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ORIGINAL ARTICLE

Concurrent validity of photogrammetric and inclinometric techniques based on assessment of anteroposterior spinal curvatures

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Abstract

Purpose The purpose of the study was to investigate correlations between parameters of anteroposterior spinal curvatures in the sagittal plane, measured with the use of photogrammetric technique and inclinometer in healthy elderly women.

Methods Randomized study involved 50 females, ranging from 50 to 70 years of age (mean 62.26 ± 6.94); mean body mass index (BMI) 27.69 ± 4.79. The examined parameters included angle of inclination in lumbosacral spine (ALFA), thoracolumbar transition (BETA), upper thoracic segment (GAMMA), angle of lumbar lordosis (LLA) and thoracic kyphosis (TKA). Results obtained with gravitational inclinometer were compared with those identified with photogrammetry method. Statistical analyses were performed with Mann–Whitney *U* test, regression analysis and Bland–Altman analysis.

Results In Mann–Whitney *U* test, with correction due to continuity, no statistically significant differences for any variable were found. Regression analysis was significant only for the variable of BETA angle. Bland–Altman coefficient for the respective angles was: ALFA 2.0%, BETA 4%, GAMMA 0%, LLA 2% and TKA 0%.

Conclusions The results acquired with gravitational inclinometer and with photogrammetric technique are comparable, as the parameters of anteroposterior spinal curvatures acquired with these two methods are found to be compatible in the case of measurements of lumbar lordosis and thoracic kyphosis.

Keywords Gravitational inclinometer · Lumbar lordosis · Photogrammetric method · Posture · Spine · Thoracic kyphosis

Introduction

One of the basic examinations performed by physiotherapists involves assessment of body posture, including diagnosis of anteroposterior spinal curvatures. This is necessary, regardless of the problem reported by a patient, since many factors may impact the shape of these curvatures [1–3], which should be taken into account in designing physiotherapy. Results of posture assessment largely depend on examiner's knowledge and experience, but they are also affected by the quality of diagnostic tools and measurement errors generated during such examination [4].

The shape of spinal curvatures is relatively easy to examine, both with invasive methods, such as X-ray, and non-invasive tools such as ultrasound Metrecom System, Zebris, photogrammetric technique, inclinometer, frequently used in screening examinations [5–9]. However, purchasing majority of these tools is very costly. These methods differ in the measuring technique, and due to this the obtained results are difficult to compare. In the literature, we can find studies designed to compare concurrent validity of two methods, e.g. Metrecom System and Saunders mechanical inclinometer [5], X-ray with photogrammetry [10], liquid-based inclinometer and phone application [11], photogrammetry and liquid-based inclinometer [12], or computer-assisted magnetic tracking device compared to inclinometer [13]. The first three reported high concurrent validity, contrary to the latter study. In view of the above, further research is needed to identify whether or not specific frequently applied methods produce consistent results.

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Photogrammetry and inclinometer measurements are common methods of assessing anteroposterior spinal curvatures [14, 15]. Inclinometer is reliable [16], handy and affordable, as a result of which it is often used in examinations [17, 18]. On the other hand, photogrammetry is based on the phenomenon of projection Moiré, and enables accurate and reliable quantitative assessment of numerous parameters, both in sagittal and frontal plane [19], yet the tool is frequently too costly for owners of average-size physiotherapy facilities. Despite the basic differences in the measuring techniques, the two methods enable assessment of specific spinal segments for their angle of inclination from vertical alignment with the use of similar technique of measuring spinal geometry. Therefore, it seems possible to perform comparative analyses of assessment results obtained independently in different facilities.

The study was designed to investigate correlations between parameters of anteroposterior spinal curvatures in the sagittal plane, measured with the use of photogrammetric technique and inclinometer in healthy elderly women.

Methods

Posture assessment was carried out during Senioriada event organized in southeastern Poland by the European Association for the Promotion of Exercise 50 +, in July 2012. The study was approved by the Medical Faculty Bioethics Commission, at the University of Rzeszów (no. 8/05/2012). The subjects provided their informed consent to participate in the study.

Participants

The study involved 50 females, ranging from 50 to 70 years of age (mean age 62.26 ± 6.94), with mean body weight 72.70 kg (± 13.15), mean body height 162.04 cm (± 4.44), mean BMI 27.69 ± 4.79. Women qualified for the study were able to walk unassisted, and did not use any orthopaedic aids (canes, crutches, or walkers). All the subjects were able to assume standing position for the assessment. Females with neurological disorders or motor deficits impairing their ability to maintain balance in standing position without aid and/or those using any orthopaedic tools were disqualified. Measurements performed using each of the techniques were repeated three times. Subsequently, 50 measures were randomly selected for each method. Detailed information regarding selection of the group is shown in Fig. 1.

Inclinometer technique and photogrammetric technique

Measurements of spinal curvatures in sagittal plane were performed in all the subjects with the use of both techniques. All the measurements based on a given method were performed by one physiotherapist with many years of experience in applying the relevant technique. The examinations were carried out in the free or the so-called habitual standing posture, with no shoes; lower limbs straightened to the width defined by hips, upper limps freely alongside the torso. If during an assessment a subject deliberately straightened up, the measurement was repeated. The first measurement (MI) of spinal curvatures in the sagittal plane was performed with gravitational inclinometer manufactured by Suunto, Finland (Fig. 2). The second measurement (MII) was performed with photogrammetric technique using the projection Moiré phenomenon (MORA 4 Generation System from CQ Elektronik System, Poland). Sample photogrammetric examination results are shown in Fig. 3. To ensure accuracy, the assessment was carried out in strictly defined conditions [20], accounting for measurement errors [4]. The measurements based on the two methods were performed at the same time, one after the other, on the same day. Before the start, characteristic points were marked on the women's backs, and they were used for measurements with both methods (Fig. 4). This was done to reduce the effect of the applied points in the final comparison of the methods. The following parameters were examined by the study: inclination angle of lumbosacral spine (ALFA), inclination angle of thoracolumbar spine (BETA) and inclination angle of upper thoracic section (GAMMA), angle of lumbar lordosis (LLA) obtained by subtracting (ALFA) and (BETA) angle from 180° as well as angle of thoracic kyphosis (TKA) obtained by subtracting (BETA) and (GAMMA) angle from 180°. The method of determining lumbar lordosis and thoracic kyphosis curvatures was adjusted to the method of computing curvature angles in Moiré-based photogrammetry.

Data analysis

Statistical analyses, performed with Statistica 13.1 (Stat Soft, Poland), assessed whether the results of measurements based on method I (gravitational inclinometer) differed significantly from the results of measurements of the same parameters obtained with the use of method II (photogrammetry). A preliminary power analysis was used to estimate a proper sample size with 0.90% power, $\alpha = 0.05$, and expected effect size 0.50. The required sample would

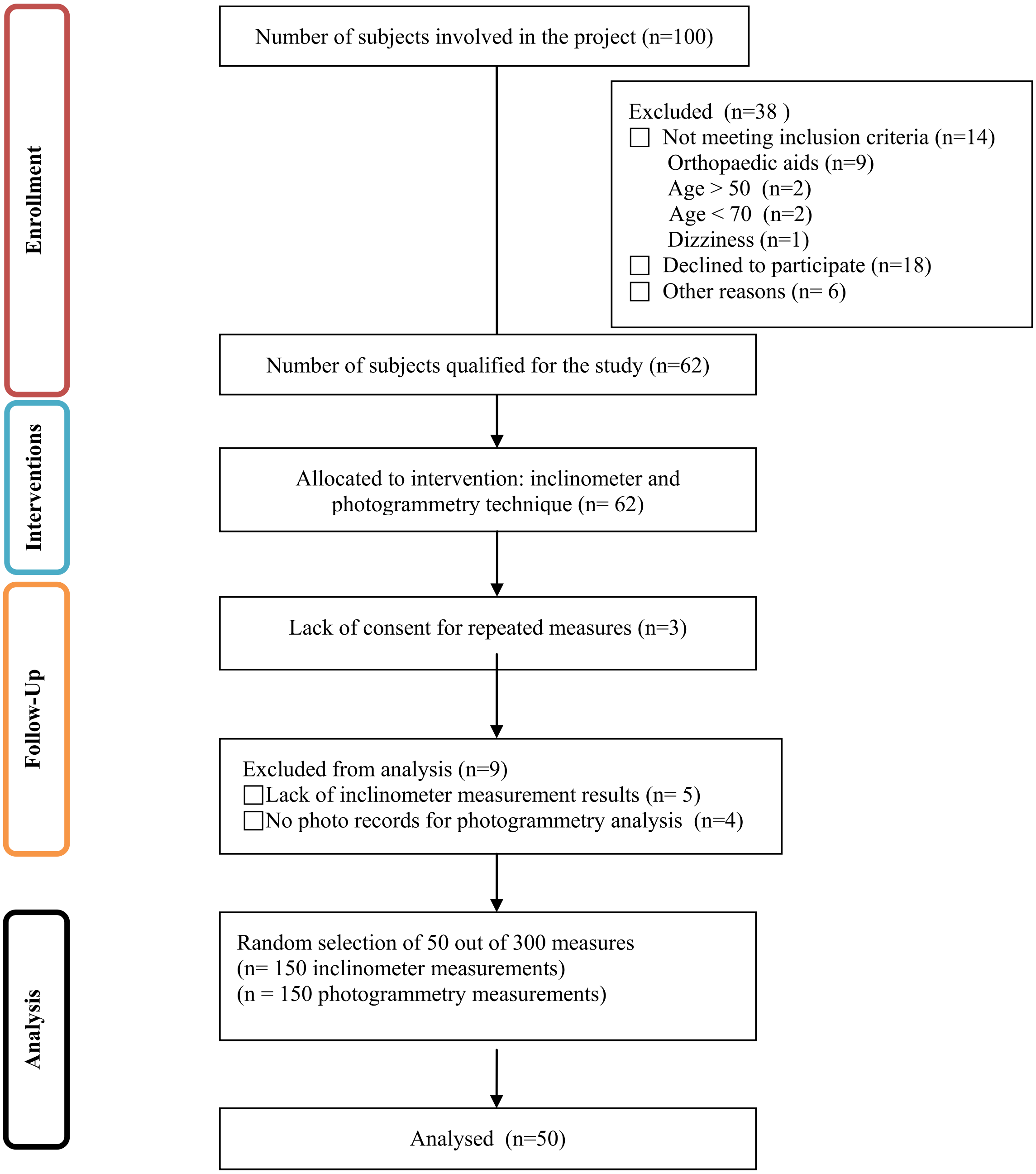

Fig. 1 Flow diagram

be 50 subjects. Each subject was measured three times, to rule out setting-related errors. Fifty measures were randomly selected out of the total of 150 results acquired using a given technique.

The results were analysed with Shapiro–Wilk test examining conformity of the sample with the normal distribution, with Mann–Whitney *U* test for independent variables to compare significance of the differences between the results acquired using method I vs. method II and regression analysis to check whether the correlations are linear. Moreover, Bland–Altman analysis was performed to verify the compliance of the results of the measurements based on gravitational inclinometer with the results of the measurements based on photogrammetric technique. The measurements were considered recurrent if the differences between the results of the measurements were in 95% confidence interval for the mean. Bland–Altman coefficient was computed, the results were considered recurrent if the percent

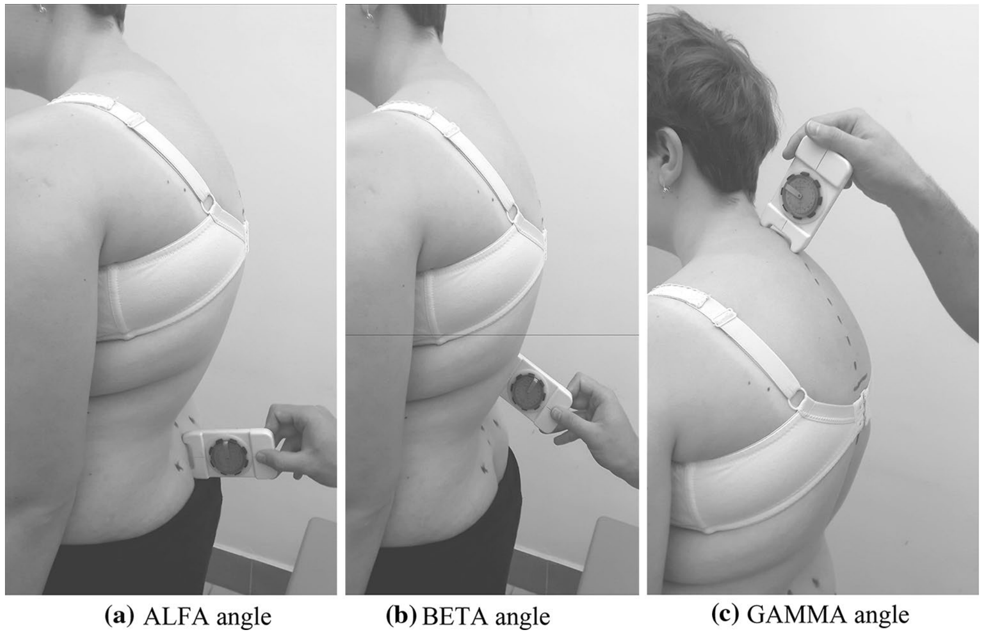

Fig. 2 Methodology for the measurement mechanical inclinometer

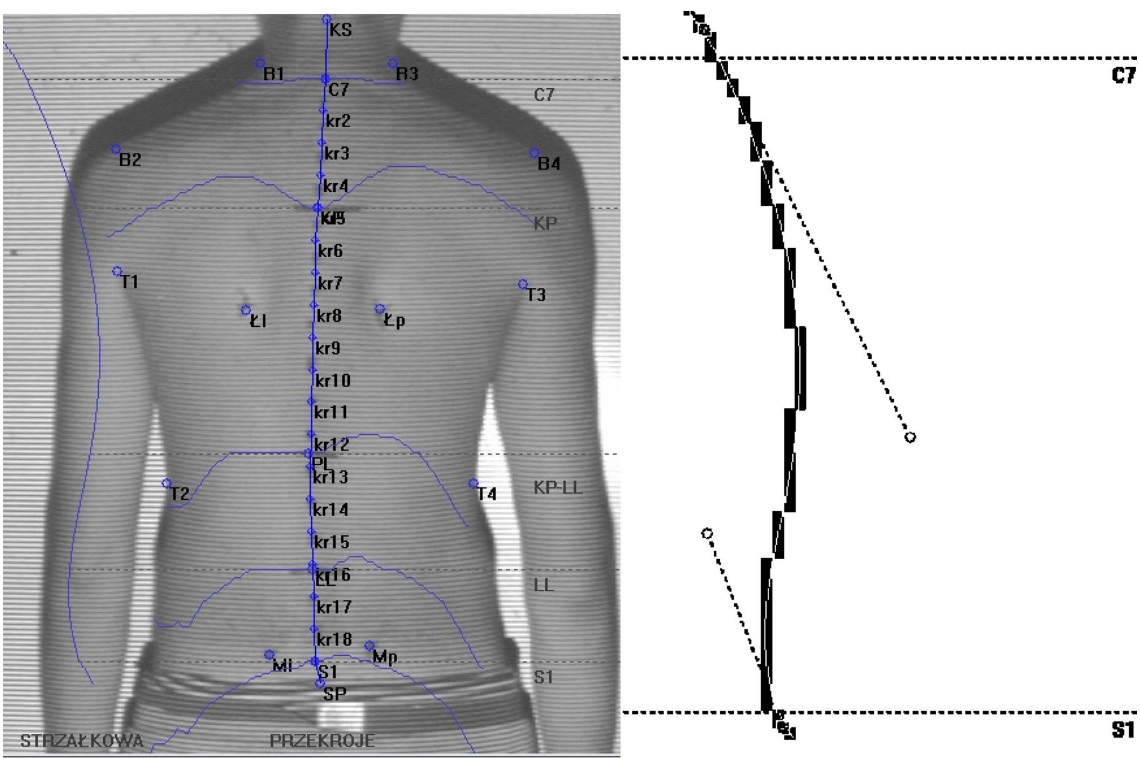

Fig. 3 Image of the anteroposterior curvatures obtained in photogrammetric assessment

of the outliers was less than 5%. Statistical significance was assumed at $\alpha < 0.05$. Descriptive statistics such as mean ($\bar{x}$), median (Me), standard deviation (s) and coefficient of variation (V) were computed for measurements I and II.

Results

The parameters of inclination identified in specific segments of the spine in sagittal plane as well as angles of spinal curvatures were calculated and are presented in Table 1.

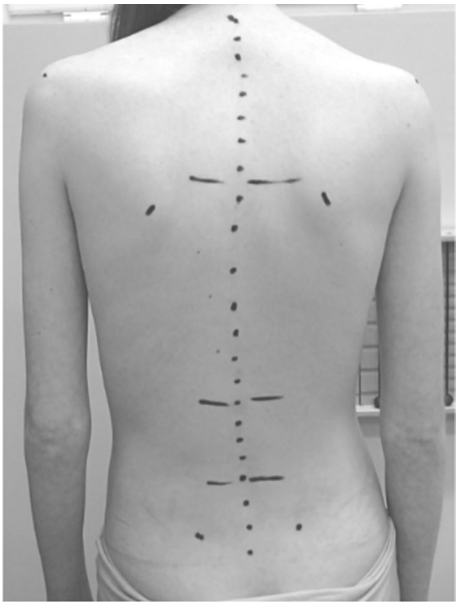

Fig. 4 Characteristic points used for measurements

Analyses were designed to examine the significance of the differences between the two measurements carried out with different tools (inclinometer and photogrammetry). Data standardization was performed prior to the analysis. In Mann–Whitney *U* test, with correction due to continuity, no statistically significant differences for any variable were found (Table 2). Additionally, parameters of the spine in the sagittal plane were subjected to regression analysis (Table 3).

Regression analysis was significant only for BETA variable. Parameter *B* (regression coefficient) was equal to 0.24 for this variable, which means that when BETA angle increases by about 1 point on the gravitational inclinometer then it increases by about 0.24 in photogrammetry measurement. Correlation of the variables MI-BETA and MII_BETA was moderate, its value was 0.45 (equal to standardized weight of Beta). No linear correlation was identified in the case of the remaining parameters.

Bland–Altman plots in Figs. 5, 6, 7, 8 and 9 present lines of 95% confidence intervals for mean differences between MI and MII as well as points with coordinates corresponding to differences in measurements acquired with the two tools for the specific parameters. In all the parameters 95% of the measurements were within the lines showing agreement; therefore, the results were deemed recurrent. Bland–Altman coefficient for the respective angles was: ALFA 2.0% (Fig. 4), BETA 4% (Fig. 5), GAMMA 0% (Fig. 6), LLA 2% (Fig. 7) and TKA 0% (Fig. 8).

Table 1 Descriptive statistics parameters obtained from measurements using photogrammetric technique and inclinometer

Variables	Measurement method I (gravitational inclinometer)				Measurement method II (photogrammetric technique)			
	$\bar{x}$	Me	*V*	*S*	$\bar{x}$	Me	*V*	*S*
ALFA	20.26	21.00	39.24	7.95	29.05	11.60	107.70	31.29
BETA	16.68	18.00	35.80	5.97	6.02	6.15	53.91	3.25
GAMMA	33.32	32.50	26.89	8.96	36.09	37.35	60.85	21.96
LLA	130.00	131.00	9.65	12.56	137.89	136.65	15.42	21.26
TKA	143.06	142.05	7.55	10.81	144.93	161.45	21.78	31.57

ALFA (*angle*) inclination of lumbosacral spine, *BETA* (*angle*) inclination of thoracolumbar spine, *GAMMA* (*angle*) inclination of upper thoracic section, *LLA* angle of lumbar lordosis obtained by subtracting (ALFA) and (BETA) angle from 180°, *Me* median, *S* standard deviation, *TKA* thoracic kyphosis angle obtained by subtracting (BETA) and (GAMMA) angle from 180°, *V* coefficient of variation, $\bar{x}$ arithmetic mean

Table 2 Comparison of analogous parameters obtained from measurements using photogrammetric and inclinometer techniques

Variables	Sum of ranges method I (gravitational inclinometer); *N* = 50	Sum of ranges method II (photogrammetric technique); *N* = 50	*Z*	*p*
ALFA	2542	2508	0.1137	0.909
BETA	2528	2522	0.0172	0.986
GAMMA	2491	2559	− 0.2309	0.817
LLA	2491	2559	− 0.2309	0.817
TKA	2499	2551	− 0.1757	0.860

ALFA (*angle*) inclination of lumbosacral spine, *BETA* (*angle*) inclination of thoracolumbar spine, *GAMMA* (*angle*) inclination of upper thoracic section, *LLA* angle of lumbar lordosis obtained by subtracting (ALFA) and (BETA) angle from 180°, *TKA* thoracic kyphosis angle obtained by subtracting (BETA) and (GAMMA) angle from 180°, *Z* result of Mann–Whitney *U* test, *p* level of probability

Table 3 Regression analysis for parameters

Variables	Regression analysis for parameters							
	Multiple *R*	Multiple R^2	Param *B*	Std err *B*	Beta (*β*)	Std err (*β*)	*F*	*p*
MI-ALFA–MII-ALFA	0.01	0.00	0.07	0.56	0.01	0.14	0.01	0.890
MI-BETA–MII-BETA	0.45	0.20	0.24	0.06	0.45	0.12	12.48	**< 0.001**
MI-GAMMA–MII-GAMMA	0.02	0.00	0.05	0.35	0.02	0.14	0.02	0.881
MI-LLA–MII-LLA	0.02	0.00	– 0.07	0.42	– 0.02	0.14	0.03	0.854
MI-TKA–MII-TKA	0.00	0.00	0.00	0.24	0.00	0.14	0.00	0.982

Bold value indicates significance at $p < 0.05$

MI method I (gravitational inclinometer), *MII* method II (photogrammetry), *ALFA* (*angle*) inclination of lumbosacral spine, *BETA* (*angle*) inclination of thoracolumbar spine, *GAMMA* (*angle*) inclination of upper thoracic section, *LLA* angle of lumbar lordosis obtained by subtracting (ALFA) and (BETA) angle from 180°, *TKA* thoracic kyphosis angle obtained by subtracting (BETA) and (GAMMA) angle from 180°, *B* regression coefficient, *R* correlation of the variables, *F* Snedecor test, *p* level of probability

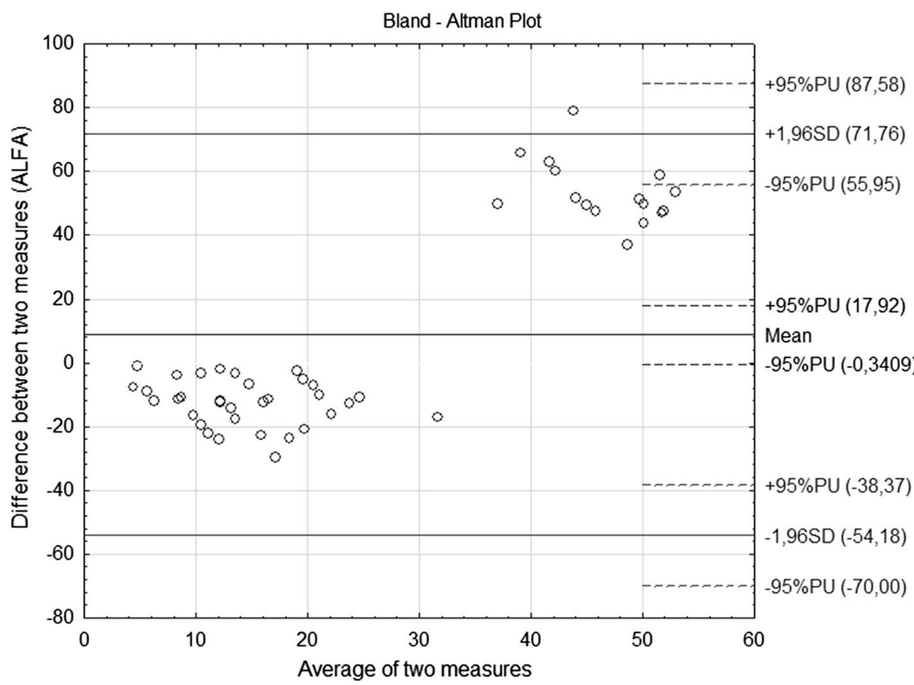

Fig. 5 Bland–Altman plot comparing measurements of inclination angle of lumbosacral spine (ALFA) performed with the two techniques

Discussion

The shape of spinal curvatures is of interest for various fields of science [21, 22], and is an element of posture assessment. In the literature focusing on spinal curvatures assessment, we can encounter various methods, which suggests that a perfect technique has not yet been found. The results reported by various researchers are difficult to compare due to the fact that different methods and measuring tools are applied; therefore, it is necessary to continue studies designed to compare results obtained with specific methods. Among the specialist publications we can encounter articles discussing concurrent validity of various techniques designed for assessing body posture [12, 23–25], yet no research has previously been reported to compare the methods based on photogrammetry and gravitational inclinometer, which has been done in the present study. The two methods were used in assessing the same subjects, which made it possible to verify the assumption regarding the concurrent validity of these measurements. Additionally, this is the first study focusing on senior citizens with increased BMI, which made it possible to verify the accuracy of these methods in this group of patients. Previously conducted comparisons related to younger individuals with no excess weight [12, 16], while measurements of spinal curvatures are necessary in older

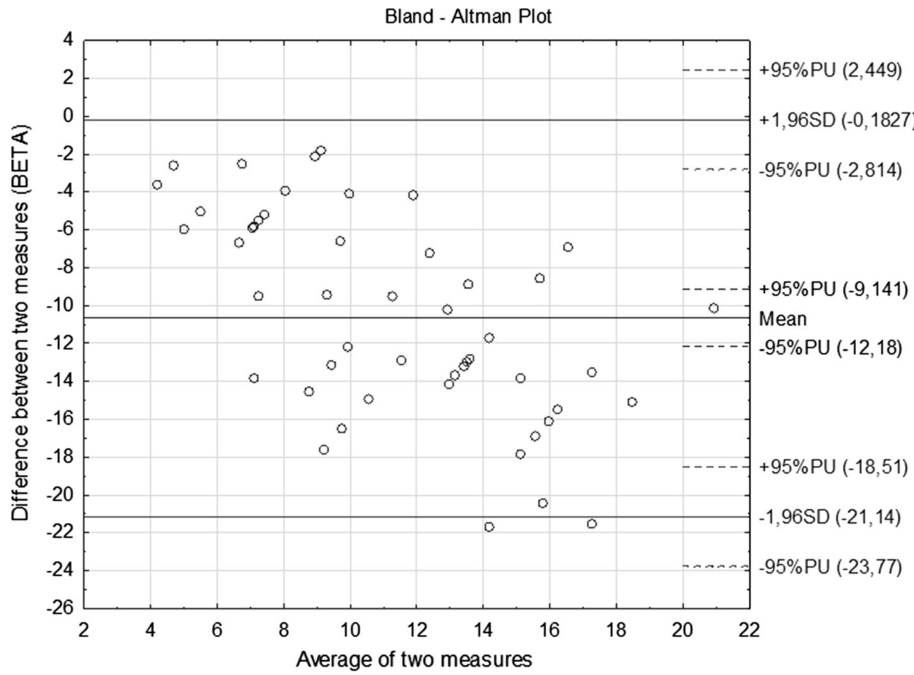

Fig. 6 Bland–Altman plot comparing measurements of inclination angle of thoracolumbar spine (BETA) performed with the two techniques

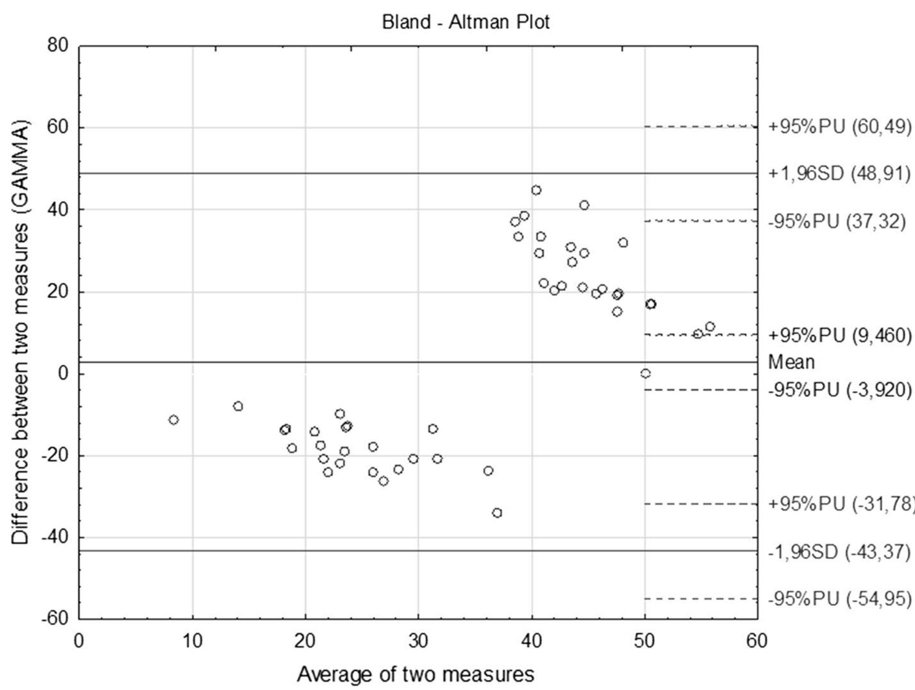

Fig. 7 Bland–Altman plot comparing measurements of inclination angle of upper thoracic section (GAMMA) performed with the two techniques

people or overweight individuals, and in fact assessments are more error prone in such cases.

The inclinometer applied in this study is a small and affordable measuring tool. It may be reused many times, which makes the diagnostic process easier. Numerous authors have shown high reliability and usefulness of this method for clinical examinations, e.g. Czaprowski [16], Saur et al. [25], Kuždżał et al. [5] and Walicka-Cupryś et al. [23]. The other device used in the present study for assessing body posture is a system whose operation is based on photogrammetric method taking advantage of Moiré phenomenon. An advanced optical system makes it possible for the computer to map out a three-dimensional image of the subject's back and to analyse over 50 parameters in the frontal and sagittal plane. The digital data may be analysed, compared, stored and subjected to statistical processing [7].

Results of the present study did not show significant differences in angles of lumbar lordosis and thoracic kyphosis

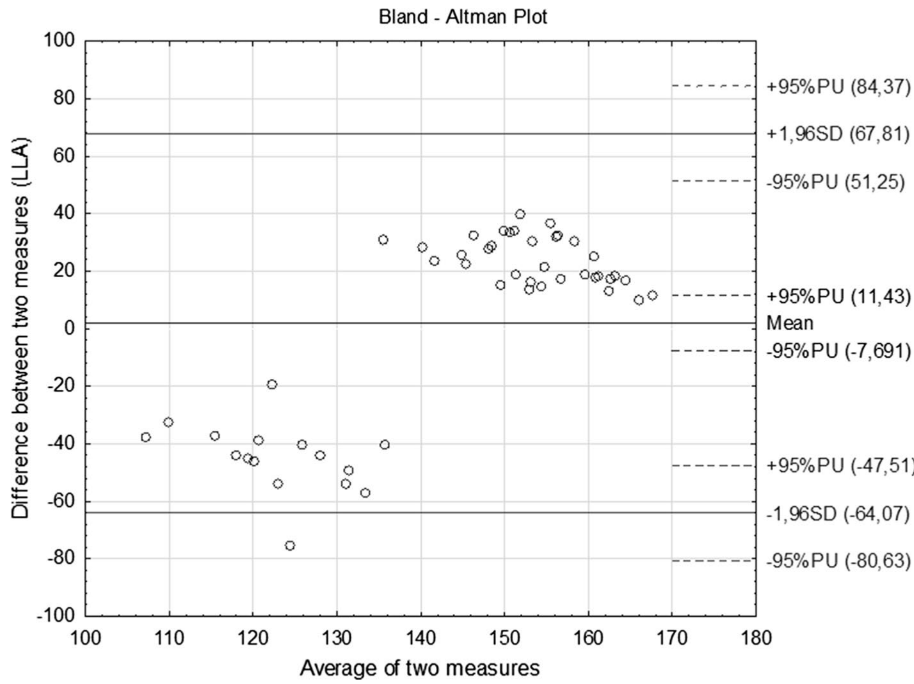

Fig. 8 Bland–Altman plot comparing measurements of angle of lumbar lordosis (LLA) performed with the two techniques

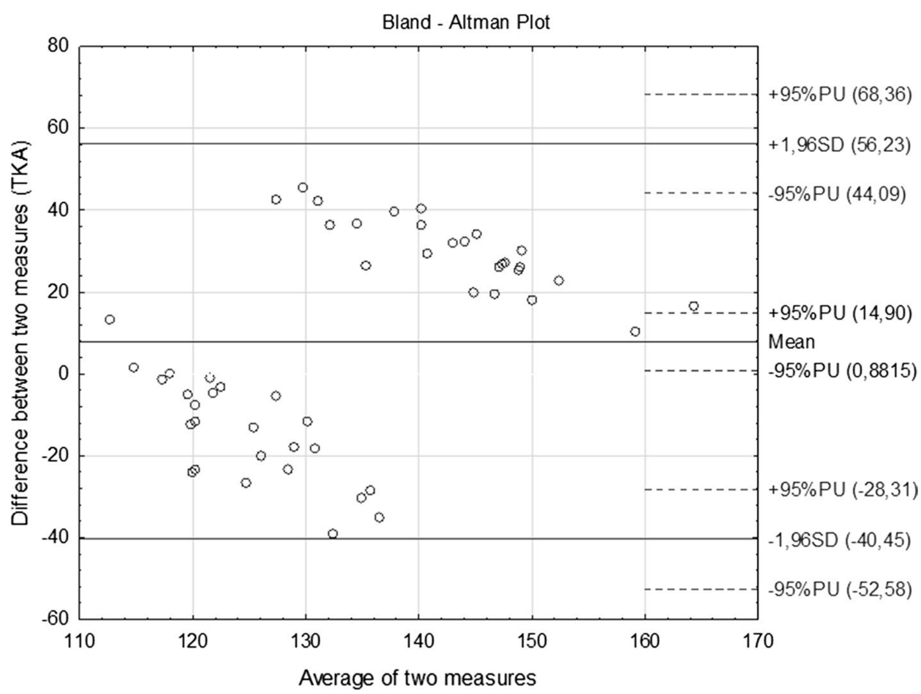

Fig. 9 Bland–Altman plot comparing measurements of angle of thoracic kyphosis (TKA) performed with the two techniques

in measurements based on photogrammetric technique and performed with gravitational inclinometer. Yet, the findings showed that measurements of some fractional parameters were not compatible. No statistically significant differences were found in the measurements of ALFA and GAMMA angles, performed with the use of the two methods. A significant difference related to the assessment of BETA angle. The above finding may have resulted from certain factors connected with conducting assessment with the use of photogrammetric and inclinometric techniques. In assessments based on photogrammetry, carried out with CQ device, the location of BETA angle depends on the ranges of curvatures. This angle is marked by the measuring system automatically, at a location where two curvatures overlap. In inclinometer the examiner marks BETA angle at a fixed point of thoracolumbar transition. It is also important to remember about other measurement errors discussed by Borek et al. [4], i.e. inaccurately determined anthropometric points necessary for performing the measurement, because in practice the error of determination amounts to 15 mm (± 5 mm) [26]; inadequate application of the inclinometer and error in its calibration due to incorrectly defined vertical alignment, resulting from miscalculation; all these add up in the measurement results (positively or negatively).

In photogrammetry the final result is affected by vertical alignment of the device, performed by means of the line levels on the camera, and then by errors in marking anthropometric points on the subject's skin and in defining measuring points on the screen.

Of importance here is the examiner's experience, as well as screen resolution, size of luminous spot and contrast of the defined points [4]. Moreover, the patients in this study had excessive body weight which may have distorted measurements of anteroposterior curvatures based on photogrammetry, due to excessive fatty tissue. The above factors may explain the differences in BETA angle measurements acquired in photogrammetric assessment and with gravitational inclinometer.

The presented findings are not consistent with the research results reported by Walicka-Cupryś et al. who assessed spinal curvatures with liquid-based inclinometer and photogrammetric technique [12, 23]. These authors did not find the two methods to be compatible. The results of examination may differ in this case due to the type of the applied device, because in assessments performed with liquid-based inclinometers there are two additional measurement errors, i.e. concave or convex meniscus, depending on inclinometer positioning, as well as error resulting from the viewing angle, because of which the readout may differ from the actual condition. In view of the above, the authors of the present study applied gravitational inclinometer which does not present these errors. The present findings are consistent with those reported by other authors who assessed the angle of kyphosis and lordosis using photogrammetry and imaging technique applying X-rays. When they compared photogrammetry results with X-ray images these authors found positive correspondence in the case of thoracic kyphosis angle, yet measurement of angle of lordosis with photogrammetric method carried significant error [27, 28]. Different findings related to measurement of lumbar lordosis were shown by Drzał-Grabiec et al., who reported that these two methods produced consistent results, yet the angular values identified with the non-invasive method were lower [10]. Leroux and Zabijek compared measurements of thoracic kyphosis; analysis of the results showed high correlation between the above methods. In the case of thoracic kyphosis the correlation coefficient was 0.89, while for lumbar lordosis it was slightly lower, at the level of 0.84 [29]. Saad et al. found high compatibility and repeatability of results in studies comparing values of Cobb angle, measured with photogrammetric technique and in X-ray examination [19, 30]. Comparative assessments of lumbar lordosis with methods based on radiography and photogrammetry were performed by Van Maanen et al. [31] and Iunes et al. [32] who confirmed concurrent validity of the two methods, and reliability of photogrammetry in assessing body posture.

As a result of technological progress a number of varied devices are available for assessing spinal curvatures. Notably, a number of non-invasive methods make it possible to perform posture assessment quickly, accurately, and safely, without putting a patient at risk of side effects of exposition to X-rays.

Analysis of the present findings and those reported by other authors confirms that both photogrammetry and inclinometer enable reliable posture assessment. An important argument is the compatibility of results obtained during photogrammetric assessment and X-ray examination, which currently is recognized as the most accurate method of posture evaluation. Inclinometric and photogrammetric assessments of anteroposterior spinal curvatures are based on the same assumptions as the commonly used Cobb method, which essentially involves identification of angle of inclination in the examined areas with respect to vertical axis [5]. The present study did not find significant differences in the inclination of the specific spinal segments, i.e. lumbosacral, and upper thoracic areas, or in the angle of lumbar lordosis and thoracic kyphosis identified during photogrammetric and inclinometric assessment. Therefore, it can be concluded that gravitational inclinometer may effectively be used for assessing spinal curvatures in sagittal plane, without the inevitable high expenditures linked with photogrammetric methods. Yet, to explicitly confirm whether or not the two methods produce consistent and reliable results it is necessary to conduct further comprehensive research with the use of more than two measuring methods, including inclinometric method, photogrammetry and X-ray.

The value of the research

This study confirms that the results acquired with gravitational inclinometer and using photogrammetric technique are comparable. A comparative study of measurement methods makes it possible to solve some problems, such as comparison of examination results identified in various clinics, or the choice of equipment for medical office to include measuring tools enabling assessment of spinal curvatures. The paper should be of interest to readers in the areas of medicine, rehabilitation, and finance management.

Conclusions

The results acquired with gravitational inclinometer and using photogrammetric technique are comparable. Analysis of the parameters of anteroposterior spinal curvatures acquired with these two methods shows their concurrent validity in the measurements of lumbar lordosis and thoracic kyphosis.

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Compliance with ethical standards

Conflict of interest Katarzyna Walicka-Cupryś, Justyna Wyszyńska, Justyna Podgórska-Bednarz and Justyna Drzał-Grabiec declare that they have no conflict of interest regarding the publication of this paper.

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