Revista Brasileira de Fisioterapia
ISSN: 1413-3555
rbfisio@ufscar.br
Associação Brasileira de Pesquisa e Pós-Graduação em Fisioterapia
Brasil

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Revista Brasileira de Fisioterapia, vol. 15, núm. 6, noviembre-diciembre, 2011, pp. 511-517
Associação Brasileira de Pesquisa e Pós-Graduação em Fisioterapia
São Carlos, Brasil

ISSN 1413-3555
Rev Bras Fisioter, São Carlos, v. 15, n. 6, p. 511-7, Nov./Dec. 2011

ORIGINAL ARTICLE

Validation, repeatability and reproducibility of a noninvasive instrument for measuring thoracic and lumbar curvature of the spine in the sagittal plane

Validade, repetibilidade e reprodutibilidade de um instrumento não-invasivo para medição das curvaturas torácica e lombar da coluna vertebral no plano sagital

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Abstract

Background: The need for early identification of postural abnormalities without exposing patients to constant radiation has stimulated the development of instruments aiming to measure the spinal curvatures. **Objective:** To verify the validity, repeatability and reproducibility of angular measures of sagittal curvatures of the spine obtained using an adapted arcometer, by comparing them with Cobb angles of the respective curvatures obtained by using X-rays. **Methods:** 52 participants were submitted to two procedures designed to evaluate the thoracic and lumbar curvatures: (1) X-ray examination from which the Cobb angles (CA) of both curvatures were obtained, and (2) measuring the angles with the arcometer (AA). Two evaluators collected the data using the arcometer, with the rods placed at T1, T12, L1 and L5 spinous processes levels in a way as to permit linear measurements which, with aid of trigonometry, supplied the AA. **Results:** There was a very strong and significant correlation between AA and CA ($r=0.94$; $p<0.01$), with no-significant difference ($p=0.32$), for the thoracic curvature. There was a strong and significant correlation for the lumbar curvature ($r=0.71$; $p<0.01$) between AA and CA, with no-significant difference ($p=0.30$). There is a very strong correlation between intra-evaluator and inter-evaluator AA. **Conclusion:** It was possible to quantify reliably the thoracic and lumbar curvatures with the arcometer and it can thus be considered valid and reliable and for use in evaluating spinal curvatures in the sagittal plane.

Keywords: evaluation; spine; X-rays; validity of tests; physical therapy.

Resumo

Contextualização: A necessidade de identificação precoce de alterações posturais, sem expor as pessoas à radiação constante, tem estimulado a construção de instrumentos para medir as curvaturas da coluna vertebral. **Objetivo:** Verificar a validade, repetibilidade e reprodutibilidade dos ângulos das curvaturas sagitais da coluna vertebral, obtidos por meio de um arcômetro adaptado, comparando-os com os ângulos de Cobb (AC) das respectivas curvaturas, obtidos por meio de exames radiográficos. **Métodos:** Cinquenta e dois indivíduos foram submetidos a dois procedimentos destinados a avaliar as curvaturas torácica e lombar: (1) exame de raios-X, a partir do qual os AC de ambas as curvaturas foram obtidos e (2) medição dos ângulos das curvaturas com o arcômetro (AA). Dois avaliadores coletaram os dados usando o arcômetro com as hastes sobre os processos espinhosos T1, T12, L1 e L5, de modo a permitir medidas que, com auxílio de trigonometria, forneceram os AA. **Resultados:** Encontrou-se correlação muito forte e significativa entre AA e AC ($r=0,94$, $p<0,01$), sem diferença significativa ($p=0,32$) para a curvatura torácica, enquanto, para a curvatura lombar, encontrou-se uma forte e significativa correlação ($r=0,71$, $p<0,01$) entre AA e AC, sem diferença significativa ($p=0,30$). Existe uma correlação muito forte intra-avaliador e inter-avaliador nos AA. **Conclusão:** O arcômetro permitiu quantificar as curvaturas torácica e lombar, podendo-se considerar as medições válidas, fidedignas e objetivas para uso na avaliação de curvaturas da coluna vertebral no plano sagital.

Palavras-chave: avaliação; coluna vertebral; raios-X; validade dos testes; fisioterapia.

Received: 09/05/2011 - **Revised:** 09/22/2011 - **Accepted:** 09/29/2011

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Introduction

Physiotherapeutic evaluation, in which the aim is to identify any possible postural alterations related to either the whole body position or a particular segment is essential prior to beginning postural correction treatment[1]. The gold standard method for the detection of postural alteration is X-ray exams[2-4]. While this method has some advantages, such as revealing the true position and extent of any alteration to the examined skeletal structure, due to its invasive nature it is considered inappropriate for repeated use when accompanying postural physiotherapeutic treatments, since the patient would undergo repeated exposure to radiation[5,6]. Therefore, the most commonly used resource by the physical therapist is postural evaluation, which depends exclusively on the anatomical knowledge, training and experience of the professional, but it does not permit objective quantification in terms of degrees or rates of the identified alterations[7]. This issue represents a gap in clinical practice that has encouraged the development and use of instruments designed to measure quantitatively measure postural alterations, mainly in relation to the spinal curvature in the sagittal and frontal planes[8,9].

Evaluating spinal curvature is an important factor which needs to be taken into account when choosing the techniques used to treat patients because therapies are based on the degree of curvature or its progression[10]. Several conditions can lead to an increase in thoracic curvature, thus requiring that the curvature is adequately monitored, such as Scheuermann's disease[4] and ankylosing spondylitis[11], or temporary health states that inhibit the use of radiography, as is the case of pregnancy, for example.

One way of monitoring the evolution of physical therapy interventions is to use noninvasive instruments for postural evaluation. Among them are: Moiré topography[12], spinal pantography[4], the kypholordometer[10,13], the flexicurve[14,15], the inclinometer[16,17] and the arcometer[18]. The choice of which instrument to use must be based on scientific parameters, such as the validity, repeatability, reproducibility and diagnostic accuracy of the measurements provided in addition to practical parameters, such as the ease of transport and use of the instrument, in order to ensure the patient can be assessed quickly and comfortably. Although Moiré topography, the spinal pantograph and kypholordometry meet these scientific standards, they are not easily portable which represents a difficulty in clinical practice. By contrast, instruments such as the flexicurve, inclinometer and D'Osualdo's, Schierano and Iannis[18] arcometer are portable and easy to use and transport. Nevertheless, there are some restrictions to their use, since they do not include all the scientific parameters, such as presenting validity and/or inter-evaluator reproducibility for only one of the sagittal curvatures of the spine.

To the best of our knowledge, the arcometer, as introduced by D'Osualdo, Schierano and Iannis[18] has not been validated for use in the lumbar region. Hence, with the understanding that measuring instruments need to be used by physical therapists in order to objectively quantify alterations affecting mainly the thoracic and lumbar regions of the spine, and to establish the criteria for planning and following up their interventions[13], the aims of the present study are to investigate (1) the accuracy of the angles of the sagittal curvature from the thoracic and lumbar regions of the spine obtained using an instrument adapted from the arcometer developed by D'Osualdo, Schierano and Iannis[18] by comparing them with those obtained using X-ray examination and (2) the inter-evaluator reproducibility and the intra-evaluator reproducibility of the arcometer. This instrument is believed to be able of producing valid, true, repeatable and reproducible information regarding the curvature of the spine.

Furthermore, the low cost of the arcometer together with the ease of use and transport encourage its use in the evaluation of large populations, providing the therapist with a primary aims of clinical evaluation. In addition, the arcometer can be a useful tool in field research, particularly for epidemiological research.

Methods

This is a cross-sectional study, conducted at the radiology department of a hospital. This study had been approved by the Ethics Committee of Hospital Nossa Senhora da Conceição (CEPHNSC), Porto Alegre, RS, Brazil (Protocol 175/08). The study included 52 participants with a mean age of 53.7 (SD=14.9) years, body mass 68.8 kg (SD=13.4), height of 1.60 m (SD=0.08) and body mass index (BMI) 26.1 (SD=4.4). The sample size was calculated based on data from a pilot study and from the literature, with a power of 95% and significance level of 5%. Exclusion criteria were: vertebral fracture, spinal fusion, deficiencies that precluded standing position and lack of precision from the radiographic images. The inclusion criterion was the need, according to medical prescription, for an X-ray examination of the lateral curvature of the thoracic and lumbar spine.

The arcometer used in the present study was an aluminum-built instrument consisting of a main shaft, 1 m in length, 0.025 m wide and 0.012 m thick and three perpendicular 0.012 m x 0.012 m rods, 0.50 m in length. A scale from 0 to 0.8 m was attached to the center of the main shaft and scales from 0 to 0.50 m were also attached to the center of each of the three perpendicular rods. Each rod is attached to the main shaft by a device, consisting of two parts, that allows the rod to be adjusted horizontally and vertically. This arcometer was adapted from the one designed by D'Osualdo, Schierano and Iannis[18], and differed from the original in following aspects: (1) free movement of all the perpendicular rods in both the vertical and horizontal planes and (2) the attachment of a spirit level to the main shaft. In addition the method of calculating the angle of the thoracic curvature was changed.

To determine whether the arcometer constitutes a reliable method, data collection was organized so as to provide three types of information: (1) the validity of the instrument based on a comparison of the measurements obtained with the arcometer and X-ray (n=52) on the same day and in the same place; (2) the intra-evaluator reproducibility of the instrument based on the comparison of the measurements obtained with the arcometer by the same evaluator on two occasions at an interval of seven days (n=15); and (3) the inter-evaluator reproducibility of the instrument based on the comparison of the measurements obtained by two different evaluators on the same day and in the same place (n=30).

Initially the participant was informed about the purpose of the study and invited to participate. Upon consenting to participate, the participant signed the consent form. On the same day and in the same place, the subjects underwent two different evaluations of the spine curvature: (1) X-rays and (2) measurement with the arcometer. For both procedures, the spinous processes of vertebrae T1, T12, L1 and L5 were identified and marked while the subjects were instructed to adopt the same standing position, with knees straight, feet parallel and 90° of flexion of the shoulder and elbows. This approach was used in order to prevent the humerus overlaying the spine[19,20]. The measurements with the arcometer were taken by two evaluators, each of which was blind to the measurements obtained by the other, to determine the degree of reproducibility of the measurements obtained by the two evaluators (inter-evaluator reproducibility). This procedure was adopted to avoid bias during the assessments. The spinous processes were identified by palpation by one of the evaluators.

Immediately following the measurement with the arcometer, the radiological examination was performed in the right sagittal plane, keeping the same position described above and adopting a distance of 0.18 m between the participants and the X-ray tube. To ensure the correct vertebral location, lead markers were used over the skin on the same vertebral spinous processes, T1, T12, L1 and L5, which demarcated the thoracic and lumbar curvatures[1]. The evaluators who assessed the X-ray examinations were not the same evaluators that used the arcometer, who were therefore blinded to the results of the X-ray examinations.

The subjects who agreed to participate in the second day of evaluation were asked to return to the same place at the same time one week later, in order to be re-evaluated by same evaluator who saw them on the first day (i.e., the first evaluator). On this second day only the arcometer was used for the evaluation. This procedure made it possible to determine the degree of reproducibility between the measurements obtained on two different days by the same evaluator (intra-evaluator reproducibility)[21].

To measure the sagittal curvatures of the spine with the arcometer, the evaluators positioned the upper and lower rods of the instrument on the spinous processes, at which stage we obtained the measures of FA and FB as can be seen on Figure 1. Soon after, the evaluators identified the apex of the curvature using the middle rod, which corresponds to measure of f. Afterwards, the scale on the instrument was read to obtain the measures h1 and h2 corresponding to the distance between the upper vertebra and the point of the apex of the curve, and between the apex of the curvature and the lower vertebrae, respectively. This procedure was repeated in order for each of the two evaluators to collect data on both the thoracic and lumbar curvatures. The data from the arcometer, i.e., the values of h1, h2, f, FA and FB of the thoracic and lumbar curvatures of the subjects were included in five equations adapted from Leroux et al.[20], and based on three trigonometric relations, the angles of the thoracic and lumbar curvatures were calculated in degrees.

In which:

$$f1 = FA - f \quad \text{Equation 1}$$

$$f2 = FB - f \quad \text{Equation 2}$$

$$\varphi 1 = 180^{o} - 2^{*} \arctan (h1/f1) \quad \text{Equation 3}$$

$$\varphi 2 = 180^{o} - 2^{*} \arctan (h2/f2) \quad \text{Equation 4}$$

$$AA = \varphi 1 + \varphi 2 \quad \text{Equation 5}$$

FA = measurement, in millimeters, of the upper rod;

FB = measurement, in millimeters, of the lower rod;

f = measurement, in millimeters, of the central rod placed at the apex of the curvature;

f1 = value, in millimeters, obtained from equation 1;

f2 = value, in millimeters, obtained from equation 2;

h1 = measurement, in millimeters, corresponding to the straight line produced between the upper vertebra and the apex of the curvature;

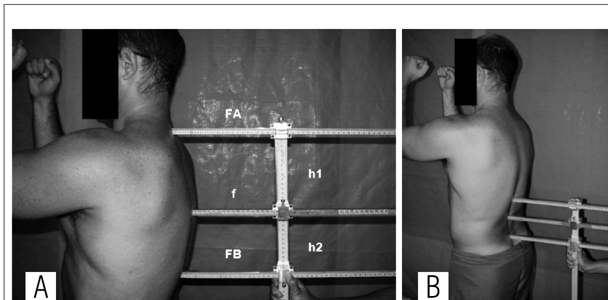

Figure 1. (A) Using the arcometer in the thoracic spine with identification of the variables (FA, FB, *f*, h1 and h2) obtained with the instrument. (B) Using the arcometer to obtain the angle of the lumbar curvature.

h2 = measurement, in millimeters, corresponding to the straight line produced between the lower vertebra and the apex of the curvature;

φ1 = angle, in degrees, corresponding to the arc obtained from the values of f1 and h1;

φ2 = angle, in degrees, corresponding to the arc obtained from the values of f2 and h2;

AA = angle of spinal curvature in degrees obtained using the arcometer.

The values of the angles of the thoracic and lumbar curvatures obtained by the X-rays were obtained using the Cobb method. This method involves manually tracing two straight lines over the image, one following the upper edge of the cranial vertebra and the other following the lower edge of the caudal vertebra which together represents the boundary of the curvature of interest. The junction of these two straight lines forms the so called Cobb angle[3,11,22,23].

The values of the angles obtained using the arcometer and the X-ray examination were subjected to inferential statistical analysis using the SPSS version 13 software. The normality of the data for both curves was initially checked using the Kolmogorov-Smirnov test. As the values of the angles of the thoracic curvature were found not to be normally distributed, there they were exponentially transformed. To assess the relationship between the angles of the curves obtained with the arcometer (AA) and those obtained with X-ray examination (CA), Pearson's correlation test and paired *t* Tests were applied in order to validate the arcometer. To assess the relationship between the angles of the curves obtained with the arcometer (AA) by the two evaluators (inter-evaluator) and the two evaluation days (intra-evaluator), intraclass correlation coefficients (ICC) type I and independent t-tests were performed. The significance level was 0.01. The graphical representation proposed by Bland and Altman[24] was used to assess the agreement between CA and AA.

Results

The values of the angles measured with the arcometer (AA) presented similar mean values to those of the Cobb Angle (CA) for both curvatures, indicating there were no significant differences between AA and CA neither the thoracic curvature (p=0.32) nor the lumbar curvature (p=0.30). Table 1 shows the mean angle of CA and AA for the thoracic and lumbar curvatures. The results of the Pearson's correlation test between AA and CA for the thoracic curve showed a very strong and significant correlation (r=0.94, p<0.01), while for the lumbar curvature, the correlation was strong and significant (r=0.71; p<0.01).

Although this study has obtained very strong and strong correlations, with both being significant, between AA and CA for the thoracic and lumbar curvatures, respectively, it is necessary to determine the agreement between CA and AA, because Pearson's coefficient correlation (r) only shows the association between the measured variables. According to Bland and Altman[24] a strong correlation, does not necessarily present a strong agreement, so in order to verify the agreement between AA and CA the statistical procedure suggested by Bland and Altman[24] was used (Figure 2).

Figure 2 shows the graphs of the average agreement in relation to the difference of CA and of AA, the standard

Table 1. Number of participants (N), mean, standard deviation (SD) and minimum and maximum values in degrees for the angles of the thoracic and lumbar curvatures obtained using the arcometer and the X-ray examination, on the first evaluation day.

Thoracic Curvature	N	Mean	SD	Minimum	Maximum
Arcometer Angle (AA)	52	46.36°	13.90°	20.10°	84.10°
Cobb Angle (CA)	52	45.00°	13.57°	15.00°	80.00°
Lumbar Curvature					
Arcometer Angle (AA)	37	32.70°	13.57°	4.70°	63.99°
Cobb Angle (CA)	37	31.05°	10.98°	6.00°	59.50°

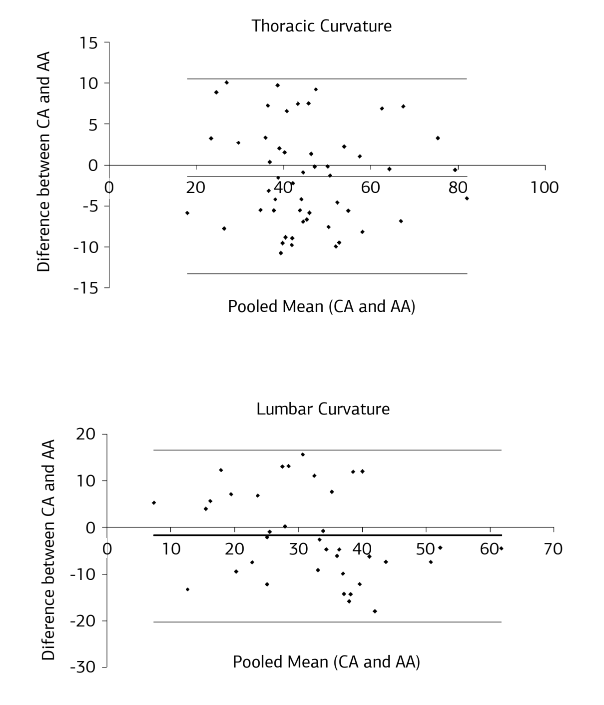

Figure 2. Graphical representation the degree of agreement in relation to the difference between CA and AA in function of the pooled mean (CA and AA). The thoracic curvature mean of difference *(md)*=-1.4° the Standard Deviation of difference (SD *d*)=6.06° and the limits of agreement are +10.53; -13.24°. The lumbar curvature *d*=-1.65°, SD *d*=9.24° and the limits of agreement are +16.56; -20.25°.

deviation of difference (SD *d*) and limits of agreement for the thoracic and lumbar curvatures, respectively. The mean difference *(md)* between CA and AA was -1.4° for the thoracic curvature and -1.65° for the lumbar curvature which represents a systematic difference in the magnitude of CA in relation to AA. Observing the two graphs, the points can be seen to be scattered randomly, which indicates the absence of any behavioral bias over the range of measurement of the two assessment procedures.

Table 2 shows a comparison of the measurements obtained by the same evaluator on the first and second evaluation days. The results demonstrate the similarity between the two evaluation days, showing that there is no significant difference of the AA, for both the thoracic and lumbar regions of the spine. When the values of the AA were correlated, the results showed there to be a strong and significant correlation between the two evaluation days, for both the thoracic and lumbar regions of the spine. These results suggest that the use of the arcometer with the methodology adopted in this study constitutes a reliable procedure, by which the results are reproducible on different evaluation days, so that the same evaluator can measure the kyphosis and lordosis angles.

Table 3 shows the results of the inter-evaluators comparison. It can be seen that there is no significant difference between the AAs obtained by the two evaluators, and that there is a strong and significant correlation between the AAs. These results suggest that the use of the arcometer with the methodology adopted in this study constitutes an intra and inter-evaluator reproducibility procedure, that is, regardless of the evaluator, use of the arcometer in the evaluation of the thoracic kyphosis and lumbar lordosis tends to provide similar results in the same participant and that the measurements of the kyphosis and lordosis obtained using the arcometer can be reproduced by different evaluators.

Discussion

The angles obtained with the arcometer (AA), when compared to those of the Cobb angles (CA) obtained by taking X-rays, allowed the thoracic and lumbar curvatures to be measured in degrees, similarly to other measuring instruments found in the literature[11].

Inter-evaluator reproducibility, is the variation of the condition "observer", while intra-evaluator reproducibility, is the variation of the condition "time", with the measurements always performed by the same evaluator. The results of the present study demonstrated that both inter and intra-evaluator reproducibility of the arcometer were adequate for the evaluation of both lumbar and thoracic curvatures (Tables 2 and 3). Similar results have been reported in the literature, that is strong and significant correlation between two evaluators or between two different evaluation days[25-27]. Nevertheless, no studies were found that demonstrated the reproducibility of the arcometer for both the thoracic and lumbar curvatures, since D'Osualdo, Schierano and Iannis[18] only noted good agreement in the inter-evaluator and intra-evaluator reproducibility for the thoracic curvature, although they did not use the Intraclass Correlation Coefficient.

When compared to the results of the radiological examination, the results obtained with the arcometer from D'Osualdo, Schierano and Iannis[18] showed a strong correlation (r=0.98) between the instrument and the Cobb method, which corroborates the results obtained in this study. It is believed that the very strong correlation found by D'Osualdo, Schierano and Iannis[18] is associated with the fact that the author models the thoracic spine using a single arc, in which the apex of the curvature is set in the middle of the arc formed between the thoracic vertebrae[28]. As a perfect arc is not usually found in patients, this can be understood as a limitation of the study by D'Osualdo, Schierano and Iannis[18]. Similarly, Caine, McConnell and Taylor[29] claim that the apex of thoracic kyphosis may lie at different locations within the arc, not necessarily at the center of the curvature. In this study both the thoracic spine and the lumbar spine were modeled after two arcs with

Table 2. Number of participants (N), mean, standard deviation (SD) in degrees for the angles of the thoracic and lumbar curvatures obtained using the arcometer on the first and second evaluation days performed by the same evaluator.

	N	First day	Second day	p value	ICC	p value
Kyphosis	15	45.4º±11.1º	46.2º±10.7º	0.137	0.992	0.000*
Lordosis	15	30.7º±10.2º	32.4º±10.8º	0.385	0.850	0.001*

* Significant correlation: $p<0.05$.

Table 3. Number of participants (N), mean, standard deviation (SD) in degrees for the angles of the thoracic and lumbar curvatures obtained using the arcometer by two different evaluators.

	N	First evaluator	Second evaluator	p value	ICC	p value
Kyphosis	52	45.15º±13.32º	44.76º±12.43º	0.496	0.981	0.000*
Lordosis	37	31.49º±11.93º	30.93º±11.77º	0.508	0.891	0.000*

* Significant correlation: $p<0.05$. ICC: type I.

different radii in an attempt to make them more representative of the spine, with two different angles being generated within the same curvature and the sum of these two angles determining the overall angle curvature. The procedure for obtaining the apexes of the measured curvatures was similar to the procedure performed by D'Osualdo, Schierano and Iannis[18], in which the central rod of the instrument was placed on the most apparent portion of the thoracic kyphosis, i.e., where the central rod had the lowest value, that point was called the apex of the thoracic curvature.

From an anatomical point of view, the thoracic vertebrae have long and slender spinous processes, which lie along and are palpable on the posterior midline that is located within the vertebral line. In addition, they have some particular features, such as the fact the T1 and T4 vertebrae exhibit characteristics similar to those of the cervical vertebrae, which make it easier to identify and palpate the spinous processes. Knowledge of these anatomical features of the thoracic region is essential for the therapist to be able to use the arcometer as well as the other measuring instruments and the acquisition of such knowledge represents the first step for the professional to be able to measure accentuation or correction of thoracic kyphosis in the sagittal plane.

Despite the excellent results found for the thoracic spine, it should be noted that one of the main findings of this study was the measurement and validation of the lumbar curvature, the results showed a strong and significant correlation ($r=0.71$, $p<0.01$) between the angles obtained with the arcometer and those from the X-ray examination. One point worth mentioning is that the lower the level chosen to define vertebral lumbar lordosis, the less radiological correlation there will be because the short distance between the vertebrae means the lumbar curve is not representative, thus permitting large angular variations when measured[20]. In this study, the spinous processes of L1-L5 were used to delimit the lumbar curvature, which represents a short range. However, with the use of this small vertebral region a strong and significant correlation was found between CA and AA.

Another noted issue is that the correlation coefficients found between measuring instruments and the Cobb angle for thoracic curvature is higher than the correlation coefficients for the lumbar curvature[4,9,18]. It is known that in order to measure the curvature of the spine by means of exterior measurement of the body surface it is necessary to identify the spinous processes that make up the chosen vertebral level. It is speculated that the lower correlation coefficient of the lumbar curvature is associated with difficulty in locating the spinous processes in this region. This may be linked to the anatomical characteristics of the lumbar vertebrae and the excess subcutaneous adipose tissue, which is more common in this region, especially in overweight people[30,31].

Anatomically, the spinous processes of the lumbar spine are thick, wide, somewhat rectangular in shape and protrude horizontally from the junction of each vertebral lamina[30,32]. The shape of these processes can hinder the evaluator when using palpation, because in some participants with severe lumbar lordosis the spinous processes are very close to each other, a fact that frequently leads the evaluator to confuse the end of one lumbar vertebral spinous process with the beginning of another[32]. The excessive subcutaneous fat associated with being overweight can also affect the correct identification of spinous processes in the lumbar region as it hampers palpation of the anatomical structures[33]. This was a factor in the present study, since 75% of participants were women with a BMI of 26.1 (±4.4)[34,35] that were overweight and had high fat levels in the abdominal region. Nevertheless, while these issues constitute limitations to the use of instruments for measuring spinal curvature, they do not preclude their use as important tools for that purpose.

In summary, by using the adapted arcometer it was possible to quantify both the angle of thoracic convexity and the angle of lumbar concavity with a degree of accuracy similar to that of the Cobb angle obtained from X-ray examination. Thus, the results showed that the adapted arcometer is a valid, repeatable and reproducible (inter and intra-evaluators) instrument for measuring the thoracic and lumbar curvatures which means the results obtained can be reproduced by different evaluators on different evaluation days, thus permitting this instrument to be used to evaluate large populations.

Acknowledgement

To Fernanda Machado Kutchak for facilitating the X-ray examinations in the hospital.

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