliosis was estimated from the calculations of sensitivity, specificity, positive predictive value, negative predictive value, and accuracy at several cut-off points using the Cobb angle progression as the gold standard. The values of the Cohen kappa coefficient, negative likelihood ration, and positive likelihood ratio were also calculated for each cut-off point. According to the tests, a positive variation between 3° and 6° showed accuracy greater than 89% (Table 4).

Fig. 4 shows the ROC curve describing the diagnostic accuracy of photogrammetry in detecting scoliosis progression. The curve provided a graphic representation of sensitivity and specificity. According to the analysis of this curve, the best cut-off point for photogrammetry in detecting scoliosis progression was 3°, with area under the curve of 0.953. At this point, the sensitivity, specificity and accuracy were 94.4%, 86.7%, and 89%, respectively. The stratified accuracy at this cut-off point for curves greater than and less than 39.5°Cobb were 93% and 85.5%, respectively.

Discussion

The objective of developing a new nonionizing method to measure the progression of scoliosis was primarily to reduce the number of unnecessary radiographs to which children and adolescents are exposed, and consequently to reduce deleterious effects to health.

Many nonradiographic methods for scoliosis evaluation have been proposed over recent decades [10,11,13,14,20], but they have not been widely incorporated in daily medical practice. There is some speculation regarding the reasons: (1) nonradiographic techniques cannot entirely replace radiographs; (2) costs are relatively high; and (3) low correlation with the radiographic method. In the present study, the values of the curves obtained through photogrammetry were similar to those obtained through radiography. There were no differences in the values of the curves measured through the two methods during the respective periods in which the methods were compared (Table 3).

The analysis of the correlation between the two methods for 90 participants in two cycles demonstrated a positive linear association, with r=0.70 in the first cycle and 0.74 in the second. Considering that the Pearson coefficient is an associative measure that tends to overestimate concordance, calculations were also performed using ICC that presented values identical to those of Pearson.

In relation to the capacity of a determined method to detect the progression of scoliosis, Cote et al. [21] estimated that the minimum acceptable sensitivity of a new test should be 90%. Photogrammetry, with a cut-off point of “three” degrees, demonstrated a sensitivity of 94.4% (Table 4). The remaining performance parameters of the method for detecting the progression of scoliosis were also considered to be good, and there were only 2.7% of patients for whom photogrammetry showed an absence of progression, whereas there was progression noted by the radiographic method (VPN=97.3). The Cohen kappa coefficient and 95% CI for identification of scoliosis progression between the methods was 0.75 (66.1−83.9). According to Landis and Koch [22], this value indicates substantial agreement between the methods.

Basis of the relationship between the radiographic and photogrammetric methods

The mathematical relationship between the Cobb angle (radiography) and the MR angle (photogrammetry) was first demonstrated by Aroeira et al. [18]. This theoretical

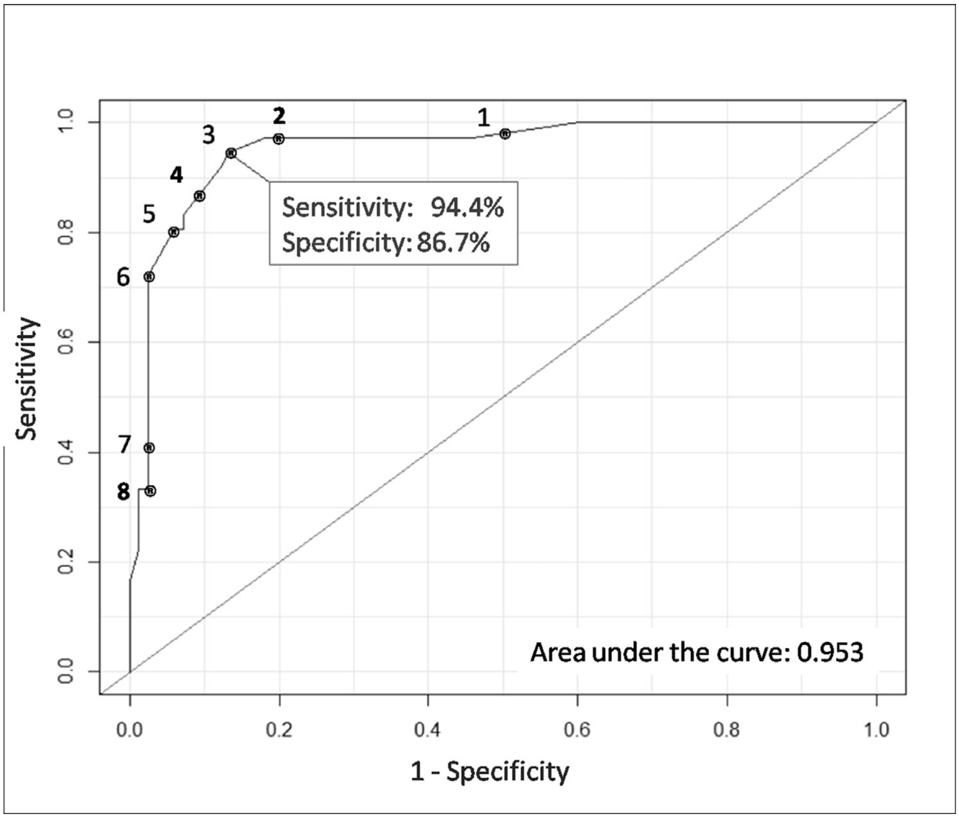

Fig. 4. Receiver operating characteristic (ROC) curve to select 3° as the best cut-off point for the identification of scoliosis progression by photogrammetry. This point corresponds to the largest area under the curve (0.953) with sensitivity of 94.4% and specificity of 86.7%.

mathematical basis considers that the scoliotic curve obtained through the Cobb method (CM) is measured by the arc defined by the superior plateau of the uppermost inclined vertebra and the inferior plateau of the lowermost inclined vertebra. The angular measurement of the scoliosis curve obtained through the photogrammetric method (MR) and its relationship with Cobb angle is demonstrated in Fig. 5. Considering the interval used in the Cobb method and the interval used in photogrammetry method, a similarity between CM and MR angles can be shown. If the

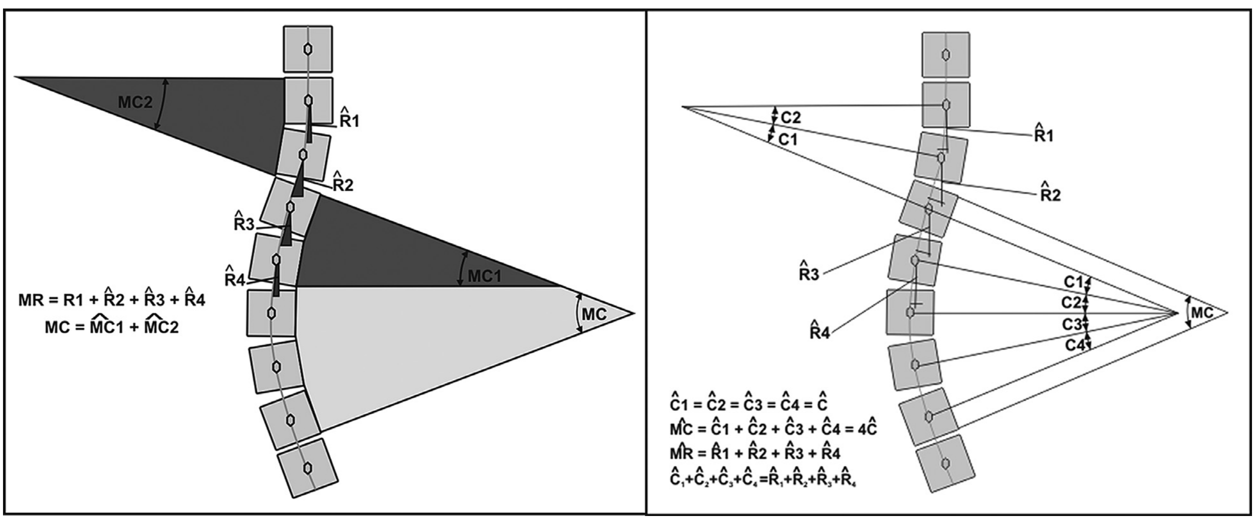

Fig. 5. Mathematical basis between curve angles obtained through the Cobb method (MC=C1+C2+C3+C4) and through the photogrammetric method (MR=R1+R2+R3+R4).

scoliotic curve can be considered as being constituted by perfect segments in a circular arc, the CM measurement is equal to the sum of the angles C1, C2, C3, and C4, obtained between the consecutive spinous processes found at the same interval of this measurement. Thus, if angles C1, C2, C3, and C4 are all equal and are equal to C, the sum of these angles obtained at the same interval through the Cobb method will be equal to 4C (Fig. 5).

Photogrammetry versus radiography

The radiographic exam with measurement of the angle by the Cobb method continues to be the gold standard of reference for the quantification and monitoring of scoliosis [23]. The use of photogrammetry cannot entirely replace radiographs. Other important information is available on the radiographs that photogrammetry can never provide, including the Risser sign, triradiate cartilage status, proximal femoral physis status, morphology of the vertebrae, and specific detail regarding trunk shift and balance. However, once these data have been established, further monitoring of the progression of curves may be considered one of the main reasons for excessive repetition of radiographic exams, and some uncomfortable facts must be considered [24]. It has been shown that during the course of monitoring scoliosis, patients may receive high doses of ionizing radiation known to be damaging to health [5−9,24]. Brenner et al. [25] suggested that there was good epidemiological evidence of an increased cancer risk for some doses of radiograph exposition. Girls with scoliosis, depending upon the cumulative dosages received, may have five times higher risk of breast cancer than girls without scoliosis [5]. Sadetzki and Mandelzweig [26] stated that children constitute a subgroup at greater risk for radiation-induced cancer. Unfortunately, children and adolescents with scoliosis continue to be exposed to ionizing radiation, practically in the same manner that they were during the past century. Although the risks involved may be relatively small, the ancient concept expressed by Hippocrates of *Primum non nocere* (first, do no harm) should serve as a guide when assessing the appropriateness of radiation-based imaging procedures in pediatric patients [18].

The photogrammetric method presents the advantages of the absence of ionizing radiation in clinical settings with transportability of the instruments. Photogrammetry is not intended to replace radiography entirely. However, if the indication for the repetition of radiographic exams is utilized strictly to determine scoliosis progression, photogrammetry may be a substitute, as it achieves this end with 94.4% sensitivity, 86.7% specificity, and 89% accuracy.

Limitations

The mathematical basis to establish the correlation between curve measurements obtained through the methods utilized assumes that the scoliotic curve is composed of perfect segments of a circular arc. Naturally, scoliotic curves are not perfect segments of an arc. Therefore, an extrapolation of the curve measurements through the Cobb method and photogrammetric method should be considered an approximation rather than a perfect relationship. However, the lack of complete adherence to this mathematical premise for the establishment of a relationship between the two methods did not result in significant differences in measurements, and there were acceptable margins. The greatest variations in the comparison of the methods were observed for larger curves, with a tendency of the photogrammetry method to underestimate curves larger than 39.5° as determined by the Cobb method. The delineation of this study and the characteristics of its sample did not allow for the identification of the possible reasons for the lesser precision observed in this group. However, even in cases of larger curves, the accuracy of the photogrammetric method in detecting curve progression remained high (93%).

The authors consider the longer duration of the photogrammetric method in comparison with the radiographic method an important drawback of the photogrammetric method. On the other hand, they believe that the automation of the photogrammetric curve measurement, along with the development of specific software for this task is feasible and, hypothetically, may reduce the time necessary to obtain the curvature angle.

Another limitation in this study is the possible violation of the assumption of independent observation of Bayesian statistics through which the concepts of sensitivity and specificity were developed [27,28], based upon the fact that the study was done at a tertiary referral center. The data collected at a tertiary center may introduce selection bias and, therefore, the conclusions of this study may not be generalizable. Further studies in various centers and populations are needed. A restrictive characteristic of this sample was the small number of patients who had an elevated body mass index. In this study, only two participants had a body mass index above 24.9 kg/m^2 (above ideal weight). Other factors considered restrictive to the application of the method were previous surgery to the spine with resection of spinous processes and examiner experience.

Conclusions

In this sample, the photogrammetric method demonstrated good accuracy for the detection of curve progression in adolescent idiopathic scoliosis.

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