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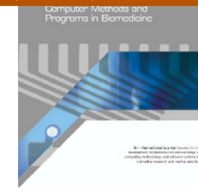

Validating a postural evaluation method developed using a Digital Image-based Postural Assessment (DIPA) software

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ABSTRACT

Objective: To investigate (1) the accuracy of the palpatory method to identify anatomical points by comparison with the X-ray exams, (2) the validity of classifying spinal posture in the frontal plane using Digital Image-Based Postural Assessment (DIPA) software by comparison with the X-ray exams and (3) the intra and inter-evaluator reproducibility of the DIPA software.

Materials and methods: The postural assessment and X-ray examination of the spine, both in the frontal plane and standing position, were performed consecutively in 24 subjects. The postural assessment protocol consisted of: (1) palpation and the use of reflective markers containing lead to mark the spinous processes (SP) of the C7, T2, T4, T6, T8, T10, T12, L2, L4 and S2 vertebrae and; (2) acquisition of photographic records. First, the X-ray examinations were used to check the correlation between the palpated and marked SP and the true location of the SP of the vertebra in question, by assessing the distance between them. The spinal posture was classified based on the calculation of the scoliosis arrows in the DIPA (DIPA-SA). The X-ray examinations provided the scoliosis arrows (X-SA), the Cobb angles and the classification of spinal posture based on the Cobb angle. The results from the DIPA protocol were compared to those from the X-ray examination-based protocol. The statistical tests used were: (1) Kruskal–Wallis – differences in terms of the numerical distance between the markers and the anatomical landmarks, (2) Pearson's Correlation – DIPA-SA and Cobb angles, (3) Pearson's Correlation – X-SA and DIPA-SA; (4) Bland and Altman's graphic representation – X-SA and DIPA-SA, (5) Spearman's Correlation – classification of spinal posture obtained using the X-ray and DIPA protocols, (6) the intraclass correlation test (ICC) for the relationship between the DIPA-SA made by each evaluator (inter-evaluator), and (7) independent *t*-test to compare the data from the two evaluation days (intra-evaluator), $\alpha = 0.05$.

Results: There were no significant differences between the location of the anatomical points located using palpation and identified with reflective markers and the respective location of the SP as identified using X-ray exams ($\chi^2 = 9.366$, $p = 0.404$). Significant correlations were

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found between the DIPA-SA and the Cobb angles in the dorsal ($r = 0.75$, $p < 0.001$) and lumbar ($r = 0.76$, $p = 0.007$) regions; between the DIPA-SA and the X-SA in the dorsal ($r = 0.79$, $p < 0.001$) and lumbar ($r = 0.92$, $p < 0.001$) regions and; between the classifications of posture obtained with the DIPA and X-ray protocols ($r = 0.804$, $p < 0.001$). Bland and Altman's representation showed agreement between DIPA-SA and X-SA for both curvatures. Significant correlations were found for the intra-evaluator test in the thoracic ($r = 0.99$, $p < 0.001$) and lumbar ($r = 0.98$, $p < 0.001$) regions; for the inter-evaluator test in the thoracic ($r = 0.99$, $p < 0.001$) and lumbar ($r = 0.88$, $p < 0.001$) regions. The results suggest that the DIPA protocol constitutes a valid simple, practical and low-cost non-invasive tool for the evaluation of the spine in the frontal plane which can be used to obtain reproducible measurements (inter and intra-evaluators).

1. Introduction

The clinical evaluation of frontal plane postural alterations, such as scoliosis, has been based on the calculation of Cobb's angle of curvature from X-ray exams, which in order to follow the evolution of the patients need to be carried out periodically [1–4]. The main problem with this clinical practice is that the patient is repeatedly exposed to radiation. This is particularly harmful in the case of adolescents given the increased risk of leukemia and breast and thyroid cancer [5–7]. In order to avoid any possible negative effect that maybe caused by multiple radiographic examinations during growth there should be a minimum of six months between such examinations [8,9]. However, in orthopedic clinical practice it can be seen that these examinations are frequently requested at shorter intervals.

Therefore, non-invasive techniques of postural evaluation are an alternative to X-ray examinations [9] when following the evolution of physiotherapy for spinal deviations. Several non-radiographical and non-invasive postural evaluation techniques have been proposed in order to evaluate and quantify postural alterations during the course of therapeutic treatment. Among them are the scoliometer [10], Moiré topography [11,12], arcometer [9,13,14], flexicurve [15–19], pantograph [20], kyphometer [21], inclinometer [22], as well as, some computer-based techniques, such as photogrammetry and postural evaluation softwares [23–28].

The process of assessing digital-image based postural evaluation softwares can be divided into two different steps: (1) using palpation to identify and mark the relevant anatomical points, and (2) using the information regarding those points as input data in an algorithm to obtain appropriate results. Although the palpation procedure and its level of accuracy when used to identify anatomical points has been described in the literature [29,30], it is considered indispensible that the procedure used to identify the inputs to be used in any software should first be tested for its accuracy, and that the results obtained using the software are tested for their intra and inter-reproducibility.

The postural evaluation software programs found in the literature are partially validated, that is, they have only been tested for inter and intra-evaluator reproducibility [25,28]. Moreover, the results provided by these software programs are limited to angles, distances and pre-established lengths, which certainly aid visual postural evaluation. However, as far as we know, there are no reports in the literature of any software that provides an effective classification of the subject's spinal posture.

Accordingly, the aims of the present study are to investigate (1) the accuracy of the identification of the anatomical points using the palpatory method by comparing them with X-ray exams, (2) the validity of classifying spinal posture in the frontal plane using Digital Image-Based Postural Assessment (DIPA) software by comparing the results with those obtained using X-ray exams and (3) the intra and inter-evaluator reproducibility of the DIPA software. The advantage of DIPA software lies not only in the identification of any deviation in the alignment of the spinous processes, but also in the application of this information to objectively classify spinal posture in frontal plane. It is believed that information of this nature maybe useful for demonstrating the reliability of treatment results, as well as providing quantitative analysis of the postural alterations in the spine.

2. Methodology

2.1. Sample

The sample consisted of 24 patients (16 women and 8 men) from a radiology clinic. The average age, body mass and height were 31.9 years (±12.3); 58.4 kg (±9.4) and 1.66 m (±0.07) respectively. The inclusion criteria were: clinical diagnosis of scoliosis and a medical prescription for X-ray examination. The exclusion criteria were: the presence of a sixth lumbar vertebra, diseases or disorders that impede orthostasis and contraindications to X-ray examination. All the subjects voluntarily agreed to participate in the study and signed a free informed consent form. The study was in accordance with Helsinki Declaration and approved by the ethics committee of the institution were the study was conducted and registered under the number 2006660.

2.2. Data acquisition procedures

Each subject, while wearing underclothes, was submitted to three data acquisition procedures in sequence: (1) palpation and marking of the anatomical reference points; (2) X-ray examination, carried out by a responsible professional; and (3) frontal plane photography. The palpation, marking procedures and photography were carried out by the same evaluator, who was previously trained in these procedures.

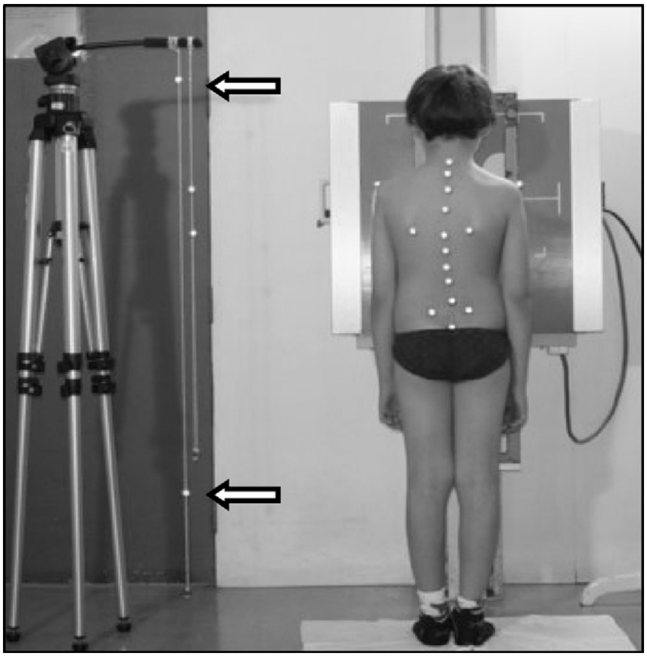

Fig. 1 – Reflective markers on the anatomical reference points and on the plumb line (white arrows).

In the same location where the X-ray examination was carried out, the anatomical points of reference were palpated and marked on the body of the patients in the standing position. Reflective markers were attached to these points using double-faced tape. The markers consisted of polystyrene spheres (1.2 cm in diameter), cover with hyper-reflective paper containing lead-based paint, so that they would simultaneously appear in the X-ray and photographic images. To ensure identification during the X-ray, a small piece of lead was placed inside each sphere. It should be pointed out that, depending on the experience of the evaluator, previous training in this technique may be necessary in order to ensure accurate results.

The palpated anatomical reference points (landmarks) were: the spinous processes of the C7, T2, T4, T6, T8, T10, T12, L2, L4 and S2 vertebrae; and bilaterally the acromion, inferior angle of the scapula and posterior-superior iliac spine (PSIS) (Fig. 1).

Once the reflective markers were in place the patient was positioned for the X-ray examination, in the frontal plane with the arms hanging at the side of the body and the feet and knees together, according to the natural stance of the patient.

Immediately after the X-ray examination, the patient was positioned for the photographic recording in the frontal plane, with the lower and upper limbs maintained in the same position adopted during the X-ray examination. For this purpose it was necessary to precisely control the alignment of the feet by marking the exact location of the feet on the floor with chalk prior to conducting the first evaluation (X-ray examination). Thus, during the two evaluations (X-ray and photographic) the subject was instructed to remain with the feet placed exactly within the marks drawn on the floor. For this photograph a plumb line with two reflective markers 1.00 m apart (Fig. 1) was positioned alongside the patient at the same distance from the plane of the lens, using the shoulders as a point of reference.

A digital camera was used (Sony Cyber-Shot DSC F717, 5 megapixels, 512 MB of memory, 5× optical zoom and 10× digital zoom), coupled to a tripod fixed at a height of 0.95 m and positioned 3.00 m from the patient. Those distances were previously tested together with the zoom option and shown not to alter the aspect ratio, previously measured as being 1:1.

2.3. *Data analysis procedures*

The digital images obtained were transferred to a microcomputer (notebook HP Pavilion, HD 80 Gb, 512 Mb RAM), where they analyzed using a software developed in the MATLAB® environment called Digital Image-Based Postural Assessment (DIPA). Similarly to other software programs [26,28], the DIPA provides quantitative information on posture by referring to the numerical values associated to the digitalized anatomical points, but it also provides a classification of the spinal posture in the frontal plane. The DIPA software was developed in two stages: postural assessment in the sagittal plane and postural assessment in the frontal plane, while only the assessment in the frontal plane was used in the present study with the main aim of identifying the deviations based on the alignment of the spinous processes.

The data analysis procedure consisted of five steps: (1) choosing the spinal postural alteration evaluation method, (2) verifying the agreement between the positioning of the reflective markers and the palpated spinous processes, (3) comparing the results obtained from the X-ray and the DIPA software, (4) verifying the intra-evaluator reproducibility of the DIPA software based on a comparison of the results (digitalized photographs) obtained by the same evaluator on two occasions at an interval of fifteen days, and (5) verifying the inter-evaluator reproducibility of the DIPA software based on the comparison of the results (digitalized photographs) obtained by two different blind evaluators on the same day.

The postural classifications in the frontal plane attributed by the DIPA software were based on the postural parameters proposed by Charière and Roy [27]. The Charière and Roy [27] method was chosen because the direct and objective manner in which the authors classify posture facilitates its adaptation for use in a computer-based tool. Another positive aspect of the method is that it only requires the use of a single photograph taken in the frontal plane.

X-ray images were used to verify the position of the markers (identified using palpation) in relation to the true position of the respective spinous process by measuring the distances (in terms of percentage values of the diameter of the markers) between the markers and the respective bone structures [29].

Based on the X-ray images a paquimeter was used to measure the distances (in millimeters) between the center of the distal part of the spinous processes (the most salient region and the target of the palpitation process) and the center of the radiopac reflective marker (d1 in Fig. 2). However, the distance between two points in an X-ray image depends on the distance from the obstacles (boney structures or lead markers) to the screen and the distance from the source of the X-ray to the obstacles. Due to the impossibility of guaranteeing the same regulation of the parameters in each radiographic image, it

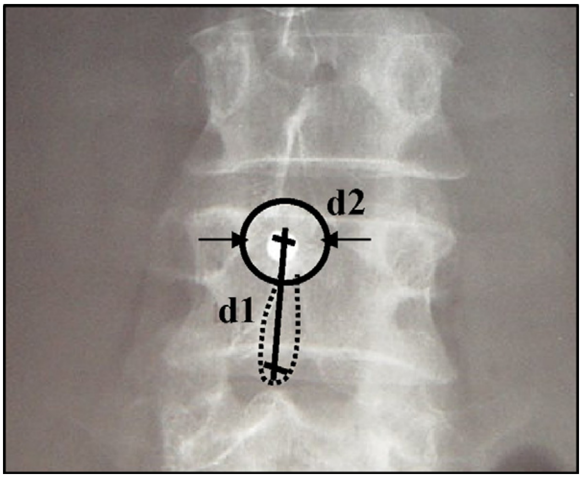

Fig. 2 – The circle was drawn over the outline of the radiopac marker and the arrows indicate the diameter (*d*2). The dotted line was drawn over the spinous process of the vertebra. The solid line represents the distance between the center of the marker and the center of the spinous process (*d*1).

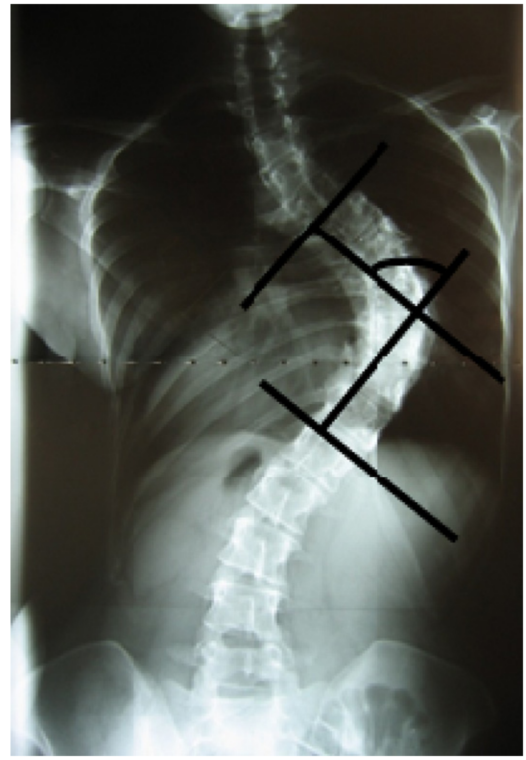

Fig. 3 – Measuring the Cobb angle.

was not possible to ensure that a specific distance in a given X-ray image corresponded to the same distance in another X-ray image. As with any distance measuring process based on images, a calibration object is necessary. However, in the X-ray images, non-linear distortion occurs in different regions of the image [31].

In order to minimize the errors arising in this process it was decided to normalize the measured distances using the diameter of the image of the marker (d2 in Fig. 2). Hence, based on the X-ray image, with the aid of a paquimeter, the distance between the center of the marker and the center of the distal part of the spinous processes (d1) was divided by the diameter of the respective marker (d2). The distances were then computed in percentage values of the marker's diameter.

The results obtained from the X-ray examination and those obtained using the DIPA software were compared in three ways: (1) by comparing the nominal identification and classification of posture obtained from both methods; (2) by correlating the scoliotic arrows, which represent the apexes of the scoliotic curves, obtained from the DIPA software, with the Cobb angle obtained from the X-ray examination; and (3) by comparing the scoliotic arrows obtained from the DIPA software with the same scoliotic arrows drawn directly on the image from the X-ray examination.

The Cobb angle was measured with the aid of a square and a protractor [4,32], in the following manner: first the terminal vertebra of the curve were identified, which are the last vertebra within the concavity of the curve. When the vertebrae were seen to be parallel, that which was furthest from the apex was considered the terminal vertebra. Then a line was traced on the upper extremity of the cranial terminal vertebra, along the terminal plate. The same procedure was repeated for the lower extremity of the caudal terminal vertebra. A second line was traced perpendicularly from each of these lines. The angle between these lines corresponds to the Cobb angle (Fig. 3).

The measurement of the Charrière and Roy [27] arrows was provided by the DIPA software following digitalization of the photographs. This method consists of tracing a straight line from the spinous process of C7 to that of S2 and measuring the distance from this reference line to the spinous process of the vertebra at the apex of the scoliotic curve. With this measurement, the DIPA software provided a classification, based on the level of the scoliosis (lumbar, thoracic–lumbar or thoracic), the side the scoliosis occurs and the size of the arrow in millimeters (Fig. 4). The scoliotic arrow supplied by the DIPA was referred to as DIPA-SA.

In addition, the same methodology was applied manually to the X-ray images (Fig. 5). The main difference between the two results was that with the X-ray there was the certainty that the vertical line was traced between the spinous processes of C7 and S2, while with the DIPA software the line was traced based on the reference points of the respective spinous processes, therefore, in the case of any error in the palpation and marking, the classification of the scoliosis could diverge. The scoliotic arrow traced directly on the X-ray image was referred to as X-SA.

2.4. *Statistical treatment*

The SPSS 13.0 software package was used in the statistical analysis. The Kruskal–Wallis test was used as a non-parametric analysis of variance to identify any differences between the markers on the skin and the true location of the anatomical points as shown by X-ray analysis. Pearson's correlation was used to quantify both the correlation between the DIPA-SA values and the Cobb angle measurements, and

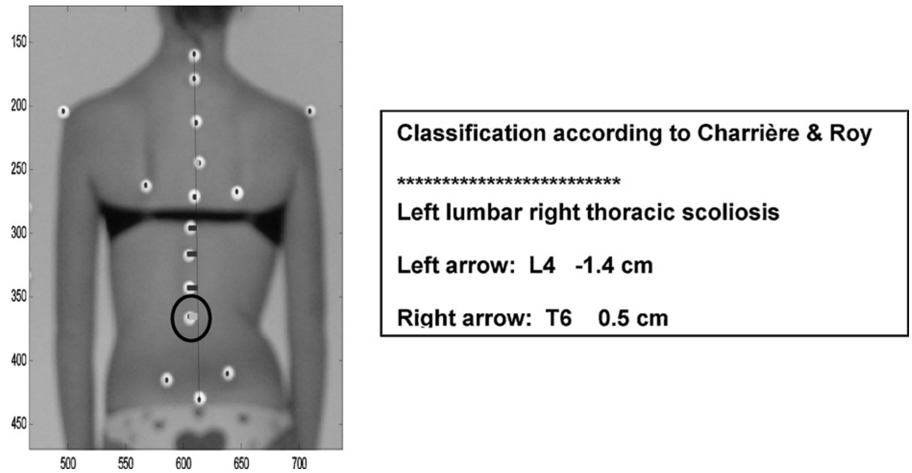

Fig. 4 – Measuring the DIPA-SA and the report supply by DIPA software. The circle indicates the DIPA-SA corresponding to the vertebral level at the apex of the scoliosis.

the correlation between the DIPA-SA and X-SA. Bland-Altman graphic analysis [33] was used to analyze the agreement between the DIPA-SA and X-SA. Spearman's correlation test was used to quantify the correlation between the nominal classification of the data from the X-ray exams and from the DIPA software. The intraclass correlation test (ICC) type I [34] and independent *t*-test were performed to assess the relationship between the DIPA-SA assessments made by the two evaluators (inter-evaluator) and made by the same evaluator on two different days (intra-evaluator), respectively. The significance level adopted in all tests was $p < 0.05$.

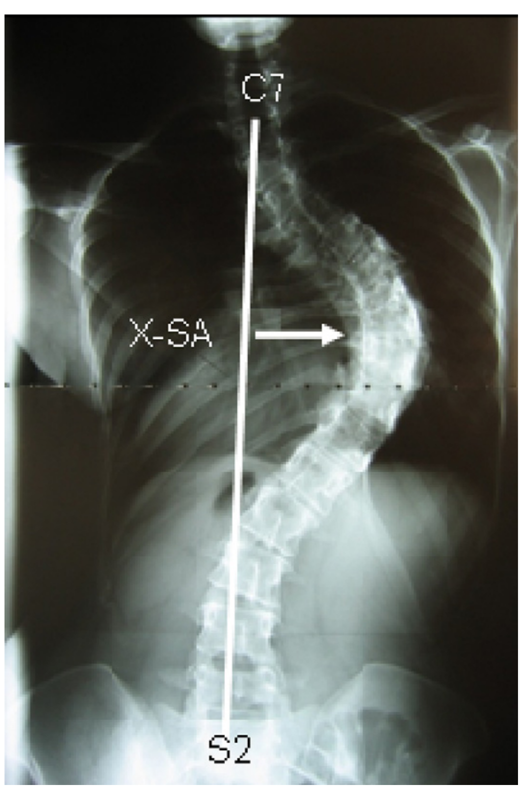

Fig. 5 – Measuring the X-SA, measured directly on the X-ray image.

3. Results

The Kruskal Wallis test showed there were no significant differences between the reflective markers placed with the aid of palpation and the true location of the respective spinous processes ($\chi^2 = 9.366$; $p = 0.404$). Table 1 shows the mean values of the distances between the markers and the spinous process normalized by the marker diameter.

When comparing the L4 vertebra (largest mean distance) with the S2 vertebra (smallest mean distance), the difference between them was not significant. Consequently, any other comparison between the means will not be significant. Furthermore, when the mean value of the distances (0.71) is multiplied by the marker diameter (12 mm) the mean error value was approximately 8 mm in absolute terms.

The mean values and standard deviations of the DIPA-SA and X-SA and Cobb angles for thoracic and lumbar curvatures are shown in Table 2. It can be seen that, in absolute values, both the arrow supplied by the DIPA software and the X-ray measurements, show similar values for both curvatures.

The DIPA-SA results were correlated with those of the Cobb angles from the thoracic and lumbar regions, separately, and the results of the Pearson test are shown in Table 3. The results show that there is a strong and significant correlation between the quantitative results supplied by both methods.

The DIPA-SA results were correlated with those of the X-SA from the thoracic and lumbar regions, separately, and the results of the Pearson test are shown in Table 4. The results show that there is a strong and significant correlation between the quantitative results indicated by the arrows obtained from the X-ray examination and from the DIPA software.

Fig. 6 shows the plot of the difference against the means of the DIPA-SA and X-SA, the standard deviation of the differences and the limits of agreement for the thoracic (Fig. 6a) and lumbar (Fig. 6b) curvatures. The mean difference between DIPA-SA and X-SA was 0.00 cm for the thoracic curvature

Table 1 – Mean values of the distances between the markers and the spinous process normalized by the marker diameter.

Vertebra	C7	T2	T4	T6	T8	T10	T12	L2	L4	S2
Mean distance	0.59	0.57	0.73	0.80	0.76	0.70	0.72	0.77	1.01	0.50

Table 2 – Mean and standard deviation (SD) of the DIPA-SA (cm), X-SA (cm) and Cobb angles (°) values of thoracic and lumbar curvatures.

	DIPA-SA thoracic	X-SA thoracic	Cobb thoracic	DIPA-SA lumbar	X-SA lumbar	Cobb lumbar
Mean	0.68	0.68	13.88	0.54	0.64	9.82
SD	0.34	0.49	8.97	0.37	0.35	8.62

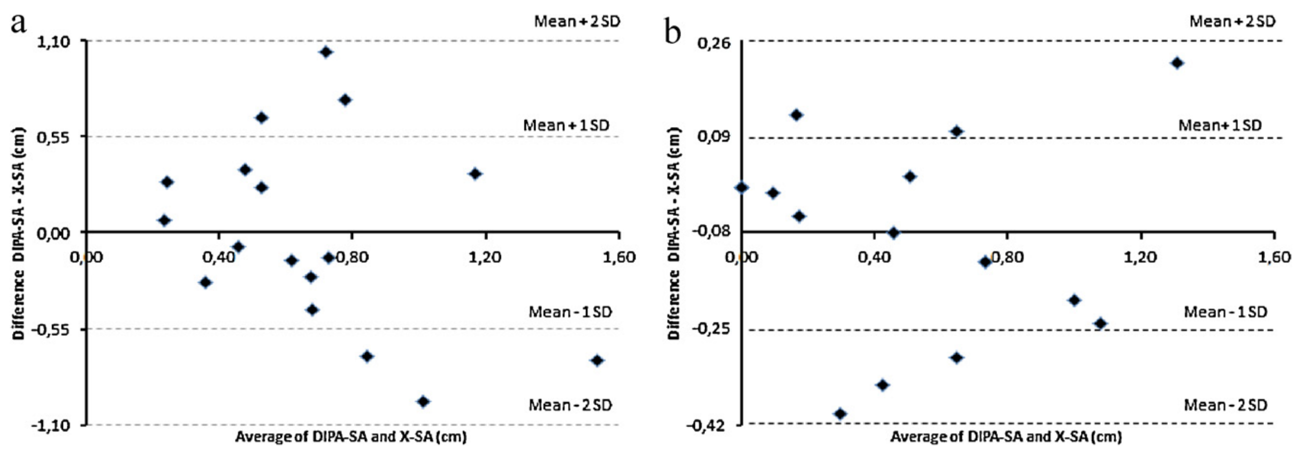

Fig. 6 – Graph showing the levels of agreement of the differences between DIPA-SA and X-SA in relation to the mean ([DIPA-SA + X-SA]/2). (a) In the thoracic spine, the mean of the difference (*d*) = 0.0 cm, standard deviation of the difference (SD *d*) = 0.55 cm and the limits of agreement are +1,10; −1.10 cm. (b) In the lumbar spine, *d* = −0.08 cm, o SD *d* = 0.17 cm and the limits of agreement are +0.26; −0.42 cm.

and 0.08 cm for the lumbar curvature. These results indicate the absence of any difference between DIPA-SA and X-SA for thoracic curvature and the presence of a negative systematic difference for the lumbar curvature, so that, the values of lumbar arrows obtained from the DIPA software are, on average, 0.08 cm smaller than those obtained from the X-ray exam. The random distribution of the points in both graphs (Fig. 6a and b) indicates the absence of any tendency throughout the range of the measurements obtained using the two assessment procedures. Hence, these analyses demonstrated the agreement between the DIPA-SA and X-SA for both curvatures.

The results of the reports obtained from the radiographic examination and classification of the posture provided by the DIPA software were coded for possible statistical analysis. The Spearman test showed a strong and significant correlation ($r = 0.804$, $p < 0.001$) between the results for the classification of posture provided by the X-ray examination and DIPA, demonstrating that, besides identifying the lateral deviations of the spine found in scoliosis, the DIPA software is able to provide a valid classificatory result for the pathology.

Table 5 shows a comparison of the results obtained by the same evaluator on two occasions at an interval of fifteen days. The results of the independent *t*-test demonstrate the similarity between the two evaluation days, showing that there is no significant difference in the DIPA-SA. When the values of the DIPA-SA were correlated, the results of the ICC showed there to be a strong and significant correlation between the two evaluation days. These results suggest that the use of the DIPA software with the methodology adopted in this study constitutes a reliable procedure, by which the results are reproducible on different evaluation days by the same evaluator.

Table 6 shows the results of the inter-evaluator comparison. It can be seen that there is no significant difference between the DIPA-SA obtained by the two evaluators, and that there is a strong and significant correlation between the DIPA-SA obtained by the two evaluators. These results suggest that

Table 3 – Pearson's coefficient correlation (*r*) and *p* values of the numerical variables supplied by DIPA software (DIPA-SA) and by X-ray examination (Cobb angle).

DIPA-SA × Cobb	Correlation (*r*)	P value
Thoracic curvature	0.752	<0.001
Lumbar curvature	0.760	0.007

Table 4 – Pearson's coefficient correlation (*r*) and *p* values of DIPA-SA and X-SA.

DIPA-SA × X-AS	Correlation (*r*)	*p* value
Thoracic curvature	0.790	<0.001
Lumbar curvature	0.918	<0.001

Table 5 – Mean and standard deviation (SD) for the DIPA-SA (cm) obtained using the DIPA software on the first and second evaluation days performed by the same evaluator.

	First day	Second day	*p* value	ICC	*p* value
Thoracic curvature	0.68 ± 0.34	0.69 ± 0.35	0.334	0.999	<0.001
Lumbar curvature	0.54 ± 0.37	0.56 ± 0.42	0.332	0.988	<0.001

the use of the DIPA software with the methodology adopted in this study constitutes a reliable and objective procedure, that is, it tends to provide similar results in the same individual and that the measurements of the DIPA-SA can be reproduced by different evaluators.

4. Discussion

The first aim of this study was to investigate the accuracy of the identification of the anatomical points obtained using palpatory method by comparing them with the X-ray exams. The results demonstrated that there was no significant statistical difference in the results obtained using palpation to locate the spinal processes in the present study, when compared with those obtained using X-ray exams.

Palpation for the identification of the correct location of anatomical landmarks is an essential prerequisite to ensure the reproducibility and reliability of postural analysis [30] and the spine is one of the regions of the body that provides the greatest difficulty for the examiner, due to several factors, such as the large number of spinal segments, most of which are relatively small; only the spinous processes are relatively close to the skin; and the high degree of variation in the shape and orientation of the spine [35,36]. The proximity between the vertebrae and rotation suffered by the vertebrae in the presence of postural changes, especially in cases of significant scoliosis, further complicate their localization [37]. However, most of the non-invasive software and equipment designed to assist in the evaluation of posture and in research into human kinematics depend on palpation of bony anatomical structures and the use of surface markers, and few studies [29,38] have attempted to analyze the feasibility of using this technique.

Within the literature, there is no apparent standardization of the techniques for the palpation of the bony prominences, as there is equally no evidence of a gold standard method of spinous palpation, due to the variability of the human species [39]. For this same reason, the use of anatomical reference points to identify the spinous processes is not advised [9], since any anatomical point of reference may vary in terms of the corresponding spinal level by up to four vertebral levels between individuals [40]. Therefore, the palpation method used in this research consisted of identifying the spinal levels from the palpation of the spinous process of the C7 vertebra, descending level by level until the L4 vertebra.

Although there was no statistically significant difference in the process of locating and palpating the vertebrae in the present study, the numerical values of the mean distance from the marker to its spinous process, show that there was greater difficulty in identifying the vertebrae in the lower lumbar region, and that, when marking the vertebra, the highest rate of error occurred with the L4 vertebra. Similarly, Billis et al. [39] conducted a study to investigate the reproducibility and reliability of locating spinal levels when performed by three groups of therapists (students, clinicians and manual therapists) who were expected to locate spinal levels C5, T6 and L5. The authors observed noted that the three groups had greatest difficulty in palpating the spinous process of L5. This can be explained by the proximity of L5 to other structures such as iliac crests and PSIS, the deep location of L5 and the small size of its spinous process compared to the other lumbar vertebrae [41]. It is also recommended that this process always be performed by an experienced assessor, since it has been demonstrated that the degree of clinical experience interferes with the quality of the palpation [39].

Considering the comparison of the results obtained from the DIPA software and X-rays examinations, we can infer that statistically the average error of 8 mm in the marking of the spinous processes did not significantly affect the diagnosis of scoliosis made by the DIPA software. Therefore, the chosen methodology, based on palpation, can be considered efficient.

The second aim of this study was to investigate the validity of the classification of the spinal posture using Digital Image-Based Postural Assessment (DIPA) software by comparing the classifications obtained with those obtained using X-ray exams. The results demonstrated the validity of the DIPA software for (1) the identification of the deviations based on the alignment of the spinous processes in the frontal plane and (2) the classification of postural alterations in the frontal plane of the spine, resulting from the lack of alignment of the spinous processes.

A number of studies using non-invasive techniques for assessing the spine in the frontal plane were found in the literature [5,42–46], though none was found to correlate the measurement of the Charrière and Roy [27] arrows with measurement of the Cobb angle. Turner-Smith et al. [42] correlated the lateral asymmetry of the spine using ISIS (Integrate Shape Imaging System scanning) surface topography technique with the Cobb angle in cases of idiopathic scoliosis in adults and adolescents and obtained values of $r = 0.80$ and $r = 0.77$, respectively. Goldberg et al. [46] correlated the Quantec angle, also

Table 6 – Mean and standard deviation (SD) for the DIPA-SA (cm) obtained using the DIPA software by two different evaluators.

	First evaluator	Second evaluator	*p* value	ICC	*p* value
Thoracic curvature	0.68 ± 0.34	0.66 ± 0.37	0.334	0.999	<0.001
Lumbar curvature	0.54 ± 0.37	0.48 ± 0.42	0.249	0.880	<0.001

provided by surface topography, with the Cobb angle, and obtained $r = 0.81$. Despite using a different methodology, the present study obtained similar results for the correlation of the DIPA-SA measurements with the Cobb angle measurements, with values of $r = 0.75$ for the thoracic and $r = 0.76$ for lumbar regions.

By contrast, other studies failed to find good results when comparing their methodologies for evaluating scoliosis with the Cobb angle. Mior et al. [5] tested the reliability and accuracy of Metrecom Skeletal Analysis System (computerized electrogoniometry instrument) in the evaluation of idiopathic scoliosis in adolescents and compared the results found with this technique with the measurement of the Cobb angle, obtaining $r = 0.64$. Nissinen [43] correlated the Cobb angle measurement with the measure of spine deformity assessed by means of a water level and ruler ($r = 0.20$) and with the Moiré topography technique ($r = 0.16$). Deacon et al. [37] suggests that the occurrence of low values of correlation in studies assessing scoliosis may be due to the vertebral rotation existing in this disease, making scoliosis a three-dimensional postural alteration. Despite this difficulty, the present study found strong and significant correlations when comparing the results from the DIPA software with the X-ray examination, in terms of the correlation between the arrows (DIPA) and Cobb angle (X-ray) and the postural classification.

The main difference between these studies and the present one is that with the DIPA software the measurement of the lateral deviation is represented by a linear measurement (arrows), in centimeters, while in the other techniques the lateral deviations are represented by angular measurements. It is also important to emphasize that correlating different measurements (linear and angular) can constitute a source of error. Therefore, in this study, besides correlating the DIPA-SA with the Cobb angle ($r = 0.752$ and $r = 0.760$, for thoracic and lumbar curves, respectively), the DIPA-SA was correlated with the X-SA. By examining the results, it is possible to note that when two similar measures are correlated (the DIPA-SA and X-SA arrows), the absolute values are very similar (DIPA-SA thoracic = 0.68 cm and X-SA thoracic = 0.68 cm; DIPA-SA lumbar = 0.54 cm and lumbar X-SA = 0.64 cm) (Table 2) and the correlation values are higher ($r = 0.790$ and $r = 0.918$ for the thoracic and lumbar curves, respectively) (Table 4) than when measurements are correlated with different units.

However, a strong correlation does not necessarily present a strong agreement. Therefore, the statistical procedure suggested by Bland and Altman [33] was used to verify the agreement between the DIPA software and the Cobb angle. However, these same authors point out that the suggested agreement methodology can only be applied to similar measures, so in the present study we only evaluated the agreement between the arrows (DIPA-SA and X-SA), and obtained good results for agreement (Fig. 6), and strong correlations (Table 4). It is important to point out that spinal curvature in the frontal was assessed and quantified by measuring the Cobb angle [47]. As it measures different variables, the DIPA-AS cannot replace the Cobb angle, but can rather be used as a complementary evaluation. From a strictly geometric point of view, it can be said that the greater the curvature (degree of scoliosis) the longer the arrow indicating this curvature will be. Thus, a strong and significant correlation between these variables (DIPA-SA and Cobb angle), together with the high level of the agreement between these measurements on the skin and from the X-ray exam (DIPA-SA and X-SA), support the use of the software as a tool for clinical analysis.

The third aim of the present study was to investigate the intra and inter-evaluator reproducibility of the DIPA software. The results of this study demonstrated that the inter and intra-evaluator reproducibility of the DIPA software were adequate for assessing the spine in the frontal plane (Tables 5 and 6). Similar results, showing a strong and significant correlation between two evaluators or between two different evaluation days have been reported in the literature [10,26,48–50]. Regarding the analysis of the inter-evaluator reproducibility of the study, the fact that only one evaluator/researcher carried out the palpation and marking of the anatomical points may be considered a limitation of the study. On the other hand, by using the results of a single palpation process, the assessment of inter-evaluator reproducibility is focused on questions specifically related to the software, such as the use of the mouse to transfer the point location from the photograph to the computer program.

In addition, DIPA software could be used as an alternative to X-ray examinations when assessing the evolution of the treatment of idiopathic scoliosis in adolescents. Nevertheless, despite the accuracy of DIPA software, the use of X-ray examinations is considered important since it is more reliable for use in diagnosis and periodic assessment of diseases such as idiopathic scoliosis. In this context, the DIPA software may represent a useful tool to aid the follow-up of prolonged treatment in cases of scoliosis, avoiding repeated exposure to X-rays within short periods of time.

5. Conclusions

The results of this study suggest that the DIPA software used in conjunction with palpation, the marking of the spinous processes and digitization of the photographs, is a valid tool which can be used to obtain reproducible measurements (inter and intra-evaluator). Furthermore, DIPA software is a simple, practical and low-cost non-invasive tool for the assessment of the spine in the frontal plane which is capable of accurately identifying, measuring and classifying scoliosis.

REFERENCES

[1] K.M. Diab, J.A. Sevastik, R. Hedlund, I.A. Suliman, Accuracy and applicability of measurement of the scoliotic angle at the frontal plane by Cobb's method, by Ferguson's method and by a new method, European Spine Journal 4 (1995) 291–295.

[2] P.D Masso, G.E. Gorton, Quantifying changes in standing body segment alignment following spinal instrumentation and fusion in idiopathic scoliosis using an optoelectronic measurement system, Spine 25 (4) (2000) 457–462.

[3] M. Gstoettner, K. Sekyra, N. Walochnik, P. Winter, R. Wachter, C.M. Bach, Inter- and intraobserver reliability assessment of the Cobb angle: manual versus digital measurement tools, European Spine Journal 16 (2007) 1587–1592.

[4] S. Allen, E. Parent, M. Khorasani, D.L. Hill, E. Lou, J.V. Raso, Validity and reliability of active shape models for the

estimation of Cobb angle in patients with adolescent idiopathic scoliosis, Journal of Digital Imaging 21 (2) (2008) 208–218.
[5] S.A. Mior, D. Kopansky-Giles, E. Crowther, J. Wright, A comparison of radiographic and electrogoniometric angles in adolescent idiopathic scoliosis, Spine 21 (13) (1996) 1549–1555.
[6] C. Bone, G. Hsieh, The risk of carcinogenesis from radiographs to pediatric orthopaedic patients, Journal of Pediatric Orthopaedics 20 (2) (2000) 251–254.
[7] M.M. Doody, J.E. Lonstein, M. Stovall, D.G. Hacker, N. Luckyanov, C.E. Land, Breast cancer mortality after diagnostic radiography, Spine 25 (16) (2000) 2052–2063.
[8] A.E. Oestreich, L.W. Young, T.Y. Poussaint, Scoliosis circa 2000: radiologic imaging perspective. I. Diagnosis and pretreatment evaluation, Skeletal Radiologic 27 (1998) 591–605.
[9] F. D'osualdo, S. Schierano, C. Cisotti, The evaluation of the spine through the surface: the role of surface measurements in the evaluation and treatment of spine diseases in Young patients, Europa Medicophysica 38 (3) (2002) 147–152.
[10] P. Côté, B. Kreitz, J.D. Cassidy, A.K. Dzus, J. Martel, A study of diagnostic accuracy and reliability of the scoliometer and Adam's forward bend test, Spine 23 (7) (1998) 796–802.
[11] J.S. Daruwalla, P. Balasubramaniam, Moiré topography in scoliosis: its accuracy in detecting the site and size of the curve, The Journal of Bone and Joint Surgery 67-B (2) (1985) 211–213.
[12] I.A.F. Stokes, M.S. Moreland, Concordance of back surface asymmetry and spine shape in idiopathic scoliosis, Spine 14 (1) (1989) 73–78.
[13] F.O. Chaise, C.T. Candotti, M. La Torre, et al., Validation, repeatability and reproducibility of a noninvasive instrument for measuring thoracic and lumbar curvature of the spine in the sagittal plane, Brazilian Journal of Physical Therapy (2011), ahead of print, EpubNov 03.
[14] F. D'osualdo, S. Schierano, M. Iannis, Validation of clinical measurement of kyphosis with a simple instrument, the arcometer, Spine 22 (1997) 408–422.
[15] S.R. Simpson, Evaluation of a flexible ruler technique for a measuring lumbar lordosis in the clinical assessment of low back pain, Journal of the Society of Occupational Medicine 39 (1989) 25–29.
[16] W.B. Cutler, E. Friedmann, E. Genovese-Stone, Prevalence of kyphosis in a healthy sample of pre- and postmenopausal women, American Journal of Physical Medicine & Rehabilitation 72 (4) (1993) 219–225.
[17] M.P. Caine, A.K. McConnell, D. Taylor, Assessment of spinal curvature: an evaluation of the flexicurve and associated means of analysis, International Journal of Rehabilitation Research 19 (1996) 271–278.
[18] M.R. Hinman, Comparison of thoracic kyphosis and postural stiffness in younger and older women, The Spine Journal 4 (2004) 413–417.
[19] R. Rajabi, F. Seidi, F. Mohamadi, Which method is accurate when using the flexible ruler to measure the lumbar curvature angle? Deep point or midpoint of arch? World Applied Sciences Journal 4 (6) (2008) 849–852.
[20] S. Willner, Spinal pantograph: a non-invasive technique for describing kyphosis and lordosis in the thoraco-lumbar spine, Acta Orthopaedica Scandinavica 52 (1981) 525–529.
[21] G. Öhlén, E. Spangfort, C. Tingvall, Measurement of spinal sagittal configuration and mobility with Debrunner's kyphometer, Spine (1989) 580–583.
[22] G. Mellin, Measurement of thoracolumbar posture and mobility with a Myrin inclinometer, Spine 11 (1986) 759–762.
[23] K.P. Singer, T.J. Jones, P.D. Breidahl, A comparison of radiographic and computer-assisted measurements of thoracic and thoracolumbar sagittal curvature, Skeletal Radiology 19 (1990) 21–26.
[24] M.A. Leroux, K. Zabjek, G. Simard, J. Badeaux, C. Coillard, C.H. Rivard, A noninvasive anthropometric technique for measuring kyphosis and lordosis, Spine 25 (13) (2000) 1689–1694.
[25] D.E. Harrison, T.J. Janik, R. Cailliet, et al., Validation of a computer analysis to determine 3-D rotations and translations of the rib cage in upright posture from three 2-D digital images, European Spine Journal 16 (2007) 213–218.
[26] M.C. Normand, M. Descarreaux, D.D. Harrison, et al., Three dimensional evaluation of posture in standing with the PosturePrint: an intra- and inter-examiner reliability study, Chiropractic & Ostheopaty 15 (15) (2007).
[27] L. Charrière, J. Roy, Kinésithérapie des déviations latérales du rachis, 2nd edition, Toray-Masson, Paris, 1983.
[28] E.A.G. Ferreira, M. Duarte, E.P. Maldonado, T.N. Burke, A.P. Marques, Postural assessment software (PAS/SAPO): validation and reliability, Clinics 65 (7) (2010) 675–681.
[29] J.R. Engsberg, L.G. Lenke, K.H. Bridwell, M.L. Uhrich, C.M. Trout, Relationships between spinal landmarks and skin surface markers, Journal of Applied Biomechanics 24 (2008) 94–97.
[30] M.T. Haneline, M. Young, A review of intraexaminer and interexaminer reliability of static spinal palpation: a literature synthesis, Journal of Manipulative and Physiological Therapeutics 32 (5) (2009) 379–386.
[31] V. Baltzopoulos, A videofluoroscopy method for optical distortion correction and measurement of knee-joint kinematics, Clinical Biomechanics 10 (2) (1995) 85–92.
[32] A.M. Briggs, T.V. Wrigley, E.A. Tully, P.E. Adams, A.M. Greig, K.L. Bennell, Radiographic measures of thoracic kyphosis in osteoporosis: Cobb and vertebral centroid angles, Skeletal Radiology 36 (2007) 761–767.
[33] J.M. Bland, D.G. Altman, Statistical methods for assessing agreement between two methods of clinical measurement, Lancet (1986) 307–310.
[34] D.E. Krebs, Declare your ICC type, Physical Therapy 66 (1986) 1431.
[35] A. Lundberg, On the use of bone and skin markers in kinematics research, Human Movement Science 15 (1996) 411–422.
[36] J.C. Harlick, S. Milosavljevic, P.D. Milburn, Palpation identification of spinous processes in the lumbar spine, Manual Therapy 12 (2007) 56–62.
[37] P. Deacon, B.M. Flood, R.A. Dickson, Idiopathic scoliosis in three dimensions, The Journal of Bone and Joint Surgery 66-B (4) (1984) 509–512.
[38] C. Fortin, D.E. Feldman, F. Cheriet, H. Labelle, Validity of a quantitative clinical measurement tool of trunk posture in idiopathic scoliosis, Spine 35 (19) (2010) E988–E994.
[39] E.V. Billis, N.E. Foster, C.C. Wright, Reproducibility and repeatability: errors of three groups of physiotherapists in locating spinal levels by palpation, Manual Therapy 8 (4) (2003) 223–232.
[40] R. Cooperstein, M.T. Haneline, Spinous process palpation using the scapular tip as a landmark vs a radiographic criterion standard, Journal of Chiropractic Medicine 6 (2007) 87–93.
[41] V.A. Fann, The prevalence of postural asymmetry in people with and without chronic low back pain, Archives of Physical Medicine and Rehabilitation 83 (12) (2002) 1736–1738.
[42] A.R. Turner-Smith, J.D. Harris, G.R. Houghton, R.J. Jefferson, A method for analysis of back shape in scoliosis, Biomechanics 21 (6) (1988) 497–509.
[43] M. Nissinen, Trunk asymmetry and scoliosis, Acta Paediatric Scandinavica 78 (1989) 747–753.

[44] T.N. Theologis, R.J. Jefferson, A.H.R.W. Simpson, A.R. Turner-Smith, J.C.T. Fairbank, Quantifying the cosmetic defect of adolescent idiopathic scoliosis, Spine 18 (7) (1993) 909–912.
[45] T.N. Theologis, J.C.T. Fairbank, A.R. Turner-Smith, T. Pantazopoulos, Early detection of progression in adolescent idiopathic scoliosis by measurement of changes in back shape with the integrated shape imaging system scanner, Spine 22 (11) (1997) 1223–1227.
[46] C.J. Goldberg, M. Kaliszer, D.P. Moore, E.E. Forgarty, F.E. Dowling, Surface topography, Cobb angles and cosmetic change in scoliosis, Spine 26 (4) (2001) E55–E63.
[47] R.T. Morrissy, G.S. Goldsmith, E.C. Hall, D. Kehl, G.H. Cowie, Measurement of the Cobb angle on radiographs of patients who have scoliosis. Evaluation of intrinsic error, Journal of Bone and Joint Surgery 72 (1990) 320–327.
[48] F. Lovell, J. Rothstein, W. Personius, Reliability of clinical measurements of lumbar lordosis taken with a flexible rule, Physical Therapy 69 (2) (1989) 96–102.
[49] P. Korovessis, G. Petsinis, Z. Papazisis, A. Baillousis, Prediction of thoracic kyphosis using the De Brunner kyphometer, Journal of Spinal Disorders 14 (1) (2001) 67–72.
[50] A. Mannion, K. Knecht, J.E. Balaban, D. Grob, A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature, European Spine Journal 13 (2004) 122–136.