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Accuracy of photogrammetry to detect thoracic changes in individuals with adolescent idiopathic scoliosis

Acurácia da fotogrametria para detectar alterações torácicas em indivíduos com escoliose idiopática do adolescente

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Abstract – Total radiography of the spine in patients with adolescent idiopathic scoliosis (EIA) is the gold standard for classifying curve severity by the Cobb method. These patients often require X-rays, thus being exposed to increased radiation. Therefore, studies have addressed alternatives for identifying vertebral alterations, as well as computerized photographic methods or photogrammetry. Thus, this study aimed to verify the accuracy of photogrammetry in detecting thoracic changes in individuals with AIS. A cross-sectional and all-time study was performed on patients diagnosed with Lenke I EIA and healthy adolescents. All patients had pictures taken of their whole body, with anatomical markers positioned at previously studied points. Roc curves were determined and the area under the curve was calculated to identify the best measurements of angles and distances in the Postural Analysis Software (SAPO). The combined points of greater sensitivity and specificity were set as the cutoff point for detecting postural changes. 78 volunteers were assessed, divided into two groups: scoliosis (n=47) and control (n=31). The angles and distances measured by SAPO showed differences between the groups. The angles and distances A2, A4D/A4E, A5D/A5E, A7, and D1D/D1E reached an area under the ROC curve above 0.7. In conclusion, the use of photogrammetry can benefit assessments by identifying thoracic alterations and screening the progression of the scoliosis curve, since the angles and relationships have good accuracy in identifying Lenke I scoliosis.

Key words: Scoliosis; Image processing; Postural.

Resumo – *A radiografia total da coluna em pacientes com escoliose idiopática do adolescente (EIA) é o padrão ouro para classificar a gravidade da curva pelo método Cobb. Esses pacientes necessitam de radiografias frequentes, o que promove um aumento da exposição à radiação. Diante disso, alternativas para identificar alterações vertebrais estão sendo estudadas, tais como métodos fotográficos computadorizados ou fotogrametria. Dessa forma, o objetivo deste trabalho foi identificar a acurácia da fotogrametria para detectar alterações torácicas em indivíduos com EIA. Foi realizado um estudo transversal com pacientes com diagnóstico de EIA Lenke I e adolescentes saudáveis, sendo que todos fizeram fotos do corpo todo, com marcadores anatômicos posicionados em pontos previamente estudados. Para identificar as melhores medidas de ângulos e distâncias no software de análise postural (SAPO), foram determinadas as curvas ROC e calculada a área sob a curva. Os pontos combinados de maior sensibilidade e especificidade foram definidos como ponto de corte para a detecção das alterações posturais. Foram avaliados 78 voluntários, divididos em dois grupos: escoliose (n=47) e controle (n=31). Em relação aos ângulos e as distâncias medidos pelo SAPO, foi observada diferença entre os grupos para os ângulos e distâncias. Os ângulos e distâncias que obtiveram área sob a curva ROC maior que 0,7 foram A2, A4D/A4E, A5D/A5E, A7 e D1D/D1E. Conclui-se que o uso da fotogrametria pode auxiliar na avaliação ao identificar alterações torácicas, podendo ser utilizada como modo de triagem da progressão da curva da escoliose, visto que os ângulos e relações apresentam boa acurácia para identificar a escoliose Lenke I.*

Palavras-chave: *Postura; Escoliose; Fotogrametria.*

INTRODUCTION

Scoliosis is a three-dimensional deformity of the spine, characterized by a lateral deviation in the frontal plane, thoracic hyperphosis in the sagittal plane, as well as vertebral rotation in the transverse[1]. The idiopathic form corresponds to most cases of scoliosis, whose occurrence in adolescents is the most common[2].

Scoliosis is diagnosed by the Adams test, which aims to identify possible asymmetries in the rib cage with the patient positioned in anterior trunk flexion, associated with total radiography of the spine[3].

Total radiography of the spine in patients with adolescent idiopathic scoliosis (AIS) is the main imaging exam that allows classifying the severity of the curve by the Cobb method. Therefore, patients with AIS often require spine radiographs for the progression of the curve to be monitored, thus being exposed to increased radiation[4]. In this context, although the Cobb method is the reference standard for identifying and assessing the magnitude of the AIS curve, there is concern about reducing as much as possible the number of radiographs to which these individuals are subjected[5].

In addition to the problems caused by radiation exposure, several factors are known to influence the calculation of scoliosis angles, such as the use of different measurement tools, the subjectivity in selecting of the vertebrae involved, and even the experience of each evaluator who measures the angle identified in the radiography[6].

Currently, studies have addressed and employed alternatives for identifying spinal changes, without health risks involved, such as the use of photographs to assess musculoskeletal conditions and changes[7-9].

In this context, computerized photographic methods, or photogrammetry, stand out among alternative assessment techniques. These methods can identify deformities and subtle changes in the trunk and rib cage based on angular and linear measurements[7,8].

Postural Analise Software (SAPO) is a free, easy-to-apply, reliable reproducibility computer program that allows assessing changes in parts of the human body that are difficult to identify by other imaging techniques. The program uses fixed and specific anatomical markers for measurement[10,11] that could be used in cases of suspected alterations or for monitoring patients with AIS.

Considering the need to use less invasive, low-cost assessment methods of easy application and reproduction, this study aims to verify the accuracy of the postural analysis software (SAPO) in detecting thoracic changes in individuals with AIS.

METHODS

This is a cross-sectional study with patients diagnosed with AIS and healthy adolescents. As inclusion criteria, the patients with AIS must present Lenk and type I classification scans with deviation from the main thoracic curve to the right, as it is the most prevalent among cases of adolescent idiopathic scoliosis[12] of both genders aged between 11 and 18 years.

Individuals with a previous or current history of heart, pulmonary, or neuromuscular diseases were excluded from the analyses in both groups, and volunteers who could not perform the appropriate assessment were excluded from the analyses.

Adolescents with idiopathic scoliosis were recruited from the Spine Outpatient Clinic of the Department of Orthopedics and Traumatology of a local hospital. All patients were submitted to radiography in anterior and lateral incidences. The Cobb angles of the proximal thoracic, main thoracic, and lumbar curves were measured.

Following the assessment by the Cobb method, the curves were classified according to Lenke, and the patients who fit the Lenke type I were selected, defined as the main thoracic curve structured with flexible and unstructured proximal and lumbar thoracic curves[12].

In turn, the volunteers of the control group were recruited through advertisements in local newspapers and those between 10 and 18 years of both sexes were included. Subsequently, to discard gibbosity – the main characteristic of scoliosis – the same trained evaluator performed the screening, which consisted of a postural evaluation observing shoulder height, leveling of the scapulae, Talhe triangle, pelvic leveling, and anterior trunk flexion test. All participants in the control group used bathing suits and radiographs were not required to discard scoliosis for screening.

This study was approved by the Ethics Committee under number 79579917.0.0000.5505. All volunteers and their guardians signed the consent form and free and informed consent and were evaluated by the same trained team.

Thoracic assessment by photogrammetry

The volunteers were positioned in an orthostatic position under a carpet of Ethyl Vinyl Acetate (EVA), at three meters from a digital camera using a manual trigger (SONY – Cyber-Shot, DCS-W300). This camera was positioned parallel to the ground, with the aid of a professional tripod positioned at half the height of each volunteer. The EVA mat was used for the foot position to remain the same in each photo shot.

The calibration of the photo dimensions in the vertical position using the software required the use of a plumb wire on the ceiling of the evaluation room, positioned near the marked location for the photo. The photos were taken in the anterior, left, right, and posterior side views.

All boys wore one-piece bathing suits, and all girls wore two pieces bathing suits for a better visualization and positioning of the markers.

Marking of anatomical points

After positioning the volunteers at a correct distance from the camera, the anatomical points were delimited on the skin by fixing half a sphere of soft balls 25 mm in diameter using a double-sided adhesive tape. The stitches were marked on the manubrium of the sternum; acromion of the scapula; xiphoid process; inframammary region corresponding to half the distance between the nipple and the last rib; last false rib positioned at the intersection of the nipple line with the last false rib; anterosuperior iliac spine (ASIS); spinous process of C7; upper angle of the scapula; spinous process of T3, and lower angle of the scapula (Figure 1).

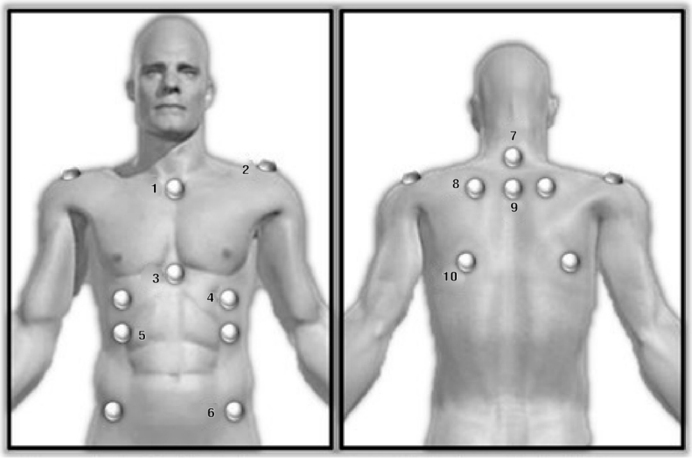

Figure 1. Anatomical points. 1. Manubrium of the sternum; *2.* Acromion of the scapula; 3. Xiphoid process of the sternum; 4. Inframammary region; 5. Last false rib; 6. Anterosuperior iliac spine 7. Spinous process of C7; 8. Upper angle of the scapula; 9. Spinous process of T3; and 10. Bottom angle of the scapula.

Postural Analysis Software (SAPO)

All analysis of the photographs on SAPO were performed by the same evaluator, according to the following routine: photo opening, 75% zoom, calibration of the image from the plumb wire, and marking of the anatomical points.

Following calibration, the photographs were analyzed according to the measurements of distances (D) and angles (A) between the previously delimited anatomical points (Figure 2). All these angles and distances were created by our team, except angle A1[13].

Statistical method

Initially, the data were analyzed and presented as mean and standard deviation and median and interquartile intervals. For the distance of the variables in centimeters, we calculated the relationship between the right and left sides. As all participants presented deviation to the right, all calculations were performed for the right distance/left distance.

The normality of the variables was analyzed by the Shapiro-Wilk test and the variables between the groups were compared by the Mann-Whitney test or unpaired T-test. Roc curves were determined and the area under the curve was calculated to identify the best measurements of angles and distances in SAPO. The combined points of greater sensitivity and specificity were defined as the cutoff point for detecting postural changes. The areas under the curve above 0.7 were considered adequate to distinguish between the postural changes.

For values under the curve above 0.7, positive and negative predictive values, sensitivity, and specificity were calculated based on the highest sensitivity and specificity values.

RESULTS

Seventy-eight volunteers were evaluated and divided into two groups: scoliosis (AIS) and control, out of which 47 patients had AIS and 31 were healthy adolescents. Seventeen patients were excluded from the scoliosis group, one due to asthma diagnosis and the others for not presenting type I Lenke classification or not showing the main thoracic curve with right deviation. Eleven volunteers were excluded from the control group for presenting postural alterations identified during screening. Thus, 30 patients with AIS and 20 healthy adolescents were included for data analysis (Figure 3).

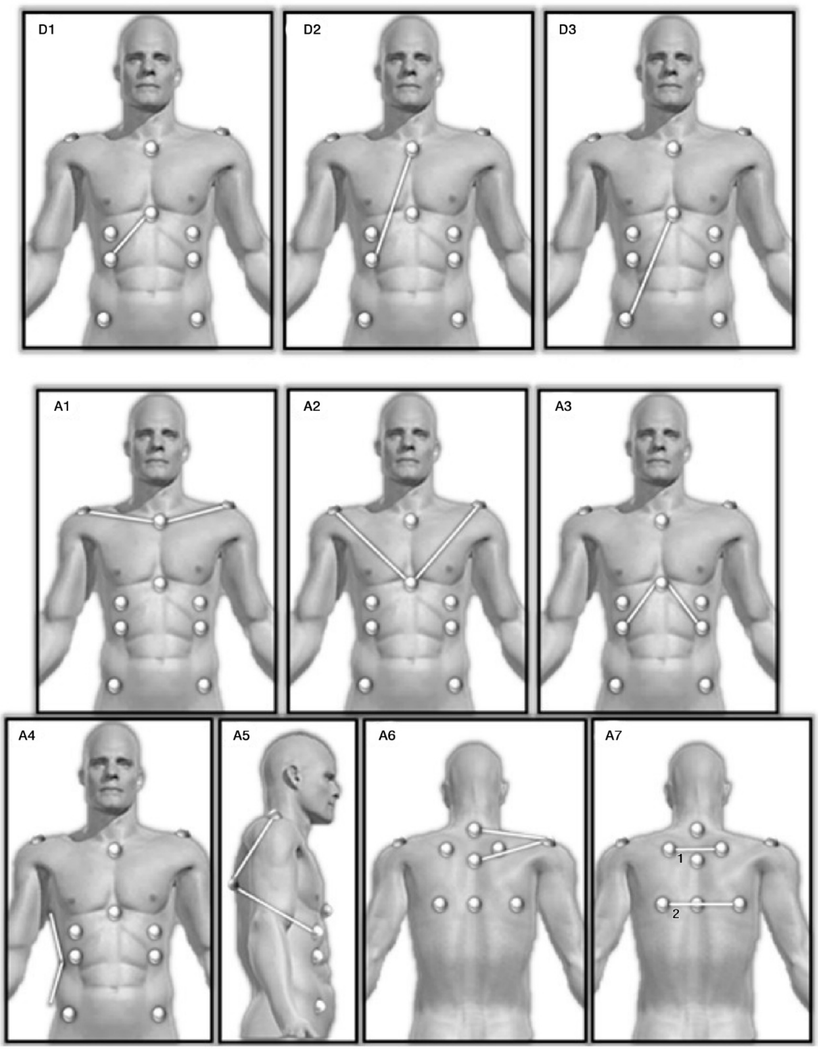

Figure 2. Postural Analysis Software. D1. Xiphoid process / last false rib on the right and left side; D2. Manubrium / last false rib on the right and left side; D3. Xiphoid process / right anterosuperior iliac spine. A1. right acromion / manubrium / left acromion; A2. Right acromion/xiphoid process / left acromion; A3. Last false right rib / xiphoid process / last false left rib; A4. Angle between the deepest point of the waist and the upper and lower edges of the waist; A5. Inframammary region / lower scapula angle/right and left acromion; A6. C7 / acromion right and left / T3; A7. Angle formed by the intersection of the tangent segments of the upper and lower scapula angles.

Table 1 describes the demographic and anthropometric characteristics, with no statistical differences found between the groups, in addition to the characterization of scoliosis by Cobb angles.

The angles and distances measured by SAPO showed a difference between the groups for angles A2, A4E, and A7, as well as D1D and D1E for distances (Table 2).

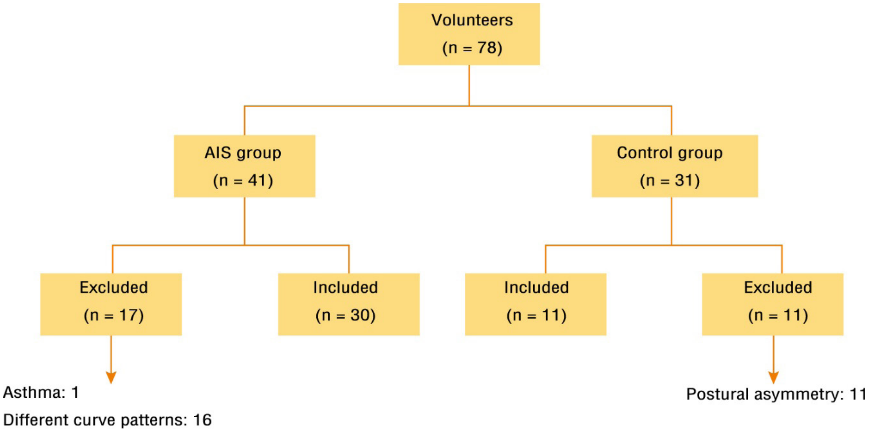

Figure 3. Volunteer selection flowchart.

Table 1. Demographic and anthropometric characteristics and Cobb angle value.

Variables	AIS (n = 30)	Control (n = 20)	p
Female	27 (90%)	17(85%)	0.670
Age (years)	14 [12.17 – 16.25]	14.5 [13 – 17]	0.645
Weight (kg)	47.64 ± 6.96	50.17 ± 9.18	0.250
Height (m)	1.58 ± 7.54	1.60 ± 7.53	0.417
IMC (kg/m²)	18.86 ± 2.24	19.44 ± 2.48	0.409
CobbTpx (°)	25.35 ± 13.37		
CobbTp (°)	60.65 ± 15.47		
Cobb L (°)	35.24 ± 10.37		

Note. AIS: adolescent idiopathic scoliosis; n: sample size; m: meters; Kg: kg; BMI: body mass index; Kg/m2: kilogram per square metre; CobbTpx: Proximal Thoracic Cobb angle; CobbTp: Main Thoracic Cobb Angle: CobbL: Lumbar Cobb Angle; p: significance level.

Table 2. Values of angles and distances measured on SAPO

Variable	AIS (n=30)	Control (n=20)	p
Angles (Degrees)			
A1	173.25 [166.37-180.87]	170.50 [164.42-179.04]	0.201
A2	88.46 ± 8.60	78.97 ± 6.23	>0.001*
A3	87.15 [77.97-97.07]	87.60 [82.85-99.97]	0.308
A4D	161.50 ± 6.99	158.59 ± 7.59	0.170
A4E	144.60 ± 9.63	158.33 ± 6.86	>0.001*
A4D/A4E	1.10 [1.07 - 1.12]	0.99 [0.98 - 0.99]	>0.001
A5D	75.36 ± 9.27	78.28 ± 6.75	0.198
A5E	83.20 [75.95 – 96.30]	78.85 [74.40 – 87.12]	0.182
A5D/A5E	0.91 [0.81 - 1.01]	0.98 [0.96 - 1.05]	0.005*
A6D	18.60 [14.60 – 23]	18.60 [15.17 - 20.95]	0.714
A6E	17.57 ± 3.96	18.63 ± 3.50	0.257
A6D/A6E	1.00 ± 0.11	0.98 ± 0.99	0.593
A7	4.70 [1.90 – 7.30]	2.65 [1.97 – 3.77]	0.016*

Table 2. Continued...

Variable	AIS (n=30)	Control (n=20)	p
Distances (cm)			
D1D	11.54 ± 2.10	10.34 ± 1.26	0.015*
D1E	11.20 ± 2.21	9.29 ± 1.24	>0.001*
D1D/D1E	1.03 ± 0.12	1.11 ± 0.11	0.020*
D2D	25.07 ± 3.02	24.74 ± 2.54	0.677
D2E	24.64 ± 3.11	23.77 ± 2.85	0.311
D2D/D2E	1.01 ± 0.05	1.04 ± 0.05	0.078
D3D	23.29 ± 2.73	23.35 ± 2.35	0.938
D3E	23.25 [21.77-26.05]	22.75 [21.50-24.94]	0.357
D3D/D3E	1.00 [0.67 - 1.03]	1.01 [0.99 - 1.04]	0.320

Note. AIS: Adolescent idiopathic scoliosis; n: sample size; A1: acromion D/manubrium/ acromion E; A2: acromion D/xiphoid process/acromion E; A3: last false rib D/xiphoid process/last false rib E; A4: lateral deviation of the trunk; A5: acromion/lower angle of the scapula/ Inframammary region; A6: C7/ acromion /T3; A7: intersection of segments 1 and 2 D1. Xiphoid process / last false rib on the right and left side; D2. Manubrium / last false rib on the right and left side; D3. Xiphoid process / right anterosuperior iliac spine; cm: centimeters; p: significance level; * - statistically significant difference (p < 0.05).

Table 3 and Figure 4 show the description of the sensitivity, specificity, positive predictive value, negative predictive value, and area under the curve (AUC) for the angles and distances with an area under the ROC curve above 0.7.

Table 3. Sensitivity, specificity, positive and negative predictive values, and accuracy of angles and distances measured on SAPO

Variable	Cutoff Point	Area	95% CI	Sensitivity (%)	Specificity (%)	VVP (%)	VVN (%)
A2	>80.5	0.792	0.653-0.896	83.33 (65.3-55)	55 (31.5-76.9)	73	69
A4D/A4E	>1.038	0.993	0.916-1.000	100 (88.4-100)	95 (75.1-99.9)	93	1
A5D/A5E	≤0.948	0.728	0.582-0.845	62.07 (42.3-79.3)	85 (62.1-96.8)	86	58
A7	>2.8	0.703	0.557-0.824	73.33 (54.1-87-7)	40 (40.8 - 84.6)	70	59
D1D/D1E	≤1.07	0.708	0.563-0.828	73.33 (54.1-87.7)	60 (36.1-80.9)	73	60

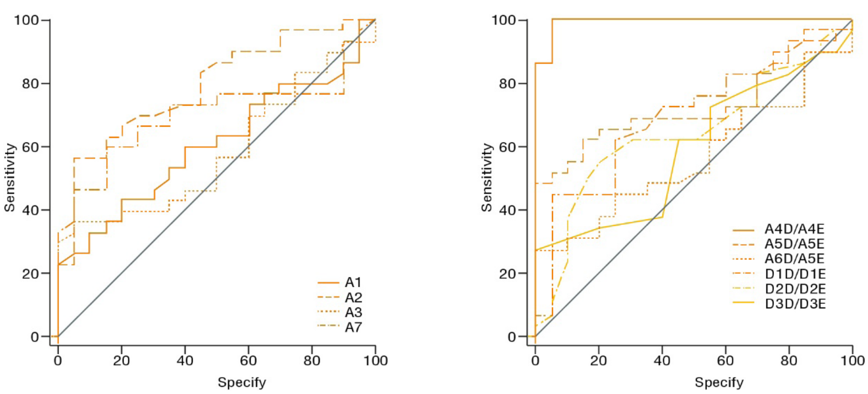

Figure 4. Curves of angles (A) and relationships between angles (A) and right (D) and left (E) distances (D).

DISCUSSION

The present study identified that some measurements of angles (A2 and A7) and relationships between the right and left side (A4D/A4E. A5D/A5E and D1D/D1E) evaluated by the Postural Assessment Software (SAPO) showed statistical differences between the scoliosis group and the control group. The proportion of right and left A4 angles presented a good accuracy in detecting postural changes that may be associated with adolescent idiopathic scoliosis.

The literature comprises several studies addressing the use of photogrammetry to evaluate patients with scoliosis; however, markers are only used in the segments of the vertebrae[8,14]. In our study, we used anatomical markers in the rib cage at specific points that are easy to identify, since the three-dimensional alterations of the spine influence the entire conformity of the structures that form the rib cage[3], which is an advantage of using the points suggested herein. In addition, the A4 angle requires no markers for the photographs to be taken, requiring just a previous photo of the individual.

Previous studies conducted by our study group used the same thoracic markers and identified differences in distances and angles between the scoliosis group and the control group, as well as important differences between patients with scoliosis before and after arthrodesis surgery[11,15,16]. In our study, in addition to identifying these differences, we assessed the accuracy of this method in identifying the patient with adolescent idiopathic scoliosis.

According to the evaluation criteria of the Brazilian Society of Orthopedics and Traumatology (SBOT), a patient with AIS, classified as Lenke type I, with a main thoracic curve deviating to the right, exhibits characteristics such as elevation of the right shoulder and a larger left Talhe triangle compared to the right. This results in left arm appearing longer and farther from the body, as well as folds on the left flank. Additionally, the left iliac crest is more prominent than the right, with an asymmetry of the anterosuperior iliac spines. The right scapula is higher and more prominent than the left, and the left breast may appear larger than the right due to trunk rotation.

Trunk asymmetry is one of the main characteristics for identifying adolescent idiopathic scoliosis. Upon finding the values of angles and distances bilaterally, SAPO proves to be sensitive enough to assist in the identification and monitoring of scoliosis. When comparing the relationship between the A4D/A4E angles, we observed 100% sensitivity and 95% specificity to identify idiopathic scoliosis classification Lenk type I with head thoracic deviation to the right for values above 1.038.

The ratio of A4 angles > 1.038 is an easy-to-measure angle for clinical practice using software for postural assessment. The A4 angle requires no marker during the photographic process, which makes it one of the easiest angles to be observed and delimited on the software.

We observed that the A4D/A4E ratio is higher in adolescents with scoliosis than in the control group, which proves the identification of asymmetry concerning the inclination of the trunk to the left side, particular to right thoracic scoliosis.

Using this measure for the relationship of the trunk inclination to the right and left sides can help in the screening of scoliosis and monitoring of the curve progression, as a simple, noninvasive, and low-cost alternative that involves no health risks.

In addition to the asymmetry of lateral inclination, the asymmetry resulting from the inclination and rotation of the ribs and sternum can be represented by changes in the measurement of angle A2, which corresponds to the angle formed by the right acromion, xiphoid process, and left acromion. The data analyzed indicated that angle A2 demonstrated 83.3% sensitivity and 55% specificity in identifying adolescent idiopathic scoliosis when exceeding 80.5°.

Based on our observations, patients with scoliosis showed higher values of angle A2 compared with those in the control group. Such an increase appears due to the rotation of the vertebral body to the convex side, as well as from the spinous process to the concave side. Hence, the ribs tend to follow vertebral rotation and rotate back and forth on the convex side and forward on the concave side[17]. Therefore, angle A2 could be a useful tool in clinical practice for the identification and follow-up of AIS, as the deformity derived from the marked spine curvature indirectly affects other structures of the rib cage.

Furthermore, we found an increase in the angulation of marker A7 in patients with AIS compared with those in the control group. This angle corresponds to the unevenness of the scapulae, which is an important characteristic found in individuals with scoliosis, with A7 presenting 73.33% sensitivity and 50% specificity when identifying scoliosis for values above 2.8°.

In addition to these differences for the A4E angle, the patients with scoliosis presented lower mean values than the adolescents in the control group. The characteristics of the lower values for the A4E angle meet the Brazilian Society of Orthopedics and Traumatology evaluation criteria describing the trunk inclination to the left side as a characteristic of patients with scoliosis classified as Lenke type 1, with deviation from the main thoracic curve to the right.

Trunk inclination is an easy-to-identify characteristic with potentially good sensitivity (70%) for the assessment of scoliosis. This angle for scoliosis with the main right curve classified as Lenke type 1 can be monitored and screened using only photogrammetry, without requiring random radiographs.

In addition to the angles obtained, some distances were identified that might represent a non-harmful assessment alternative for the follow-up of the progression of the scoliosis curve. The distances D1D and D1E showed differences between the groups studied. We found that both distances were higher in the group of adolescents with scoliosis compared with the control group.

Anatomical markers of distances D1 can help identify rib cage rotation. The ribs tend to follow vertebral rotation as they rotate back and forth on the convex side, which favors the increase of D1D. In contrast, the increase in D1E occurs by vertebral rotation rotating the ribs forward on the concave side.

Radiography is a gold standard method to assess the magnitude of scoliosis[18] and different imaging methods have already been developed[8,15,19,20]. We understand that photogrammetry with SAPO could increase the intervals of need for further radiographic assessments based on the monitoring of angular values and distances obtained in our study.

The limitations of our study include the sample size referring to other types of scoliosis since we evaluated only adolescents with scoliosis with Lenk classification of type I with deviation from the main thoracic curve to the right. Perhaps the values of angles and distances would present differences in the identification of the different types of scoliosis.

CONCLUSION

In conclusion, we suggest that using markers identified by SAPO can assist the patient's assessment by finding alterations in other anatomical structures, besides the spine itself, in the context of adolescent idiopathic scoliosis, complementing the assessment of the curve severity by the Cobb method. We also suggest the use of SAPO as an alternative for screening the progression of the scoliosis curve since the angles and ratios A2, A7, 4D/A4E, A5D/A5E, and D1D/D1E present good accuracy in identifying scoliosis.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee – Federal University of Sao Paulo and the protocol (no. 1.349.351) was written in accordance with the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Conceived and designed the experiments: ASA, EFS, MCV. Performed the experiments: ASA, EFS. Analyzed the data: BMAS, ASA, JD, MCV. Contributed reagents/materials/analysis tools: BMAS, JD, VZD. Wrote the paper: BMAS, JD, VZD, MCV.

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