EDUCATION & TRAINING

Geometric Model for the Postural Characterization in the Sagital Plane of Lumbar Raquis

Pilar San Pedro[1] · Fernando Blaya[1] · Roberto D'Amato[1] · Juan A. Juanes[2] · Luis Tomás Gallego Morales[3] ·
José Antonio Rodríguez Montes[3]

Abstract

The individual's posture is the physical expression of his body. It is modified throughout life and it is determined by the particular anatomical characteristics that directly affect the biomechanics of the spine. The typing of the spinal curvature is important for the knowledge of body posture. The possibility of having a method for the systematic postural characterization of the spine is an essential objective resource in order to obtain normal or control patterns of the spinal morphology of the population. A widely accepted methodology of morphological characterization of the spine is a necessary requirement for the establishment of preventive criteria for spinal pathologies based on epidemiological population studies. It also represents a necessary requirement for the classification of individuals, based on the biomechanical, orthopaedic or ergonomic criteria necessary for disciplines such as sports, industrial design or sports performance. The present study proposes the development of a morphological postural model of the spine in the lumbar region. The model is based on a system of measurement of objective and comparable parameters by means of X-ray analysis, in order to characterize its morphology in the sagittal plane. The comparison of the results in a population of 47 individuals allowed the possibility to carry out a statistical study on three morphological parameters: sacral angle ($\alpha 1$); reversal angle (α_2) and degree of lordosis (D_L). The statistical hypothesis that the results behave according to a normal distribution with $p < 0.05$ is relevant and allows the systematization and postural modelling of the individual.

Keywords Morphological model · Lumbar región · Spine

Introduction

"The posture is an integrated association of biomechanical, neurophysiological and neuropsychic phenomena that influence each other and compensated at every moment. They are always conditioned by simple eye movements, by the position and mobilization of the head and upper limbs, by the type of plantar support, by walking and even by resting in a sitting position or in a decubitus position" [1].

Every human being has a unique position which is the result of a particular set of three-dimensional alignments.

These alignments are also affected by variables such as age, sex, weight or pelvic morphology [2, 3]. The individual's posture is the physical expression of the body that is modified

✉ Roberto D'Amato
r.damato@upm.es

Pilar San Pedro
pilarsanpedro@yahoo.es

Fernando Blaya
Fernando.blaya@upm.es

Juan A. Juanes
jajm@usal.es

Luis Tomás Gallego Morales
luis.gallego@salud.madrid.org

José Antonio Rodríguez Montes
rodriguezmontes@gmail.com

[1] Technical University of Madrid, 28012 Madrid, Spain

[2] University of Salamanca, Campus Miguel de Unamuno, 37007 Salamanca, Spain

[3] Hospital Universitario La Paz, Universidad Autónoma de Madrid, 28046 Madrid, Spain

throughout life due to the different changes in kyphosis and lordosis of the spine that occur at different stages of human growth.

The correct posture is defined as the best location of the spinal segments of each part of the body with respect to the adjacent body segment, as well as the entire spinal segment. It is generally considered that "it is the natural and comfortable support of the body in normal and healthy people." This means that in standing position the body is naturally, but not rigidly, straight [4].

The rate of increase in cases of musculoskeletal injuries and, as result, the increase in relative costs [5] requires the performance of studies focused on documenting the sagittal morphology of the spine [6]. For example, Jackson RP at al., in their study dimostrate that lumbopelvic lordosis and pelvic balance were strongly correlative [7]. Harrison et al. have developed a new mathematical model, by using least squares method, of thoracic kyphosis was constructed as digitized points from radiographs of 50 healthy patients. [8]. All this in order to identify and to understand the factors that affect the balance and the geometry of the spine, and also allow the knowledge of the causes and factors involved in the development of a variety of spinal disorders, pain chronic lumbar [9], spondylosis [10, 11] or Scheuermann's kyphosis [12].

The lumbar region is chosen as the object of this study due to the fact that it constitutes an anatomical structure, perfectly and functionally defined. The lumbar region plays a decisive role in the biomechanics of the spine and in the postural analysis of individuals. The majority of the lumbar affections corresponds to mechanical alterations of the vertebral structures. These are caused by improper functioning of this part of the spine [13, 14].

There is no standard procedure for the analysis of posture and for this reason in recent years several methods have been developed for a more precise postural evaluation in standing. The highly reliable techniques for the objective evaluation of the posture of the spine can basically be summarized as follows: X-rays [15], three-dimensional motion analysis using electromagnetic and optical instruments [16], screen stereograph [17], photographic analysis and postural methods [18, 19] and manuals.

Plain radiographs are a very precise standard procedure and are widely used for the analysis of standing posture since they provide clear images of reference points [20, 21]. For this reason, the purpose of this study is to develop a new geometric model based on a system for measuring parameters of the spine in the lumbar region by analysing X-rays in order to characterize its morphology in the sagittal plane.

Material and methods

The proposed postural morphological model of the lumbar spine is based on a geometric study for the graphic representation of the lumbar spine. This is developed in four basic steps; 1. Definition of variables to measure; 2. Radiographic procedure; 3. Protocol for measuring the samples; 4. Graphic representation and statistical analysis for the comparison of the obtained results.

Measured variables

The initial sample population was 55 elements. 8 individuals, who lacked data necessary for the study such as weight, height or age or whose radiological images were not suitable for observing the contour of the vertebral bodies or for the inclusion of the lumbar and sacral section complete (L1 -L5 and S1-S2) were rejected. Thus, a cohort of 47 weightlifting athletes with similar training, preparation and level of exigency, and the same sports technique practiced were analysed. 14 women (mean age: 20.6 years, SD 3.04; mean height: 162 cm, SD 6.7; mean weight: 65.2 kg, SD 12.88; body mass index (BMI) 24.8, SD 4.99) and 23 men (mean age: 20.04 years, SD 5.18; mean height: 170 cm, SD 5.2; mean weight: 75 kg, SD 11.67; body mass index (BMI) 25.56, SD 2.99) were tested. The anthropometric and sagittal X-ray variables used for the establishment of the geometric model equation related to the lumbar spine are described in Table 1 and la Fig. 1.

Radiographic procedure

The radiological study was performed on a sample of 47 individuals. The protocol followed establishes a lateral X-ray shot (sagittal plane) of the lumbar and sacral region (L) (Fig. 2).

Before carrying out each of the examinations of the individuals, a request for informed consent was provided in all cases (Mod.CBE-A1), previously accepted by ethics agencies, with a brief description of the study to be developed, along with a brief interview about the personal history, contraindications and possible risks. All personal data obtained in this study are confidential and have been treated in accordance with the Organic Law of Protection of Personal Data 15/99. Once the exploration was accepted and such a consent was signed by both the subject under study and the responsible physician, the radiological study was carried out for evaluation.

Due to the fact that it is a protocolled diagnostic test, all radiological shots are made with the same rigor, indications received by the subject, posture, place, distance to the focus and the screen, and mode of action. In order to perform the radiological shots established of the lumbar spine (L) Philips 9890–000-85,282 X-Ray Tube Housing Assy Low Speed RO1750/ROT350, 9890–000-85,271, High Speed 9806–206-70,102 SRO33100/ROT350, with a focus of 0,6 y 1,2 mm, has been used with a chassis of 35 × 43 cm and a chassis with diaphragm Bucky-Potter [22] in order to

Table 1 The anthropometric and spinal X-ray variables used for the establishment of the geometric model equation related to the lumbar spine

The anthropometric variables		
Age		Months
Sex		
Height	Standing total height	Centimetres
Weight	Total weight	Kg
BMI	Weight/height^2	kg/cm^2
The spinal variables (Fig. 2)		
Sacral angle (α_1)	Measured angle between the upper face of sacral plate (S1) and the horizontal line	Degrees (°)
Reversion angle (α_2)	Between the lumbar cord and the plumb line drawn from the posterosuperior vertex of the L1 vertebra	Degrees (°)
Lumbar-sacral angle (α_3)	Angle determined by the lower face of L5 vertebra with the upper face of the sacral plate S1. This angle is located in the so-called lumbosacral hinge	Degrees (°)
Postural variables used in geometrical model		
Degree of lordosis (D_L)	Ratio between max length of the Lumbar lordosis arrow (F) and Lumbar cord (C)	Dimensionless
Lumbar spinal index (I_{RL})	Ratio between the length of the lumbar cord (c) and the length of the lumbar curve (s)	Dimensionless

attenuate scattered radiation. The radiographic system described above is completed with the Carestream 10.0 diagnostic imaging management and treatment software It incorporates automatic image processing filters that allow to see the anatomical structures with greater definition and detail.

Once the digital X-ray files were obtained, they were processed by using the computer assisted design program AutoCAD 2015. In this way, an image was obtained in which the values of the geometric variables (Table 1) were measured for each radiography of the lumbar spine (Fig. 1). The data

recorded after the measurements were made on radiography image and were associated with the numerical code linked to each individual.

Protocol for graphical representation of the Lumbar Raquis

Raising a geometric measurement system based on linear and angular variables requires developing a methodology that allows establishing a relative comparison between all the samples taken. All this in order to obtain comparable valid data and to avoid the particularity that supposes the absolute linear measurements of each one of the individuals of the sample. For this, a homothetic transformation [23] of the radiological
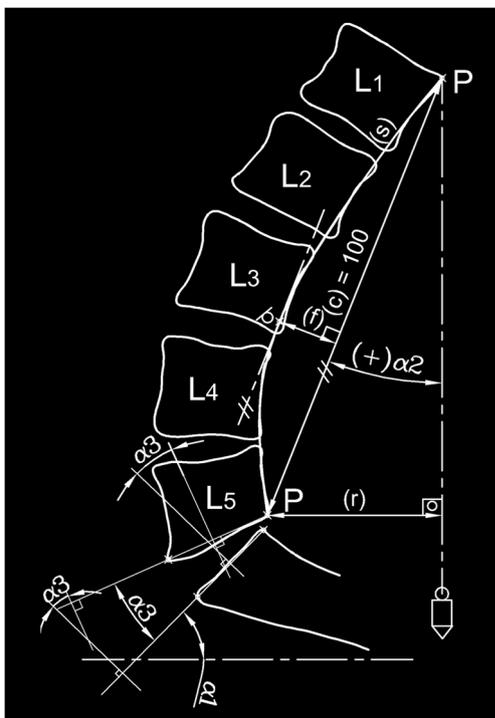

Fig. 1 Sagittal spinal (rachis) variables

Fig. 2 Patient's position in X-Ray machine for lumbar Lateral (L) radiography

samples taken is proposed. This transformation is based on a fixed proportionality constant applied to a significant segment of the lumbar region, which is easily identifiable in all of them. (lumbar cord (c)).

In addition, thanks to the use of proportional parameters and the choice of geometric variables of the spine measured in this study (Table 1), it has been possible to compare the obtained radiographic images. One of the problems for the analysis and for the postural comparison of different individuals, when using other geometric models reported in the scientific literature, is the realization of radiological images of particular diagnosis [7]. In fact, other models need radiographs with areas of interest of the column larger than those used in this study, because the postural analysis is carried out by using reference coordinates of the pelvis. As shown in Fig. 1, in this study the morphometric characterizations of the spine have been possible through the use of images where the area of interest is limited between the posterior-superior vertex of the L1 vertebra and the posterior-inferior vertex of the L5 vertebra (lumbar cord). (Fig. 3)

The method used to compare the characteristic measures of the lumbar curve, regardless of the size of the subject, or the presence of radiological tests not obtained at natural scale, consisted of fixing a segment as reference on the radiological, L1-L5, keeping the vertical position of the image and applying a Homothetic transformation with reference of proportionality. The centre of the Homothetic transformation is taken in the superior vertex of the cord L1-L5. Due to this, each lumbar cord of each athlete has been considered as follows:

$$C = Lumbar\ cord\ length\ L_1 - L_5 = 100\ units = (c) \qquad (1)$$

Once the reference parameter has been obtained as defined in (1), the homothetic transformation allows defining two dimensionless parameters (Figs. 1 and 2).. The first one is the Degree of lordosis (D_L) defined in: as a ratio between the maximum length of the lumbar lordosis arrow (f) and the lumbar cord (c) (eq. (2)). The second parameter is the lumbar spinal column index (I_RL) defined as a ratio between the length of the lumbar curve (s) and the lumbar cord (c) (eq. (3)).

$$D_L = \frac{Length\ of\ Lumbar\ lordosis\ arrow\ (f)}{Lumbar\ cord\ length\ (c)} \qquad (2)$$

$$I_{RL} = \frac{Lumbar\ Length\ curve\ (s)}{Lumbar\ cord\ length\ (c)} \qquad (3)$$

It should be noted that the sacral angle (α_1), reversion angle (α_2), degree of lordosis (D_L) and lumbar spinal index (I_RL) are radiographic parameters or postural variables that allow the relative comparison between all the samples taken from both same individual as between different individuals and avoid the particular character of the variables based on absolute linear measurements on the samples.

Statistical analysis for the comparison of results for the posture analysis

In order to predict or extrapolate the behaviour of the variables considered most relevant in the posture in subjects of a population not included in the sample of population under study, it has been determined, by means of a goodness-of-fit test, whether the values available in the sample under study, fit a theoretical probability distribution function. Obtaining the distribution is the first step to characterize a sample. This allows comparison with other samples that have different characteristics. For this reason, a known distribution model for spinal
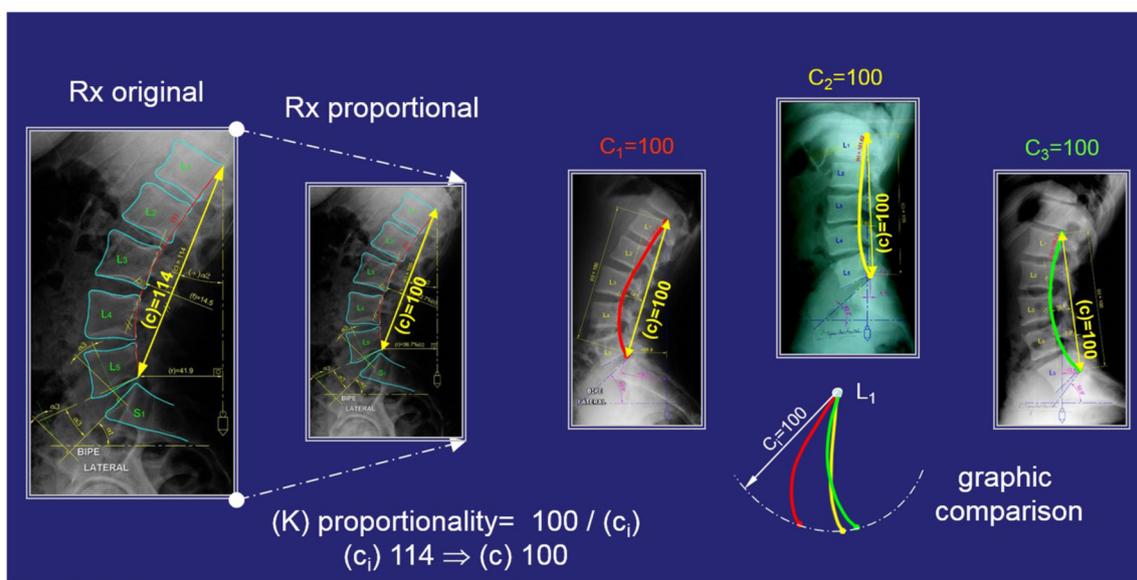

Fig. 3 Homothetic transformation with fixed proportionality constant

variables (considered in group B) has been sought: Sacral angle (α_1); Reversal angle (α_2); Degree of lordosis (D_L). For the search of the distribution model, the goodness-of-fit contrast of the corrected χ^2 was used. The corrected χ^2 test is based on the comparison of the observed frequencies of the data, compared to the frequencies that would be obtained if the data followed a Normal distribution (expected frequencies).

The statistic, which is used, is the aggregation of the relative quadratic differences of these frequencies that is distributed according to a χ^2 with *k-1* degrees of freedom, if the Normal distribution hypothesis of the variables is fulfilled. The *k* intervals, used in the calculation of the statistic, have all expected frequencies greater than 5.

To test the goodness of the adjustment to the normal distribution, the *p* value of the test is used. The *p* value is the probability of finding an equal value, or greater than that of the statistic calculated with the sample, when the assumed distribution hypothesis is true. Naturally, the higher the value of *p*, the greater the confidence in the goodness of the adjustment to the distribution. Values lower than 0.05 are considered a clear indication of lack of adjustment to the normal distribution. The steps for the development of the goodness of fit test have been:

1. Sort the values of the sample for the studied variable.
2. Calculation of the average ($\overline{X}$) and of standard deviation (σ).
3. I classes or groups of data are established and the average value of each of them is calculated ($\overline{x}_i$).

4. Contingency table.
5. Calculation of estimated χ^2 estimado.
6. Obtaining the degree of reliability or probability of finding a value greater than or equal to the tabulated χ^2 in the distribution χ^2 table.

$[\overline{X} \pm 2\sigma]$ Delimits a statistically safe value (95% of cases)
$[\overline{X} \pm \sigma]$ Delimits a very likely value.

Results and discussions

Results of the measurement of each x-ray of the lumbar spine

The result obtained with the measurement of each radiograph of the lumbar spine will be an image that reflects the values of the geometric variables raised as shown in Figs. 4, 5, 6 and 7. These figures show the results of the geometric model as a function of 4 different geometric parameters. Four cases, by way of example, of the sample solved according to the described procedure are shown below. The results of the measured postural variables for the cases shown in Figs. 4, 5, 6 and 7 are summarized in Table 2.

Fig. 4 Examples of the results obtained for the measurement of lumbar spine for of 23 years female patient in the case of Long lumbar curve (S): a) X-ray image; b) Geometrical model (Individual 12)
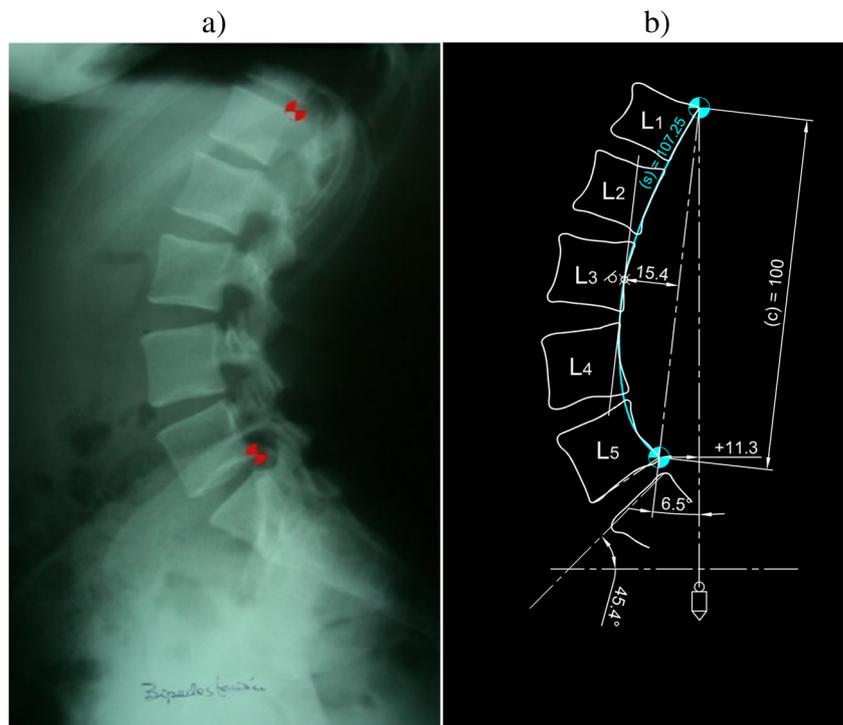
Fig. 5 Examples of the results obtained for the measurement of lumbar spine of 17 years male patient in the case of Height of lordosis (4): a) X-ray image; b) Geometrical model (individual 21)
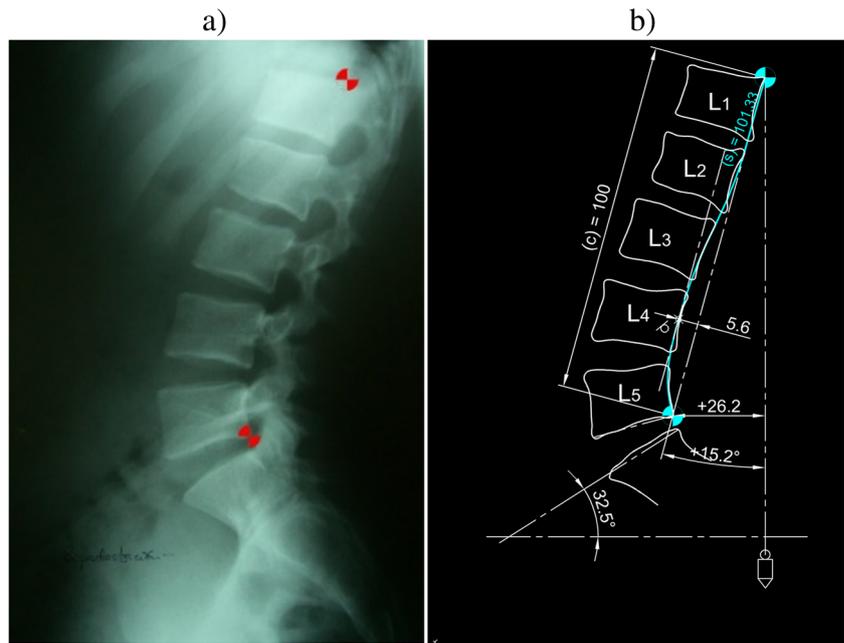

Figure 4 shows the geometric reconstruction of the spine for a 23-year-old woman with a large length of the lumbar curve. Figure 5 shows the geometric reconstruction of the spine in the case of a 17-year-old male patient with a high degree of lordosis. Figure 6 shows the geometric reconstruction of the spine in the case of a 22-year-old patient with a negative reversion angle (α_2). Finally, Fig. 7 shows the

geometric reconstruction of the spine in the case of a patient of 18 years with a high value of the sacral angle (α_1).

Table 2 shows the results of the anthropometric and morphometric variables measured in the subjects of the sample considered in this study. In this table, the variables: age, weight, height, sacral angle (α_1) and reversion angle (α_2) are expressed in dimensional form. While the variables: degree of

Fig. 6 Examples of the results obtained for the measurement of lumbar spine of 22 years female patient in the case of Negative reversion angle (α_2): a) X-ray image; b) Geometrical model (individual 11)
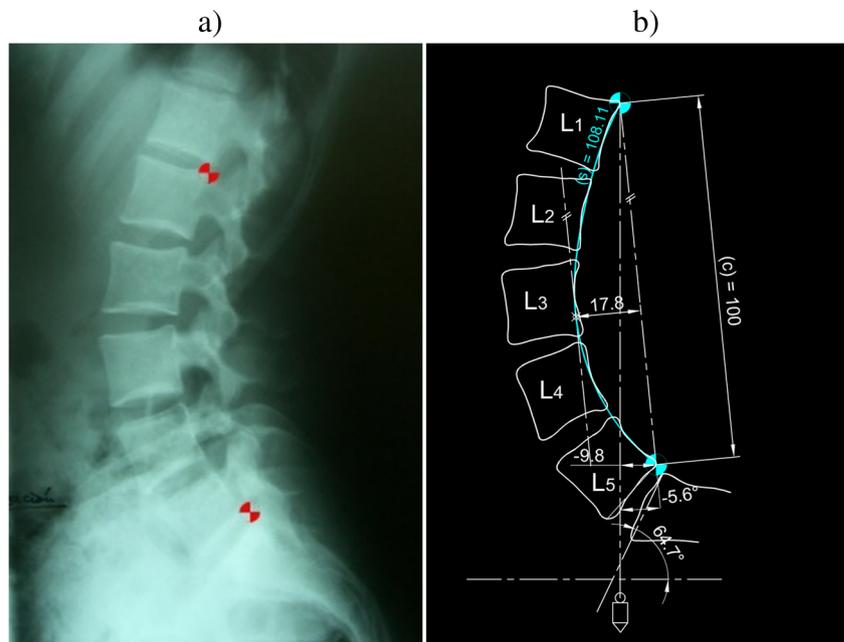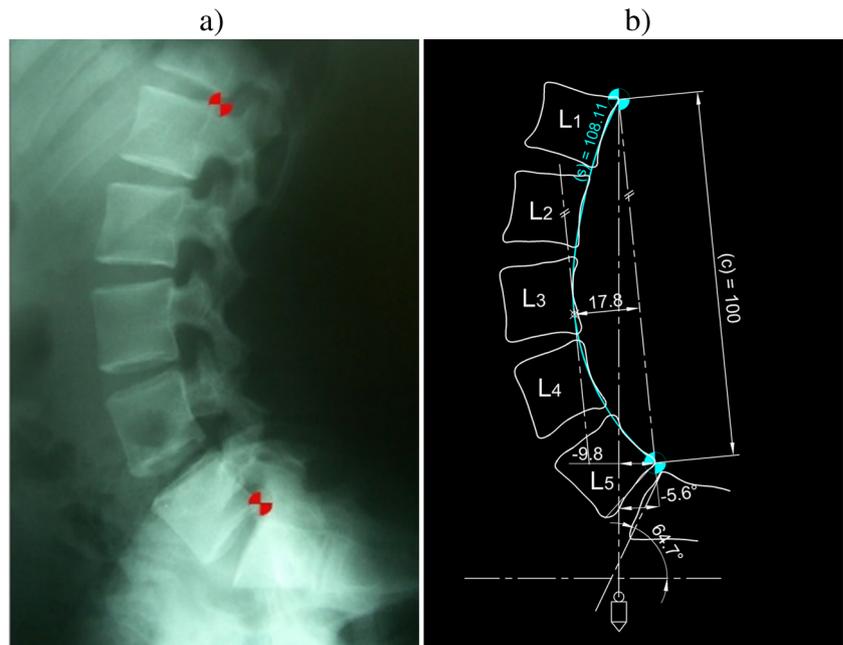
Fig. 7 Examples of the results obtained for the measurement of lumbar spine of 18 years female patient in the case of height value of Sacral angle (α1): a) X-ray image; b) Geometrical model (Individual 4)

lordosis (D_L), lumbar spinal index (I_{RL}), relative reversion (r), lumbar cord (C_L), length of lumbar curves (S_L), lumbar lordosis arrow (F_L) and height of Lordosis (H_L) are expressed in dimensionless form. This is due to the normalization of the given parameters and is carried out through a proportional geometric transformation through the application of a homothetic transformation in each image.

Goodness of fit test results

Once the values of the measured variables were obtained, a goodness-of-fit test was carried out, as explained in the previous section. Therefore, in this study a theoretical probability distribution model for the variables has been investigated: sacral angle (α_1), reversion angle (α_2) and degree of lordosis (D_L). In all cases, the most appropriate distribution and the one that best fits were the Normal distribution. (Table 3)

As an example, this section will show the development of the goodness-of-fit test only for the sacral angle (α_1) according to the procedure explained in proper section. Calculation of the mean ($\overline{X}$) and standard deviation (σ):

$$\overline{X} = 46,74$$

$$\sigma^2 = 51,41; \sigma = 7,17$$

Calculation of estimated χ^2.

$$\chi^2_{tabulated} = \chi^2_{c-r-1} = \chi^2_{6-2-1} = \chi^2_3$$

Where:

$\overline{x}$	mean of the I class, or group, of data.
n_i	n° of i values of the class, or group, of data.
n_i	Total number of values of the sample.
P_i	probability of the event.
$c-r-1$	degree of freedom of χ^2
c	number of classes
r	number of unknown parameters ($\overline{X}, \sigma$)

The test statistic takes the value 14.685 with 22 class intervals of expected frequencies higher than 5 and a p value = 0.8259, which indicates that it cannot be rejected that the data come from the Normal distribution with 95% of confidence.

Table 2 The morphological parameter in the athletes under analysis

	Sex	Age (Years)	Weight (Kg)	Height (cm)	BMI	(α_1) (degree)	(α_2) (degree)	c_L	s_L	I_{RL}	f_L	G_L
4	F	18,00	52,50	162,50	19,7	64,70	−5,6	100	108,11	10,811	17,8	0,178
11	F	22,92	51,40	154,10	21	48,90	−6,9	100	108,32	10,832	16,2	0,162
12	F	23,92	73,00	164,30	27	45,40	11,3	100	107,25	10,725	15,4	0,154
21	M	17,83	70,00	177,00	22,1	32,50	15,2	100	101,33	10,133	5,6	0,056

Table 3 Contingency table for the sacral angle (α_1) according to the goodness-of-fit method

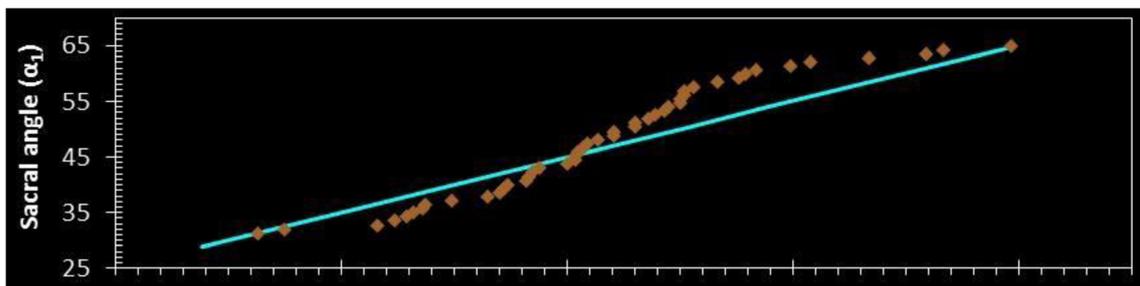| Class or group	n_i	$\bar{x}_i$	$\frac{\bar{x}_i - \bar{X}}{\sigma}$	$\bar{P}_i$ N(0,1)	$n\bar{P}_i$	$\frac{(n_i - n\bar{P}_i)^2}{nP}$
$a_1 < 32°$	1	31.3	−2,15	0,02	0,94	0,011
$32° \le a_1 < 37°$	2	33,2	−1,70	0,06	1,88	
$37° \le a_1 < 42°$	7	38,23	−1,10	0,21	7,05	0,001
$42° \le a_1 < 47°$	14	42,6	−0,35	0,51	14,1	
$47° \le a_1 < 52°$	14	47,0	0,35	0,81	14,1	0,006
$52° \le a_1 < 57°$	5	51,9	1,00	0,91	5,17	
$57° \le a_1 < 62°$	3	56,7	1,90	0,98	2,82	0,011
$62° \le a_1$	1	64,2	2,50	1	0,94	0.004
	$n = 47$					

Fig. 8 Graph of the best fit line for the sacral angle $\alpha1$

For the reversion angle ($\alpha2$) the test statistic takes the value 23, with 22 class intervals of expected frequencies higher than 5 and a p value = 0.18523, which indicates that the data cannot be rejected of the Normal distribution with 95% confidence.
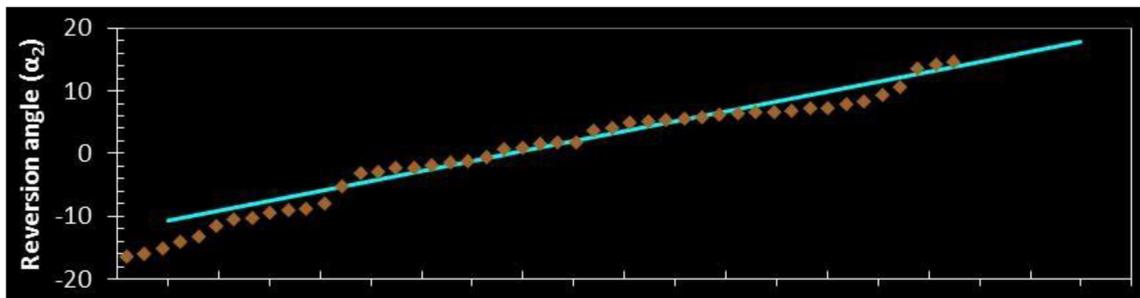
For the degree of lordosis (D_L) the test statistic takes the value 18.458 with 22 class intervals of expected frequencies higher than 5 and a p value = 0.51688, which indicates that the data cannot be rejected from Normal distribution with 95% confidence.

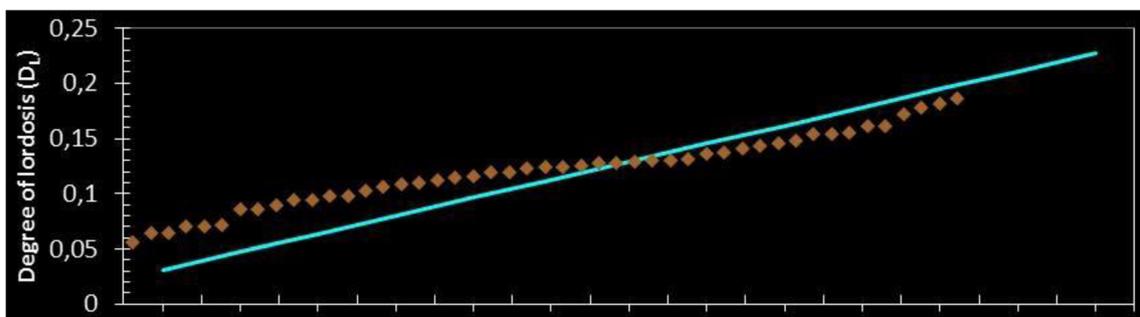**Fig. 9** Graph of the best fit line for reversion angle $\alpha2$

Fig. 10 Graph of the best fit line for the degree of lordosis DL

Table 4 Statistical parameters for all variables for the goodness of fit contrast of the corrected $\chi 2$

Variables	Means	Standard deviation	Degree of freedom	Probability (p)
α_1	46,74	7,17	3	$p = 0.05$
α_2	5,09	6,33	3	$p = 0.05$
D_L	0,12	0,03	3	$p = 0.05$

Figures 8, 9 and 10 show the result of the goodness of fit test taking into account the statistical parameters shown in Table 4.

Conclusions

The proposed morphological model has allowed an analysis of the lumbar spine in its sagittal plane, by analysing and by comparing the postural parameters of different individuals. It should be noted that the sacral angle (α_1), the reversion angle (α_2), the degree of lordosis (D_L) and the lumbar spinal index (I_{RL}) are radiographic parameters or postural variables that allow the relative comparison between all samples taken both from the same individual and between different individuals. These avoid the particular character of the variables based on absolute linear measurements on the samples. It has been possible to develop the model by fixing a segment as a reference in the radiological image, L1-L5, maintaining the vertical position of the image and applying a homothetic transformation with proportionality reference. In this way, it was possible to compare the angles of the rachis with the use of different images. The comparison of the results in a population of 47 individuals allowed the possibility to carry out a statistical study on three morphological parameters: sacral angle (α_1); reversal angle (α_2) and degree of lordosis (D_L). The statistical hypothesis that the results behave according to a normal distribution with $p < 0.05$ is relevant and allows the systematization and postural modelling of the individual. In addition, it allows to characterize a sample from the postural point of view and proceed to its comparison with other populations with different characteristics.

The application of the proposed morphological postural model can be of great interest for its methodological usefulness for all those professionals who are dedicated to the study and measurement of the spine from different areas: biomechanical, geometric, diagnostic, medical, physiotherapeutic, sports, etc.

The systematization through geometric and mathematical models is very useful in the study and in the anatomical measurement of the lumbar spine. This is an instrument that can be very useful for the improvement of sports techniques, to acquire individual postural patterns of behaviour, for the historical and evolutional comparison of the same individual or between groups of different individuals. It can also be used to prevent lumbar spine pathologies, to improve orthopaedic systems and to help people with disabilities, and to optimize ergonomics and postural simulation in the field of industrial design.

Compliance with ethical standards

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