New Method of Scoliosis Assessment
Preliminary Results Using Computerized Photogrammetry
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Abstract and Introduction

Study Design. A new method for nonradiographic evaluation of scoliosis was independently compared with the Cobb radiographic method, for the quantification of scoliotic curvature.

Objective. To develop a protocol for computerized photogrammetry, as a nonradiographic method, for the quantification of scoliosis, and to mathematically relate this proposed method with the Cobb radiographic method.

Summary of Background Data. Repeated exposure to radiation of children can be harmful to their health. Nevertheless, no nonradiographic method until now proposed has gained popularity as a routine method for evaluation, mainly due to a low correspondence to the Cobb radiographic method.

Methods. Patients undergoing standing posteroanterior full-length spine radiographs, who were willing to participate in this study, were submitted to dorsal digital photography in the orthostatic position with special surface markers over the spinous process, specifically the vertebrae C7 to L5. The radiographic and photographic images were sent separately for independent analysis to two examiners, trained in quantification of scoliosis for the types of images received. The scoliosis curvature angles obtained through computerized photogrammetry (the new method) were compared to those obtained through the Cobb radiographic method.

Results. Sixteen individuals were evaluated (14 female and 2 male). All presented idiopathic scoliosis, and were between 21.4 ± 6.1 years of age; 52.9 ± 5.8 kg in weight; 1.63 ± 0.05 m in height, with a body mass index of 19.8 ± 0.2. There was no statistically significant difference between the scoliosis angle measurements obtained in the comparative analysis of both methods, and a mathematical relationship was formulated between both methods.

Conclusion. The preliminary results presented demonstrate equivalence between the two methods. More studies are needed to firmly assess the potential of this new method as a coadjuvant tool in the routine following of scoliosis treatment.

Introduction

Scoliosis has been defined as a lateral curvature of the spinal column superior to 10° Cobb, generally associated to vertebral rotation. Monitoring of this angle has been one of the principal parameters used in defining the type of treatment to be instituted in young patients who are still growing. The most trustworthy method to accompany the evolution of the curvature has been the standing posteroanterior full-length spine radiograph, with curvature measurement using the Cobb method. However, over the course of follow-up, this can result in taking more than 25 radiographs. Nearly 15% of patients in one study had undergone 50 or more radiographic examinations, and approximately 17% had received an estimated cumulative radiation dose of 20 cGy or greater. This high number of radiographs can expose patients to relatively high doses of ionizing radiation. Various studies have shown that repeated exposure to radiation in children could be harmful to their health.

Many nonradiographic methods of scoliosis accompaniment have been proposed as an alternative to radiographic evaluation. Nevertheless, the majority has not demonstrated a good correlation with the Cobb method.

Photogrammetry can be regarded as the science and technology of obtaining spatial measurements, and other geometrically reliable information, derived from photographs. The computerized photogrammetry method proposed in this study can be considered one of many uses of photogrammetry. It has been used in different fields, such as: cartography, architecture, engineering, quality control, and three-dimensional modeling. However, its use in the evaluation of...
scoliosis has not been well studied. To the authors' knowledge, no data are presently available in the literature that proposes a protocol for photogrammetric measurement of scoliosis, which is applicable to clinical practice.

The goals of this investigation were to develop a protocol for computerized photogrammetry method for the quantification of scoliosis curvature as well as to compare the results with those from the Cobb radiographic method in the group of volunteers. Our hypothesis is that both methods yield similar results in obtaining the scoliosis curvature angle.

**Materials and Methods**

**Field Studies**

After approval from the research ethics committee of our hospital, all patients who were undergoing conservative treatment for idiopathic scoliosis in the spine unit between March and October of 2008, and who had received the medical requisition for radiologic monitoring of their deformity, were invited to participate in this study. The only exclusion criterion adopted for this phase was the refusal of the patient or of his parents. All accepted the invitation and gave their formal informed consent.

**Radiologic Examination**

Full-length standing posteroanterior spine radiographs were obtained using a radiograph generator TOSHIBA KXO 1SR (Toshiba, Tokyo, Japan) and a digital radiography Agfa Health System (AGFA, Mortsel, Belgium). The images were acquired in a single exposure for each incidence, and then digitally obtained images were printed on a single sheet of 35.6 × 43.2 cm film. Only the posteroanterior incidence for each patient was chosen for radiographic analysis. The scoliotic curvature and the apical vertebra were determined for each patient by one examiner. Five separate measurements were made at different times for each examination, and the average of these five values was used for statistical analysis.

**Computerized Photogrammetry Examination**

Immediately after the radiologic examination, a single trained, experienced examiner initiated palpation and marking on the spinous process with surface markers, for all vertebrae localized between C7 and L5. An anatomic landmarks type vector (ALTV), 45 mm in length with a metallic base of 8 mm, was developed and standardized as a surface marker specifically for this study. After this, each patient was photographed in standing, dorsal, lateral (right side visualization 90°), and oblique (left side 45°) positions, using a digital camera, Sony 7.1 megapixel (Sony, Manaus, Amazonas, Brazil), at definition 3072 × 2304, mounted on a Greika WT3750 (Greika, São Paulo, SP, Brazil) tripod, set to a height of 1.10 m, with a focal distance of 1.30 m. A Carci Simetograph (Carci, Americanópolis, SP, Brazil), 2.02 m in height and 0.72 m in width, was used to provide a base metric reference. The images were imported and analyzed using CorelDraw13 software (CorelCorporation, Ottawa, Canada), and the angle of deviation of scoliotic curvature was calculated. The protocol for the deviation calculation consisted, initially, of the identification of the apical vertebra and the superior limit vertebra of the upper curve. This procedure was done by tracing two vertical lines (using the free hand tool in the software toolbar), one line tangential to the convex face of the curve, and the other crossing through the vertical axis of the C7 vertebra (Figure 1). The apical vertebra was defined as that furthest from the vertical axis of C7 and touching the tangential line.
The left line (white) identifies the apical vertebra through the tangent of the vertical line and convexity of the curve (T10). The right line (gray) identifies the first vertebra to interrupt the vertical alignment (T4) as the superior limit vertebra.

The second step of the calculation consisted of measurement of the angle of deviation of each segment between the superior limit vertebra and the apical vertebra marked with the ALTV, using the dimension tool located in. The sum of the angles of deviation of the previous segments determined the final angle calculated through computerized photogrammetry, which is called angle MR (Figure 2).

Figure 2.
Measurement of angle Rn for each segment localized between the superior limit vertebra (T4) and the apical vertebra (T10): R1 = 10°, R2 = 4°, R3 = 8°, R4 = 12°, R5 = 10°, R6 = 9°, and R7 = 4°. Angle MR = sum Rn = 57°.

Definition of Angle MR

Angle MR was defined as the angular quantification calculated for a specific scoliotic curve obtained through computerized photogrammetry in the frontal plane. It was calculated through the sum of the lateral deviation of each segment between the superior limit vertebra and the apical vertebra. Its radiologic correspondent is the Cobb angle as obtained through the radiographic method.

Calculation of Angle MR

The deviation of each segment was denominated as angle Rn (R1, R2, R3, etc.). Angle Rn was that formed between the lines traced between the centers of the ALTV in two vertebrae of the segment (adjacent vertebrae) with the line of the vertical axis y (Figure 2). The sum of these angle Rn measurements for each segment between the superior limit vertebra and the apical vertebra determined the Angle MR.

For each volunteer in this study, five measurements were taken of each angle Rn, at distinct intervals, by the same examiner. The average of the sum of these angle measurements was considered to be the angular value of the deformity.

Analysis of Data

The radiographic and photogrammetric measurements were performed separately by an orthopedic spine surgeon, and a physiotherapist experienced in photogrammetry of the spine, respectively.

To determine the profile of the study participants, a frequency distribution was performed for the variables "sex" and "type of curvature," along with calculation of the central tendency for the variables of "age" and "body mass index" (BMI).

To verify the differences in measurements of thoracic and lumbar scoliosis curvatures between the Cobb and computerized photogrammetry methods, the Wilcoxon test was realized.

The localization of the apical vertebra was compared between the two methods through concordance calculation using Kappa statistics. The nonparametric test was used, considering the size and the characteristics of the sample. Concordance in the localization of the apical vertebra in this study was defined as the identification of the same vertebra, or at most, one adjacent vertebra. This definition was established considering that the computerized photogrammetry method actually detects the tip
of the spinous process rather than the vertebral body of the apical vertebra, and also considering that the real apex curve detected through radiographic method could be localized in the intervertebral space. The significance level adopted for all tests was 5%.

Results

Sixteen volunteers were evaluated using the two methods. All presented idiopathic scoliosis. The average age was 21.4 years. For weight, height, and BMI, the averages were 52.9 kg, 1.63 m and 19.8 kg/m², respectively. There was predominance of female volunteers (87.5%), and with a female to male ratio of 7:1. In relation to curvature type, a double thoracic/lumbar curve was the most frequent, with 12 cases observed (75%), followed by a single lumbar curve (18.7%), and a single thoracic curve (6.2%). The general characteristics and the measurements using Cobb and computerized photogrammetry methods of each individual included in the study are presented in Table 1.

The values of the thoracic curve measurements obtained using the Cobb method varied between 17.8° and 73.0°, with an average of 36.1°, while the values of the curve measurements obtained using the computerized photogrammetry method varied between 19.6° and 74.2°, with an average of 36.4°, with no significant difference noted between the two groups (Table 2 and Figure 3).

![Figure 3](source: Spine © 2011 Lippincott Williams & Wilkins)

Comparison between the curve measurements obtained through the Cobb method and the computerized photogrammetry method for (A) thoracic and (B) lumbar curves.

The average difference between the angle values obtained through the Cobb method and the computerized photogrammetry method was 2.9° for thoracic curves.

In the lumbar region, the average of the curvature evaluated through the Cobb method was 27.2°, with a variation of 14° to 48.6°, while the average through the computerized photogrammetry method was 25.7°, with a variation of 10° to 55.0° (Table 2 and Figure 3). The average difference between
the two methods in the lumbar region was 5.1°.

There was no significant difference between the average curve measurement values obtained through the Cobb and computerized photogrammetry methods for all curves analyzed together. The average of the differences between the methods for all curves was 4.1°.

The average Kappa index for evaluation of intensity of concordance in the localization of the apical vertebra between the methods for the thoracic region was 0.92. For the lumbar region the Kappa index was 0.82.

Discussion

Various nonradiographic methods for the quantification of scoliosis have been proposed in the last 30 years.[11–15] Unfortunately, they have not survived the test of time, due to a variety of possible reasons, notably: (1) nonradiographic techniques cannot entirely replace radiographs; (2) there are important direct costs in the implementation of new technology as well as recurrent costs with training, salary of the technician, and others; (3) these techniques take more time than the radiologic examination; and (4) finally, the majority have demonstrated low correlation to the Cobb method.[16]

The radiologic examination with frontal plane measurement of the Cobb angle has been considered to be the gold-standard for the quantification and monitoring of scoliosis.[1,2] In addition to the determination of the Cobb angle, it provides information as to skeletal maturity, the flexibility of the curve, the presence of congenital bone malformations, and the general balance of the spine, which is all indispensable to good clinical practice in scoliotic patients. However, once these data have been established, further monitoring of the Cobb angle may be considered the main reason for the repetition of radiologic examination.[3] Along with the important benefits of radiographs, there are risks that need to be considered as well. Brenner et al,[18] in a study conducted by a large group of epidemiologists and radiation scientists, concluded that there is good epidemiological evidence for an increased cancer risk for some doses of radiograph exposition. Doody et al,[4] analyzing breast cancer mortality in 5573 women, reported a 69% excess in breast cancer mortality among women with scoliosis. And consistent with radiation as a causative factor, they showed that the risk of dying of breast cancer increased significantly with number of radiograph exposures and with cumulative radiation dose. Sadetzki and Mandelzweig,[19] in a recent article, stated that children constitute a subgroup at greater risk from exposure to develop radiation-induced cancer. Uncomfortably, patients with scoliosis continue to be exposed to ionizing radiation, practically the same as they were 30 years ago. 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.

Mathematical Relationship Between the Cobb and the Photogrammetry Methods

The scoliotic curve obtained through the Cobb method (MC), is measured by the arc, defined by the superior plateau of the uppermost inclined vertebra, and by the inferior plateau of the lowermost inclined vertebra (Figure 4). The angular measurement of the scoliosis curve obtained through computerized photogrammetry method (MR) was calculated by the sum of the deviation angles of axis y, denominated R1, R2, R3, and R4 (the sum of the deviation angles of each segment between the superior limit vertebra and the apical vertebra). Thus, the deviation angle is considered to be that encountered between the secant lines drawn from two consecutive spinous processes, and the y-axis. In addition, considering the interval used in the Cobb method and the interval used in computerized photogrammetry method, a similarity between MC and MR angles can be shown (Figure 4).
Figure 4.
Angle of scoliosis curvature obtained through the Cobb method (MC = C1 + C2 + C3 + C4), and obtained through the computerized photogrammetry method (MR = R1 + R2 + R3 + R4).

In our study, it was possible to establish a mathematical correlation between curve measurements obtained through the methods taking into account some conditions. Defining the scoliotic curve as being constituted of perfect segments of a circular arc, as indicated in Figure 4, then the MC 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 equal to C, we will find that the sum of these angles obtained at the same interval through the Cobb method will be equal to 4C.

Naturally, the scoliotic curve is not a perfect segment of an arc, so a perfect extrapolation between the curve measurements through the Cobb method and the computerized photogrammetry method should not easily be made. However, the failure of complete adherence to mathematical premises for the establishment of a relationship between the two methods did not result in significant differences in measurements, and appeared to be valid for practical use within acceptable margins.

Equations

Further considering that the scoliotic curvature is constituted of segments of circular arcs, the triangles BAD, DAE, GFH, and HFJ (Figure 5) will be isosceles triangles.

Therefore, angle X will be indicated by equation (1):

In addition, there is a relationship between the angles of deviation of axis y (R1, R2, R3 e R4) obtained through computerized photogrammetry, with the angles (C) of each vertebral segment as obtained using the Cobb method, as indicated in equations (2), (3), (4), (5):

Thus, the MR measurement will be indicated by equation (6):

As a result, mathematically, the value of the measurement obtained through computerized photogrammetry will be equal to that obtained through the Cobb method.

The mathematical proof proposal considered the scoliotic curve as a polynomial arc of degree 2. It is important to bear in mind that the prior demonstration does not represent a general solution. However, it makes it easier to understand, as observed in clinical practice, that there is equivalence between the measurements obtained in this study and those obtained through the Cobb method.

Results
The curvature values obtained using the computerized photogrammetry method were similar to the values obtained using the Cobb radiographic method. The proposed method showed less difference in the thoracic region than in the lumbar region. The total average of difference of 4.1° between the methods, which includes all thoracic and lumbar curves, was compatible with the intrinsic error of the Cobb method in inter- and intraobserver analysis.\textsuperscript{[20–22]} Measurements of the Cobb angle bear both an inter- and intraobserver variability of approximately 4° to 8°.\textsuperscript{[21,23–29]} The average for the individual measurement differences between the methods in the thoracic region was 2.9°, while in the lumbar region the average difference was 5.1°, influenced by the differences observed in two volunteers. Unfortunately, the limited number of cases in this initial study did not allow for inferences to be made about the possible causes involved.

The identification of the apical vertebra was an important step of the computerized photogrammetry method, and the use of ALTV marks helped in this task. The vertebra with the largest variation in the analysis of the three-dimensional coordinates from the base to the tip of the ALTV coincided, generally, with the identified apical vertebra. The concordance in the localization of the apical vertebra between the computerized photogrammetry method and the Cobb method, as estimated through Kappa index, was excellent, according to criteria based on the interpretation of Landis and Koch (Kappa > 0.80 = excellent concordance).\textsuperscript{[30]} Besides, with the use of these marks, virtual images of the spatial behavior of the spinal column could be generated using SolidWorks software (SolidWorks, Santa Monica, CA, USA) (Figure 6).

\textbf{Figure 6.}\textsuperscript{[31]} Döhnert and Tomasi\textsuperscript{[31]} attempted, without success, to detect mild scoliosis using photogrammetric principles. The protocol used by them was different from the protocol applied in this study. They chose an analysis protocol using surface marks only in C7, T9, and L5. Saad et al\textsuperscript{[32]} also did not find a linear relationship between the photogrammetric and radiographic methods using a similar protocol to that used by Döhnert and Tomasi. We believe that the protocol used in both studies does not allow adequate angular quantification of scoliotic curvature, because a mathematical relation of similarity is not possible with the Cobb method using their methodology and parameters.

Although this study did not have as an objective the evaluation of costs, a few considerations on the topic are pertinent. The total cost of the photogrammetric equipment (computer, software license, simetograph, digital camera, tripod, surface markers) was USD 1826. Strictly for use as a comparison, the cost of installed radiographic equipment used in this study was USD 216,238. Basic skills needed for the use of this method were: primary knowledge on spinal anatomy, photography, and imaging software. The time spent with the radiographic method on a typical patient was 13 minutes (positioning, photographic exposure, and one curve measurement), while the time spent using the manual photogrammetric measurement was 28 minutes (surface marking, photographic exposure, and one curve measurement). We considered this longer time period the principal drawback of the photogrammetric method. On the contrary, we believe that the automation of the photogrammetric curve measurement with the development of software specific to this task is feasible and, hypothetically, may reduce the time necessary to obtain the curvature angle.

This study presents limitations. In this consecutive series, the majority of volunteers presented a BMI below or within normal variation (18.5–25 kg/m\(^2\)), which may have facilitated a more precise localization of the spinous process and, presumably, have positively influenced the performance of
this method, having the Cobb method as a reference. Beyond body weight, factors such as lumbar curves, previous spine surgery, and the ability of the examiner, may constitute obstacles, which could restrict the application of the method.

Radiography currently is and probably will remain the principal examination method for children with spinal deformities. The method presented in this study does not seek or intend to replace the radiologic examination. It introduces a new approach in the nonradiographic evaluation of scoliosis, with potential application in monitoring the curvature. Further studies are needed to firmly assess the potential of this method as a coadjuvant tool in the routine follow-up of scoliosis treatment. Important points arising from this preliminary evaluation, such as refinement of the photogrammetric technique, costs, and validation of a new diagnostic test are now under current investigation in our institution.

References