

COMPUTERIZED PHOTOGRAMMETRY PROTOCOL ON THE ANGULAR QUANTIFICATION OF SCOLIOSIS

Rozilene Maria Cota Aroeira, rozecota@hotmail.

Jefferson Soares Leal, jeffersonleal@terra.com.br.

Antônio Eustáquio de Melo Pertence, pertence@demec.ufmg.br.

Federal University of the Minas Gerais State, 6627 Antônio Carlos Avenue, CEP 31270-901, Belo Horizonte, MG, Brazil.

Abstract. *The objectives of this study was to develop a noninvasive method using computerized photogrammetry for the measurement and monitoring of scoliosis and, also, correlate the proposed method with the Cobb method. We evaluated 16 individuals (14 females and 2 males) with idiopathic scoliosis in adolescents (ISA), which had application to conduct medical examination of radiological digital, panoramic, anterior-posterior and profile of the spine and whose means were: age 21.44 ± 6.17 years, weight 52.91 ± 5.88 kgf, height 1.63 ± 0.05 m and 19.86 ± 0.26 BMI. Each subject was radiographed in upright position, anterior posterior and profile, and then was photographed with digital camera in upright position frontal posterior, right and left profile (45° and 90°). A rotatory platform was created to position the subject in the several postural planes, necessary in the radiologic evaluation and photo collection procedures. Anatomic landmarks of the vectorial type were developed and positioned in the subject skin, on the spinous processes of the C7 through L5 vertebrae. The photographic images were submitted to the measurement of the Cobb angles and identification of the apical vertebra, according to the proposed protocol, using the software CorelDraw13[®]. The radiographs were submitted to measurement of the Cobb angle and the identification of the apical vertebra. The angles obtained by computerized photogrammetry were compared with those obtained by the Cobb method, and were compared to the apical vertebrae identified by two methods. Furthermore, it was formulated a mathematical correlation between the two methods. Statistical analysis of data showed that there was no statistically significant difference ($p\text{-value} > 5\%$) between measurements of the scoliosis angle in both methods, for thoracic and lumbar curves. There was no statistically significant difference ($p\text{-value} > 5\%$) for the identification of the apical vertebra (thoracic and lumbar), in both methods. Thus, preliminary studies have demonstrated the equivalence between the two methods in both the mathematical correlation as presented in the statistical analysis of data. The proposed methodology is original in all the stages of the protocol creating a new approach for the noninvasive quantization of the scoliosis angle.*

Keywords: *scoliosis, computerized photogrammetry, Cobb method*

1. INTRODUCTION

The scoliosis is a three-dimensional deformity of the spine and, in most cases, as a musculoskeletal disorder with characteristic deformation of structural bone. It is considered that 70% of cases arise in the period of body growth and bone maturation (Tribastone, 2001). Thus, the period of body growth is that where there is greater need for monitoring the development of deformity.

Traditionally, the measurement and monitoring of scoliosis has been made by panoramic radiography, anterior-posterior, in combination with the method of Cobb. Such monitoring may result in an average of 25 radiographs during treatment, during which patients are exposed to for high doses of ionizing radiation (average of 10.8 cGy) (Doody et al, 2000).

Much has been studied on the effects of radiation in the monitoring of scoliosis patients (Levy et al 1994, 1996, Golberg 1998; Doody et al 2000; Cap & Hsieh 2000, Ron 2003, Berrington & Darby 2004). The interaction of ionizing radiation with living matter can generate changes in cellular level, as the cell death, interruption or slowdown of the process of cell division, permanent change that is transmitted to the daughter-cells. According Tribastone (2001), these effects are amplified in individuals without complete bone maturation is not desirable to subject the patient to X-rays for more than twice a year.

The above considerations have motivated, in the last two decades, the development of alternative methods of evaluation of scoliosis, such as those based on studying the surface topography of the coast, as proposed in various ways (Ovadia, 2007). Two basic types of technology have been implemented: 1 - the measure by direct contact with the back of the patient (Ortelius800TM, Ultrasound-Based, SpinalMouse system (Cote 1998, Ovadia 2006, Zsidai 2003) 2 - the use of various methods of photographic or scanning techniques to map the surface, as Moire Contourgraphy, Quantec[®] (Ovadia et al, 2007).

In the last decade, computerized photogrammetry has been showing a promising tool in the evaluation of the postural geometry as it is a noninvasive method, easy to use and low cost clinic. In literature there is no paper propose that the protocol of photogrammetric measurement presented in this study, as well as the use of anatomic landmarks of the vectorial type.

2. METHODOLOGY

2.1. Study area

Sixteen patients diagnosed with idiopathic scoliosis in adolescents (ISA) were included in this study with the approval of the Research Ethics Committee COEP-Federal University of Minas Gerais State process n°. ETIC 579/07. End of free consent was obtained from parents and guardians for minors. The mean age was 21.44 ± 6.17 years. The population sample was composed of 14 individuals were female and 2 males, all over 11 years of age and Cobb thoracic minimum of 17.8° and a maximum of 73° , lumbar Cobb minimum of 14° and maximum of 48.6° . None of the subjects has undergone previous surgery of the spine.

All subjects were referred for clinical evaluation of digital radiographic (panoramic, orthostatism in anterior-posterior) and immediately after, were sent to the studio for the collection of digital photos (posterior frontal and sagittal in orthostatism). Measurements of the Cobb angle on radiographs were performed by orthopedic surgeon and the photos were stored and analyzed by physiotherapist, using the method of computerized photogrammetry by software CorelDraw13[®].

2.2. Radiological analysis

Digital radiography, anterior-posterior, in orthostatism was obtained from each individual. An orthopedic surgeon examined the printed digital radiographs, according to the standard method for measuring Cobb angle. Five measurements were performed in each test and the average of the values was considered for statistical analysis. For this procedure were used to 30cm acrylic ruler, protractor 180 acrylic, ballpoint pen and sheets of transparency. The radiological analysis showed a mean Cobb angle of the back of 36.14° (standard deviation of 16.38°) and the lumbar Cobb of 27.20° (standard deviation of 10.05°), which included 12 individuals with double curve (thoracic and lumbar), 3 subjects with single lumbar curve and 1 person with single thoracic curve.

2.3. Protocol for evaluation with computerized photogrammetry

The protocol of computerized photogrammetry was used in quantitative analysis of digital photographs using the software CorelDraw13[®]. Firstly, to palpation and marking of the spinous processes from C7 to L5 vertebrae, by a single examiner, using of anatomic landmarks of the vectorial type (MASV), circular, 45mm in length and base metal of 8mm, developed for this study and indicated in Fig.1. Then the individual was photographed in upright position, posterior frontal and sagittal, using Sony digital camera 7.1 mega pixels, 3072 x 2304 setting, placed on brand GREIKA WT3750 tripod at a height of 1.10m and focal length of 1, 30m. A metric reference device, brand Carci[®], 2.02 m high and 0.72 m wide, was used to make reference to the background metric. To standardize the frontal and sagittal postures, each volunteer was photographed and radiographed on a rotatory platform (360°), with square bottom measuring 49X49 cm, upper circular base measuring 38 cm in diameter, placed on a system of 5 wheels and total height of equipment of 12 cm, specially designed for this study showed in Fig. 2.

The images were imported into the software CorelDraw13[®] and subjected to analysis angular second protocol proposed in this study. This protocol consisted of two phases of photo interpretation. The 1st phase was the identification of the apical vertebra and the vertebra upper of the scoliotic curvature to define the vertebral segment to be analyzed. This procedure was performed by drawing two vertical lines (the free hand tool from the toolbar), a tangential face and one convex curve through the vertical axis of C7, as showed in Fig. 3. The apical vertebra is the vertebra furthest from the vertical axis of C7 and usually one that is more rotation of his body, which was viewed by the change of direction of the body of the vector. The upper vertebra is the first vertebra to leave the vertical alignment of C7 and suffer rotation.

The 2nd phase of photo interpretation consisted of angular measurement in the Y axis of each vertebra involved identified in the semi-arc between the end vertebrae upper and the apical vertebrae, using the size of the toolbar software CorelDraw13[®]. Five measures were performed for each volunteer, involving the identification of MASV center and measurement of the angle itself, and the average of these values was considered for the final angle sum. The angles sum, that makes the semi-arc, was considered the value of the deformity, indicated in Fig.4.

2.4. Mathematical relationship between the Cobb method and the method of computerized photogrammetry proposed in this study.

In the Cobb method, scoliosis curvature is measured by the arc angle (MC) restricted by the upper plateau of the most tilted end vertebrae top (in the horizontal plane), and the plateau of the end vertebrae inferiorly more inclined, as shown schematically in Fig 5. In this study, the angle of the scoliotic curvature (MR) was obtained by the sum of the

angles of deviation of the Y axis, named R1, R2, R3 and R4, measured between the first vertebra to suffer axis deviation vertical and axial rotation and apical vertebra.

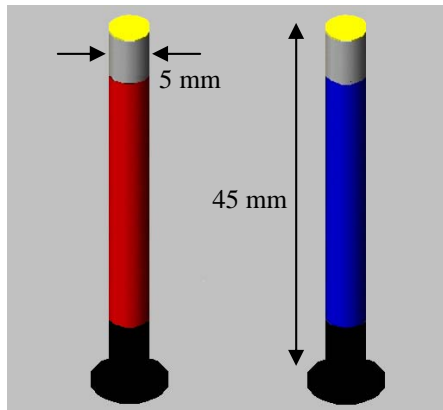


Figure 1. The figure schematically represents two anatomic landmarks of the vectorial type (MASV).

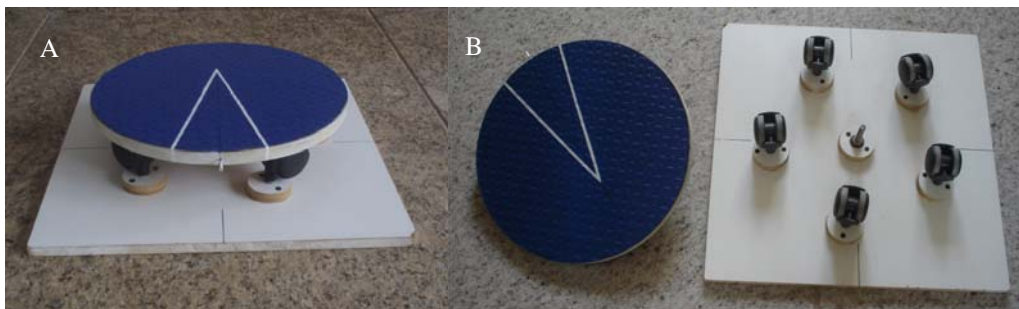


Figure 2. Rotatory platform for placement of the individual during the capture of images radiographic and photographic. (A) Position platform in front. (B) View of system of 5 wheel base of the device.

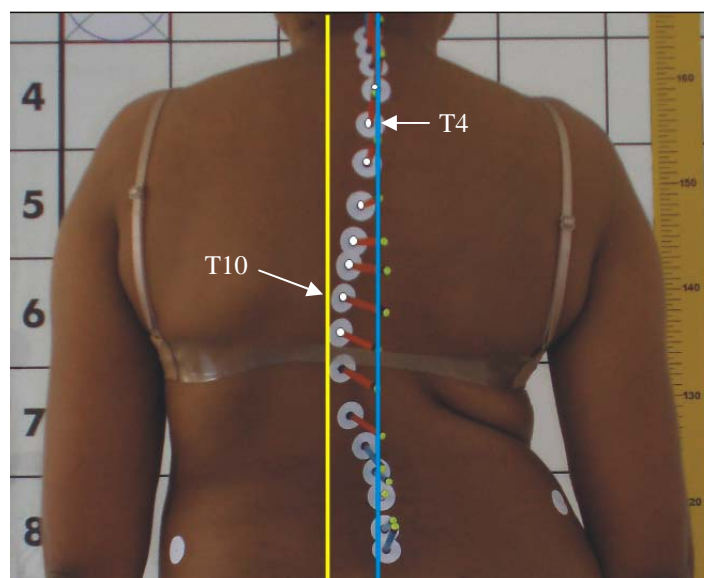


Figure 3. 1st stage of photo interpretation: a vertical line on the left, identifies the apical vertebra through vertical tangential to the convexity of the curve (T10 vertebra). The vertical line on the right identifies the end vertebra top by vertebra vertical passing through C7 and the first vertebrae breaking with the vertical alignment (T4 vertebra).

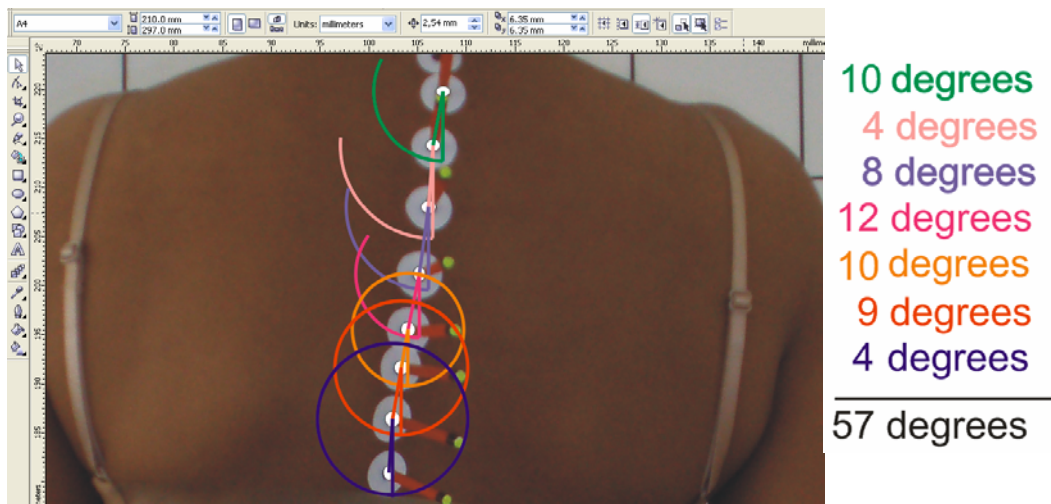


Figure 4. 2nd phase of photo interpretation, angular measurement, by software CorelDraw 13®, a volunteer with ISA, with main thoracic curve convex to left. Measurement of the angles of spinal deflection balance in the Y axis between the end vertebra top (T4) and the apical vertebra (T10): T3-T4 (10°), T4-T5 (4°), T5-T6 (8°), T6-T7 (12°), T7-T8 (10°), T8-T9 (9°) and T9-T10 (4°).

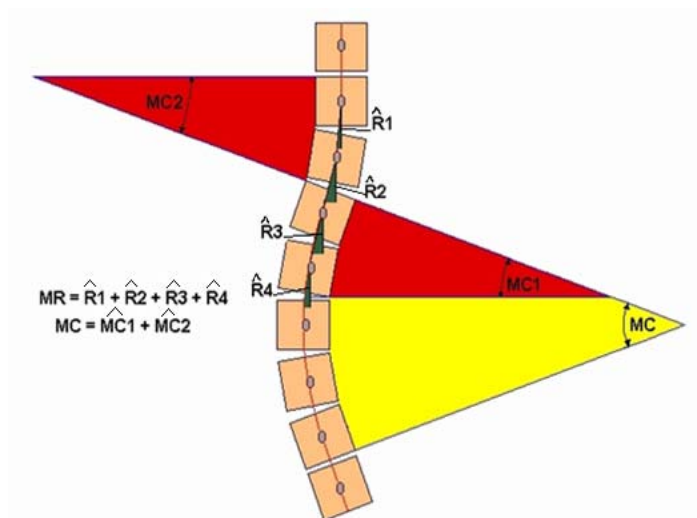


Figure 5. Schematic figure of the extent of the scoliotic curvature MR (obtained by the method of the present study) and MC (obtained by the method of Cobb).

Thus, it is the angular values found between the driers drawn between two spinous processes consecutive and negative Y axis. Moreover, considering the range used by the method of Cobb and that used in this study it is possible to observe a correlation of values.

It is mathematically possible to relate the measures of scoliotic curvature obtained by the Cobb method and the method of the present study, considering some conditions. Setting up the scoliotic curvature as constituted by segments of arcs of circles, as shown in Fig. 6a, it is possible to consider the measure MC equals the sum of the angles C1, C2, C3 and C4, obtained between consecutive spinous processes found in the same range of the measure. Thus, if the angles C1, C2, C3 and C4 are equal among themselves and equal to C we have, then, that the sum of the angles obtained in the range of the Cobb method is equal to 4C.

Whereas the scoliotic curvature is constituted by segments of arcs of circles, the triangles ABD, ADE, HGF and FHJ, Fig. 6b, are isosceles triangles. So, the X angle is given by Eq. (1).

$$X = (180 - C) / 2 \tag{1}$$

Moreover, there is the relationship between the angles of deviation of the y axis (R1, R2, R3 and R4), obtained by the method proposed in this study, with the angles (C) of each vertebral segment obtained by the Cobb method, as indicated the Eqs. (2), (3), (4) and (5).

$$R1 = 90 - X = 90 - (180 - C) / 2 = C / 2 \tag{2}$$

$$R1 + R2 = C = C / 2 + C = 3C / 2 \tag{3}$$

$$R3 = R4 = C + C / 2 + C = 3C / 2 \tag{4}$$

$$R4 = 90 - X = 90 - (180 - C) / 2 = C / 2 \tag{5}$$

Thus, the MR measurement is indicated by Eq. (6).

$$MR = R1 + R2 + R3 + R4 = C / 2 + 3C / 2 + 3C / 2 + C / 2 = 4C \tag{6}$$

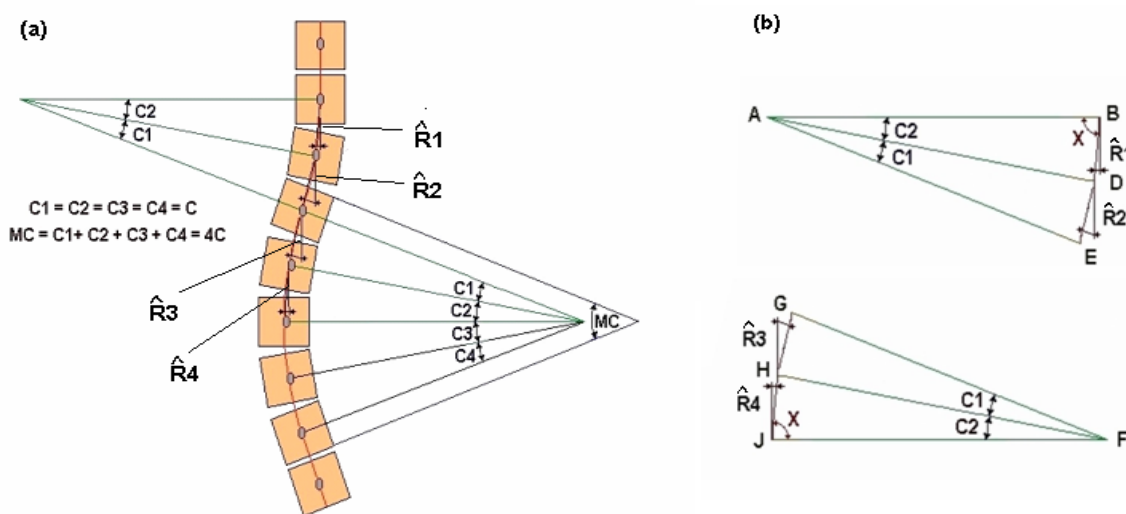


Figure 6. (a) Demonstration of the angle of scoliosis by the Cobb method ($MC = C1 + C2 + C3 + C4$) and the method of the present study ($MR = R1 + R2 + R3 + R4$). (b) Demonstration of the isosceles triangles formed by arcs of circle of each vertebral segment (BAD, DAE, and HFJ, HFG) and its relation to the angles R1, R2, R3 and R4.

Therefore, in this case, the value of the measurement obtained by this study will be obtained by the Cobb method. It is important to note that the previous statement does not represent a general solution, however, provides an understanding of the fact, observed in practice, that there is equivalence between the measure obtained by the method of this study and that obtained by the Cobb method.

3. RESULTS

In order to ascertain whether there is difference in measurements of dorsal and lumbar curve scoliotic between the Cobb method and the method proposed in this study, with regard to quantitative variables, there was the Wilcoxon test, which corresponds to the parametric paired t test. Table 1 shows the descriptive analysis of variables and p-value for the Wilcoxon test on values of scoliotic curvature using the Cobb method and computerized photogrammetry.

Table 1. Descriptive analysis and Wilcoxon test for angular values of the scoliotic curvature, obtained by Cobb method and computerized photogrammetry.

Method	N	Min.	Max.	Average	Standard deviation	p-value
Dorsal Cobb	13	17.80°	73.00°	36.14°	16.38°	0.529
Dorsal Photogrammetry	13	19.60°	74.20°	36.43°	16.67°	
Lumbar Cobb	15	10.00°	55.00°	25.71°	11.04°	0.615
Lumbar Photogrammetry	15	14.00°	48.60°	27.20°	10.05°	

According to the Table 1 is not possible to identify differences ($p\text{-value} > 5\%$) between the methods of computerized photogrammetry and Cobb in any of the two measurements (dorsal and lumbar). The similarity between the two methods can be better observed through Figs. 7 and 8.

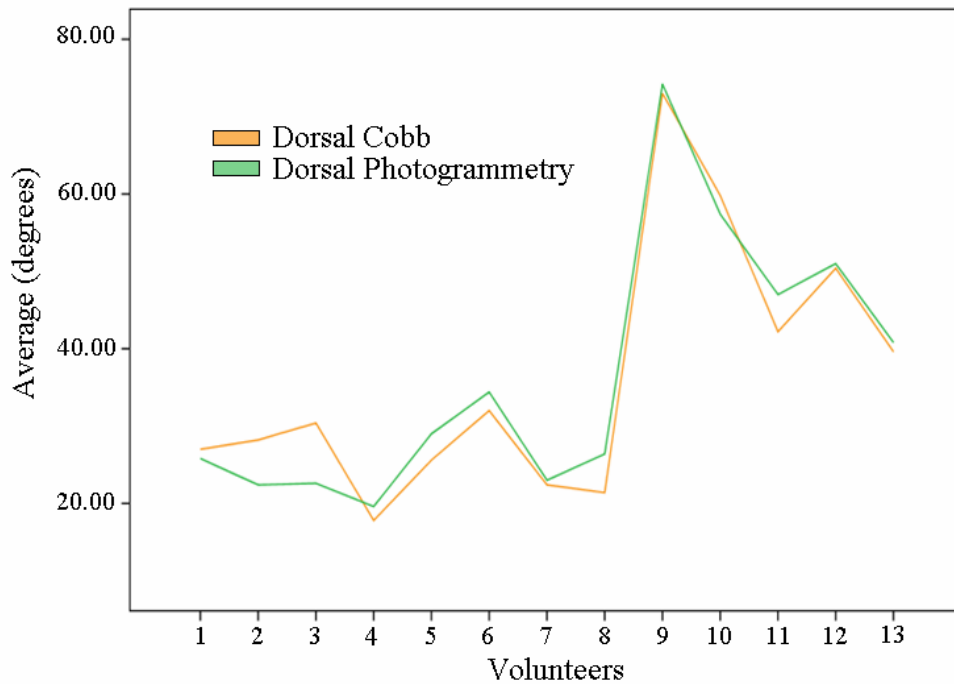


Figure 7. Comparative study between the values of the scoliotic dorsal curvature, obtained using the Cobb method and the computerized photogrammetry method, as proposed this study.

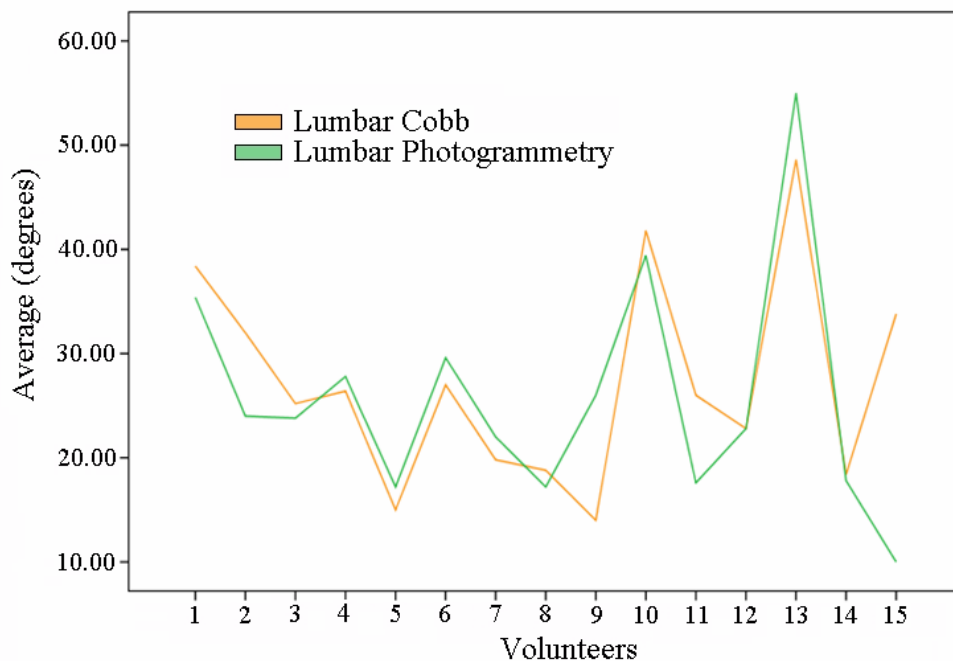


Figure 8. Comparative study between the values of the angle scoliotic lumbar curvature, obtained by Cobb method and the computerized photogrammetry method, as proposed in this study.

Figures 9 and 10 show the comparative study of the identification of the apical vertebra by means of radiography and by the computerized photogrammetry method, proposed in this study, for dorsal and lumbar curves.

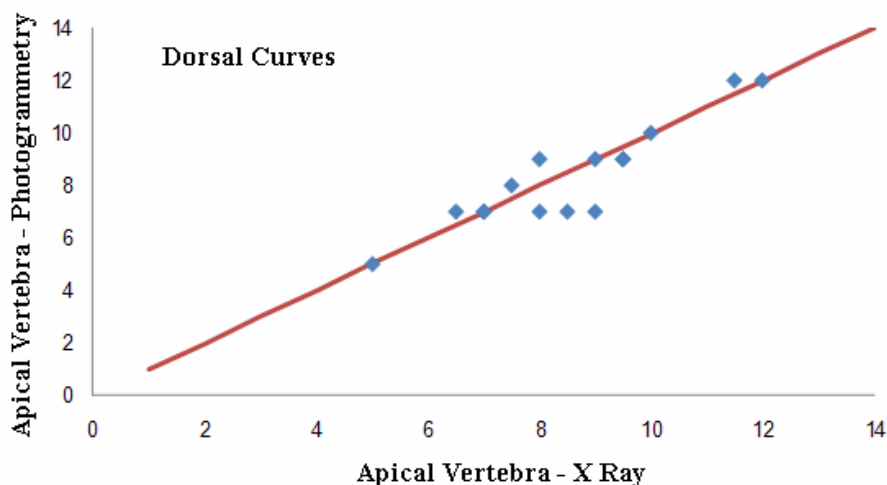


Figure 9. Comparative study for identification of the apical dorsal vertebra by computerized photogrammetry and X-rays.

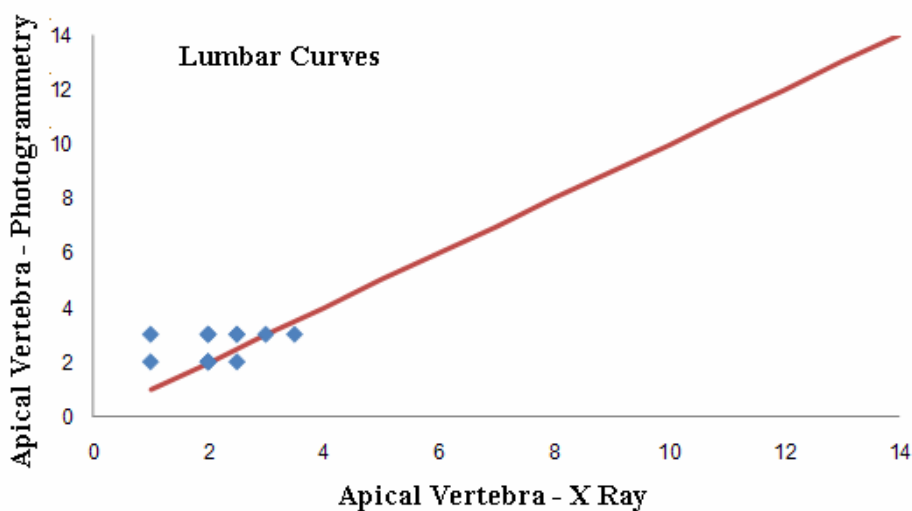


Figure 10. Comparative study for identification of the apical lumbar vertebra by computerized photogrammetry and X-rays.

The study shows that there is no significant difference between the vertebrae identified as apical, so for the thoracic segment as the lumbar segment of the spine, by two methods (p-value greater than 0.05).

4. DISCUSSION

The Cobb method is considered the gold standard for measuring and monitoring of scoliosis (Ovadia et al., 2007, Goldberg et al., 2006). However, several limitations are attributed to this method, such as multiple exposures to radiation, 2D projection for 3D deformation, the limit of tolerance related to changes within and between observers, in addition to the incomplete correlation between the Cobb angle and other aspects the scoliosis (Goldberg et al. 2006; Carman et al. 1990; Zmurko et al. 2003, Cheung et al. 2002). These reasons have motivated several studies in the search, among others, of noninvasive alternative for the quantification of the deformity (Ovadia et al. 2007; Zsidai, 2003, Goldberg et al. 2001; Sakka & Mehta 1995).

The evaluation method presented in this study introduces a new approach to noninvasive evaluation of scoliosis. He promoted measures of scoliotic curvature relatives of those obtained by the Cobb method. Silva (2002) and Dohnert & Tomasi (2008) studied the correlation between the angles of scoliosis obtained by the Cobb method with those obtained by computerized photogrammetry. In those studies, the authors observed no correlation between the angular values obtained by photogrammetry and computed radiography. The methodology used by these authors is different from presented in this study. First, were used in their studies anatomical landmarks of surface adherent, circulars and plans

used by Dohnert & Tomasi (2008), and low relief (15mm) used by Silva (2002). Because the three-dimensional nature of scoliosis, it is important to identify vertebral changes, not only in the frontal plane, but also in the axial and sagittal. For this reason it was developed, in this study, anatomic landmarks of the vectorial type, which enabled not only the identification of vertebrae showing deviation in the frontal plane, but also those who suffered in the axial plan. The possibility of finding three-dimensional coordinates of the base to the tip of the vector, allowed the visualization of the angular variation of the vector in any of the three spatial planes. Thus, a major step was to play a more appropriate, through the surface, the phenomenon of the deformity. Secondly, in previous studies, the spine was divided into 2 segments using as a reference, only, 3 vertebrae. This analysis model reproduced by the surface, measuring the angular Risser-Ferguson method, originally designed for analysis of radiography, not allowing the precise identification of the apical vertebrae and limits the curve to be seen committing the results.

Importantly, however, that the use of palpation of the spinous processes as the basis of information for analysis by computerized photogrammetry factors as body mass index (BMI) high, surgical resection of the spinous processes and inability of the examiner may be intervening factors. In this study, there was particular difficulty in locating the spinous processes of the lumbar spine and, in two volunteers, had no success in playing the skin on the geometry of the spinal line. These data corroborate those presented in the study of Comerlato (2007). In their study, the author showed that, although no statistically significant difference existed between the localization process of the spinous processes of vertebrae by radiography and palpation, there was a more pronounced difficulty in identifying the vertebrae of the lower lumbar spine, and the L4 vertebra presented the biggest mistake.

5. CONCLUSION

According to the descriptive statistics, there was no statistically significant difference ($p\text{-value} > 5\%$) between measurements of the scoliosis angle in the thoracic and lumbar curves. These results showed agreement with the mathematical relationship presented. Furthermore, there was no statistically significant difference ($p\text{-value} > 5\%$) between the location of the apical vertebra of the thoracic and lumbar scoliotic curvature by both the methods.

Further studies are needed to validate routines and experiments in larger groups of individuals, grouped by value angle (10° to 20° , 20° to 40° and above 40°) and by location of the scoliotic curvature (thoracic, lumbar and double curve).

The devices developed, rotating platform and MASV, have proved essential in developing the proposed protocol, making it important for the development of future studies. However, some procedures may be made to improve them. The rotating platform can receive engine with electronic control of positioning in the various angles required in the examination. This would reduce the time spent in the examination and make it more comfortable for the assessor. Moreover, the MASV should be made of material more resistant to currently used in the clinical practice.

6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

7. REFERENCES

- Berrington de Gonzales, A., Darby, S., 2004, "Risk of Cancer from Diagnostic X-rays: Estimates for the UK and 14 Other Countries", *Lancet*, v.363, p.345-351.
- Boné, C.M., Hsieh, G.H., 2000, "The Risk of Carcinogenesis from Radiographs to Pediatric Ortho-Pedic Patients", *J Pediatr Orthop*, v.20, p.251-254.
- Carman, D.L., Browne, R.H., Birch, J.G., 1990, "Measurement of Scoliosis and Kyphosis: Radiographs Intraobserver and Interobserver variation", *J Bone Joint Surg Am*, v.72, p.32-33.
- Cheung, J., Wever, D.J., Veldhuizen, A.G., et al, 2002, "The Reliability of Quantitative Analysis on Digital Images of the Scoliotic Spine", *Eur. Spine J*, v.11, p.535-542.
- Comerlato, T, 2007, "Avaliação da Postura Corporal Estática no Plano Frontal a Partir de Imagem Digital" Dissertação (Mestrado em Ciências do Movimento Humano): Universidade Federal do Rio Grande do Sul; Porto Alegre.
- Dohenert, M.B. & Tomasi, E., 2008, "Validação da Fotogrametria Computadorizada na Detecção de Escoliose Idiopática Adolescente", *Revista Brasileira de Fisioterapia*, v.12, n. 4, p.290-7.
- Doody, M, Lonstein, J.E., Stovall, M., Hacker, D.G., Luckyanov, N., Land, C.E., 2000, "Breast Cancer Mortality after Diagnostic Radiography: Finding from the U.S. Scoliosis Cohort Study", *Spine*, v.25, p.2052-2063.
- Goldberg, M.S., Mayo, N.E., Levy, A.R., Scott, S.C., Poitras, B., 1998, "Adverse Reproductive Outcomes among Women Exposed to Low Levels of Ionizing Radiation from Diagnostic Radiography for Adolescent Idiopathic Scoliosis", *Epidemiology*, v.9, p.271-278.

- Goldberg, C.J., Groves, D., Moore, D.P., Forgarty, E.E., Dowling, F.E., 2006, "Surface topography and vectors: A new measure for the three dimensional quantification of scoliotic deformity", *Research into Spinal Deformities*, v.5, p. 449-455.
- Levy, A.R., Goldberg, M.S., Hanley, J.A., Mayo, N.E., Pointras, B., 1994, "Projecting the Lifetime Risk of Cancer from Exposure to Diagnostic Ionizing Radiation for Adolescent Idiopathic Scoliosis", *Health Phys*, v.66, p.621-633.
- Levy, A.R., Goldberg, M.S., Mayo, N.E., Hanley, J.A., Pointras, B., 1996, "Reducing the Lifetime Risk of Cancer from Spinal Radiographs among People with Adolescent Idiopathic Scoliosis" *Spine*, v.21, p.1540-1547.
- Ovadia, D., Baron, E., Fragnière, B.; Rigo, M.; Dickman, D., Leitner, J., Wientroub, S., Dubousset, J.2007, "Radiation-Free Quantitative Assessment of Scoliosis: A multi Center Prospective Study", *Eur Spine J*, v.16; p.97-105.
- Ron, E., 2003, "Cancer risks from medical radiation", *Health Phys*, v.85, p.47-59.
- Sakka, S.A., Mehta, M.H., 1995, "Correlation of the Quantec Scanner Measurements with X-Ray Measurements in Scoliosis", Presented at the Annual Meeting of the British Orthopedic Association, Aberdeen, UK, Sept. 19 – 22.
- Sahlstrand, T., 1986, "The Clinical Value of Moiré Topography in the Management of Scoliosis", *Spine*, v.11, p.409-417.
- Silva, T. F., 2002, "O Uso da Biofotogrametria Computadorizada na Mensuração da Curva Escoliótica", Dissertação (Mestrado em Fisioterapia), UNITRI- Centro Universitário do Triângulo, Uberlândia.
- Tribastone, F., 2001 "Tratado de Exercícios Corretivos - Aplicados à Reeducação Motora Postural", São Paulo, Ed. Manole, cap.15; p. 213-216.
- Zmurko, M.G., Mooney, J.F. 3rd, Podeszwa, D.A., 2003, "Inter and Intraobserver Variance of Cobb Angle Measurements with Digital Radiographs" *J Surg. Orthop. Adv.*, v.12, p.208-213.
- Zsidai, A., Kocsis, L., 2003, "Ultrasound Based Spinal Column Examination Systems", *Facta Physical Education and Sport*, v.1.n. 8, p.1-12.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.