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Application of a geometric and mathematical model to the biomechanics of the lumbar region in weightlifting athletes.

Modelo geométrico y matemático aplicado a la biomecánica de la región lumbar en atletas de halterofilia.

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Abstract
Introduction: The lumbar spine plays an important role in the biomechanics of the individual as well as contributes to define the posture.
Material and methods: In this study we have proposed a geometric and mathematical model in the subjects who practice the sport of weightlifting, in order to evaluate and characterize graphically the morphology of the lumbar spine in the sagittal plane to define, analyze and predict its behavior.
Results and discussion: The technical aspect of weightlifting is very precise and requires excessive joint mobility of the lumbar spine in the same time when it is integrating certain axial compressive forces due to the weight to be lifted. The scope of the results obtained in the geometric and mathematical models are of great interest due to their methodological significance for professionals who dedicate to the study and measurement of spine from different perspectives such as biomechanics, geometric, diagnostic, medical, physiotherapeutic, athletic, etc.
Conclusions: We believe that the results obtained by the proposed models are relevant for the systematization and posture modeling of the individual, once the dependency relationships are formulated between the proposed variables, thereby extending the study to other regions and fundamental concepts in the overall analysis of posture.

KEYWORDS
Biomechanics; lumbar spine; postural variables; weightlifting.

Resumen
Introducción: La columna lumbar juega un papel relevante tanto en la biomecánica del individuo como en la aportación a la definición de su postura.
Material y métodos: Planteamos un estudio geométrico y matemático, en sujetos que practican la disciplina deportiva de Halterofilia, con el fin de valorar y caracterizar gráficamente la morfología del raquis lumbar en su plano sagital, para poder así definirlo, analizarlo y predecir su comportamiento.
Resultados y discusión: La Halterofilia es un deporte cuya ejecución técnica es muy precisa y requiere gran movilidad articular de la columna lumbar a la vez que soporta fuerzas de compresión axial por el peso a elevar. El alcance de los resultados obtenidos en los modelos geométrico y matemático resultan de interés por su utilidad metodológica para aquellos profesionales que se dediquen al estudio y medición del raquis desde distintos ámbitos: biomecánico, geométrico, diagnóstico, médico, fisioterápico, deportivo, etc.
Conclusiones: Consideramos que los resultados obtenidos en los modelos propuestos son relevantes para la sistematización y modelización postural del individuo, una vez se formulen las relaciones de dependencia entre las variables propuestas ampliando el estudio a otras regiones y conceptos fundamentales en el análisis global de la postura.

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PALABRAS CLAVE
Biomecánica; columna lumbar; variables posturales; Halterofilia.

Introduction:

The lumbar spine is basically a structure of mechanical character that holds the maximum load of our body. Approximately 90% of lumbar disorders correspond to mechanical alterations of vertebral structures, caused by improper operation of that section of the vertebral column[1,2,3].

The top athlete after years of training transforms or adapts a physique that is required according to the demands of the sport specialty hence changing the morphology of the vertebral column, which supposedly occurs in a similar fashion in all practitioners of this specialty[4,5].

Sports that require training including intense weights to strenuous workout, such as weightlifting, can increase the load on the lumbar spine and pose significant lumbar spine problems to the athlete[2,6,7,8].

Weightlifting is a sport that is always practiced under same rules and conditions for all athletes[8]. Its technique is very accurate and requires a specific joint mobility of the lumbar region at the same time when it supports axial compressive forces in the handling and lifting the barbells[9,10]. Weightlifting involves a movement that goes from upright position to a deep flexion of the hip, knee and ankle, and from this position going back to upright position lifting the weight. Therefore, the lower back is the key anatomical region, in the technique of this sport, as it has to adjust to the movement required under flexion and hip extension and also compensate for the imbalance produced in other areas to overcome the weight. In this sport modality several factors are involved, among which we mention neuromuscular coordination, proprioception, joint flexibility, the proportion in bone levers, development of strength and speed of execution, and coordination of all joint segments members lower, hip, torso and upper limbs simultaneously.

Weightlifting technique has two specialties: 1. Snatch, involving a movement that requires high speed and precision in addition to rapid force in the legs and torso and great flexibility in all joints. 2. Clean and jerk: clean, where the bar goes from the platform to the shoulders, and jerk, where the bar goes from the shoulders to overhead on straight arms; consisting of bending, braking and extension of the legs.

Therefore, it is clear that in weightlifting, the lumbar area is under pressure by the weight load and the compression action of the lumbar muscles. In addition, the vertebrae are burdened by excessive compression in flexion and extension movements, in an irreversible manner because of maintaining forced postures during training[9]. The pressure inside the disc varies depending on body position and the external stress. The selection of this sport for the present study is due to the reason that this specialty is always practiced in the same conditions for all athletes, regarding the characteristics of the material, the bar and discs, clothing and shoes, the stage and in being independent of the external conditions.

Undoubtedly during training the athlete needs to introduce an ever more specific preparation in all aspects: physical, tactical, technical, psychological, medical control in various specialties such as stress testing, cardiology, endocrinology, but also a stabilographic and postural analysis, due to which personal morphological characteristics, deviations from normality and sequelae of previous injuries are observed.

Given these considerations, our objective was to apply a geometric and mathematical model, based on a system of measuring parameters of the spine in the lumbar region, which allows describing graphically the morphology of the lumbar spine in the sagittal plane of weightlifting athletes, in order to define, analyze and then simulate its behavior. This study and analysis of results will permit to act accordingly and achieve optimal predisposition for sports performance, which will certainly help to prevent injuries in the locomotor system and spine.

This geometric model is to be performed on a representative sample of the group of top weightlifting athletes, members of the Spanish national team and regional teams in official competitions.

Methods

The group of people considered for our study belongs to the population of top weightlifting athletes. We studied 77 athletes (48 men and 29 women). The group was heterogeneous regarding sex, age and weight, but the factors such as training, preparation, requirements and the technique practiced by the subjects were the similar. Radiographic data were obtained from the Center for Sports Medicine, Superior Council of Sports of Madrid.

A study was carried out including three radiological analysis i.e. anteroposterior teleradiography of full length of the vertebral column; lateral (sagittal) plane of lumbosacral region and anteroposterior thorax. The sagittal section of the lumbosacral region was chosen for this study.

In order to perform these analyses the subject was made to stand in an upright position in a relaxed and natural way without moving and provided with the instructions on when to take a full breath, holding the breath until the firing signal and completion of the test. As all the tests followed a proper protocol, technical rigor of the firing shots, indications received by the subjects, position, place, distance to the focus and the screen, and mode of action were all the same.

Once the digital files of radiographic analysis were collected, data treatment was done using the software AutoCAD 2015. The results obtained from the radiological analysis of each lumbar spine section were images that show the values of the geometric variables (Figure 1).

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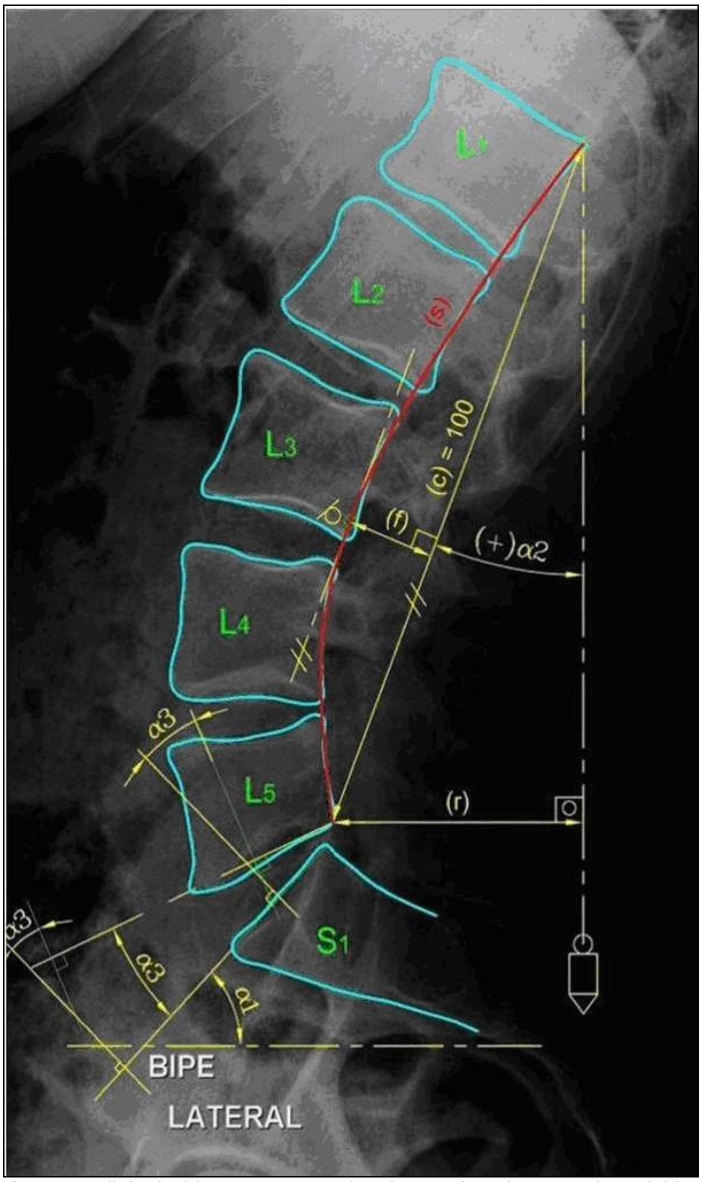

Fig. 1.- Radiological image representing the employed geometric variables

It should be noted that both the data provided by the each individual in the group and the digital files of radiographs used were associated with a numerical identification code, provided by the Superior Council of Sports, in order to ensure the anonymity and protection of personal data. The data recorded from the radiographic measurements was associated to the numerical code linked to each person.

Geometric Model:

The geometric model was supported by a system based on the measurement of parameters of the spine in the lumbar region, which allowed us to graphically describe the morphology of the lumbar spine in the sagittal plane, in order to define, analyze and simulate their behavior posteriorly.

The parameters obtained from the geometric measurement of the curves were used as variables in the study of this graphic model of lumbar curvature that fits into its actual contour allowing us to work with the concept of posture. To this end, some variables were taken which when considered jointly provided us with a graphical representation of the lumbar morphology. These variables provided concepts and understanding to define and assess the position of the lumbar region.

Obtaining comparable models of lumbar curvature, between individuals of different morphology and size, or circumstances such as unavailability of radiological samples on full-scale, forced us to develop a proportional geometric transformation, following the curves obtained, to fit them according to the unique references in order to ensure an objective comparison.

In order to achieve the comparison between the characteristic measurements of the lumbar curves, not taking into account the differences in the size of the subjects, or the fact that full scale radiological evidence was not available in the original or digitalized form; the proposed method consisted in setting a reference segment over the radiological test/report, in our case L_1-L_5, lumbar cord, maintaining the vertical reference of the test and apply a homothetic transformation of the image with reference of proportionality

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Length of L_1-L_5 (lumbar cord) = 100 units

and homothetic origin or center at the vertex of the cord (postero-superior vertex of the L_1 vertebra). This allowed us to achieve that the size of the lumbar cord is same and the lumbar curves can be overlapped for comparison making them coincide with the superior extreme end of the same lumbar cord. The longitudinal variables are made relative to a reference segment of the same length and therefore its relevance to the curve is comparable.

Postural Variables used:

The spinal variables obtained from measurements made on the radiographic analysis were as follows:

Sacral angle (α1): measured between the upper face of S_1 or Sacral and horizontal plate. Its value determines how the sacrum receives the vertebral column especially L_5. The ideal angulation of the S_1 upper and horizontal face is about 34º.

Reversion angle (α_2): comprised between the lumbar cord and a line drawn from the postero-superior vertex of the vertebra L_1. When the lumbar cord and line coincide the lumbar curvature the angular value would be 0 (the section considered to classify a reversal as neutral will be between -1º and +4º). When there exists an anterior inclination in the lumbar curvature, the reversion angle will be negative and in case of posterior inclination will be positive.

Lumbar cord (C_L): corresponds to the length of the segment L_1-L_5, where L_1 is the postero-superior vertex of the vertebra L_1 and L_5 is the postero-inferior vertex of the vertebra L_5. In our study, this will be a constant value equal to 100 to be considered as a reference for the comparison in percentage of the linear parameters.

Degree of Lordosis (D_L): the relation between the length of $arch_{max}$ and lumbar cord.

$$D_L = \frac{length\ of\ arch\ \max(f)}{length\ of\ lumbar\ cord(c)}$$

It is an indicator of the degree or extent of lordosis of the curve like the lordosis arch.

Lumbar spinal index (I_{SL}): It is the relation between the length of lumbar cord (c) and the lumbar curve (s)

$$I_{SL} = \frac{length\ of\ lumbar\ curve(S_L)}{length\ of\ lumbar\ cord(C_L)}$$

This value indicates how many times the circumference of the lumbar curve is greater than the straight section covering lumbar cord and measures the degree of deviation of the lumbar curve relative to the cord, without taking into account the considerations of the curvature type. In other words, it makes a comparison between the length of the lumbar curve developed and the length that is covered by the cord.

Height of lordosis: it is the position of maximum arrow of the curve. Its position is found to the tangent of the lumbar curve in a direction parallel to the lumbar cord L_1-L_5. This height represents the lumbar curve vertex and is found at the point where maximum arrow is considered. If the vertex is found in the lumbar vertebra L_3, the lumbar curve will have a more homogeneous morphology and the pressures between all lumbars will be better distributed and from lumbars upwards to the dorsal ridges and down to the sacrum and pelvis.

The mathematical model. In order to develop the mathematical model, two groups of variables were established, classified on the basis of their origin and source. Thus, those variables drawn from the personal files of sample data of weightlifting athletes, constitute the so-called group A general variables: age, sex, height, BMI. Moreover, the variables obtained from radiological analysis will form part of group B of spinal variables: sacral angle, reversion angle, lumbar spinal index, degree of lordosis, height of lordosis and wedged vertebra.

Results:

The geometric model developed from the graphical representation of spine provides the basis to characterize graphically the component of human posture that has its origin in the lumbar region tracing through the actual circumference of the spine obtained from both geometric variables already considered as well as the concepts related to the posture.

Variables have been proposed that allow presenting the problem in geometric terms. These variables include the ones used previously as well as new variables proposed in this study. The sample as well as the data considered in the study are highly reliable as it presents a percentage of individuals close to the total population, due to employing the unique and advanced facilities and a unique protocol for obtaining X-rays. Finally the use of the applied protocol that was formulated exclusively for the study guarantees the quality of the data collected.

A geometric model of graphical representation of lumbar spine has been proposed that adapts to the original contour of spine and allows working with the concept of posture[11]. Thus, we have developed a methodology that allows establishing the treatment of the acquired data in order to ensure the validity of results, and a method developed by us has been presented for the measurement and processing of variables based on the geometric transformation proportional

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to the variables used. This allows a comparison between individuals of different size and morphology. Furthermore, the variables that have significance in highlighting the problem have been proposed in geometric terms.

Mathematical model proposed in this study is based on two tests:

1. Test of independency, this test allowed determining the correaltion between the variables considered in the lumbar spine (Table 1). The statistic technique used for the analysis as described earlier is based on a theoretical distribution χ^2 (chi-square).

Table 1. Summary table of related variables.

		TYPE A				TYPE B					
		Age	Sex	Size	BMI	Sacral angle a_1	Reversion angle a_2	Lumbar Spinal Index	Degree of Lordosis	Height of lordosis	Wedge
TYPE A	Age				X	X	X		X	X	
	Sex				X	X	X	X	X	X	
	Size					X	X	X	X		
	BMI	X	X			X	X		X	X	
TYPE B	Sacral angle a_1	X	X	X	X		X	X	X	X	X
	Reversion angle a_2	X	X	X	X	X		X	X	X	X
	Lumbar Spinal Index		X	X		X	X			X	
	Degree of Lordosis	X	X	X	X	X	X			X	X
	Height of lordosis	X	X		X	X	X	X	X		X
	Wedge					X	X		X	X	

Contingency tables have been considered in proportion to the variables pairs indicated in Table 1, and after determining the Id identifier of the number of each of the variables, a comparison, we proceeded to perform the comparison with characteristic percentile of confidence level of 95% in the distribution table of χ^2.

Tables 2 and 3 provide the results of test of independency and the value of independence obtained for each pair of variables.

Table 2. Results of Independency test.

		TYPE A			TYPE B					
		Sex	Size	BMI	Sacral angle a_1	Reversion angle a_2	Lumbar Spinal Index	Degree of Lordosis	Height of Lordosis	Wedge
TYPE A	Age			D	I	I		I	I	
	Sex			D	I	I	I	I	D	
	Size				I	D	I	I		
	BMI				I	I		I	I	
TYPE B	Sacral angle a_1					D	D	D	I	I
	Reversion angle a_2						D	D	I	I
	Lumbar Spinal Index								D	
	Degree of Lordosis								D	I
	Height of Lordosis									I

Table 3. Degree of independency between the variables.

		TIPO A			TIPO B					
		Sex	Size	BMI	Sacral angle a_1	Reversion angle a_2	Lumbar Spinal Index	Degree of Lordosis	Height of Lordosis	Wedge
TYPE A	Age			1.01	-6.96	-4.78		-0.71	-3.74	
	Sex			3.08	-6.19	-4.03	-0.34	-4.85	0.14	
	Size				-9.63	0.08	-3.20	-4.16		
	BMI				-5.11	-14.22		-6.97	-2.51	
TYPE B	Sacral angle a_1					7.56	8.37	11.94	-1.64	-4.71
	Reversion angle a_2						3.98	13.40	-1.90	-4.25
	Lumbar Spinal Index								2.49	
	Degree of Lordosis								0.98	-5.74
	Height of Lordosis									-1.72

Independent Variables
Dependent Variables
Value of Independence intermediate between -1 y 1

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The results obtained provided some interesting dependence relationships that is a first step towards mathematical formulation of the concept “entirety of posture” or “global nature of posture”. It could be expected that the studies among the variables that were associated with sex (sacral angle – sex, reversion angle – sex, medulla index – sex and degree of lordosis – sex) would show a dependency relationship, but the results show independence with respect to this factor.

It is important to notice that the lumbar spinal variable does not depend on sex indicating that there are no difference between men and women as could be expected if the differences in shape and size of bones near the pelvis are considered (different shape and size).

In the case of height of lordosis – sex and BMI – sex, however the factor of sex has shown a dependence in the results. In the case of height in L_4, this dependency has been registered in 1/3 of the male and only in 2 female subjects, meanwhile in L_3 it was found in 27 out of 29 female and 2/3 of male subjects.

The wedged vertebra, which could be presumed to be dependent on the degree of lordosis, reversion angle and height of lordosis, has found to be independent in all cases.

Other pairs of variables that have shown dependency relationship have been the sacral angle – reversion angle as expected. "The changes in the value of the sacral angle influence the reversion angle. However the height of lordosis is independent of both of them."

The variables that are clearly dependent include, sacral angle – reversion angle, sacral angle – lumbar spinal index and sacral angle – degree of lordosis. As in the previous case, this means that modifications of sacral angle influence the values of the other variables.

Reversion angle – degree of lordosis, also show dependency relationship as in principle could be expected given its significance and impact on posture.

The variable BMI is dependen ton the age and sex.

The degree of lordosis is greater with height of lordosis in L_3.

However, improving compartmentalization certain variables could have provided greater reliability in analysis, such as sacral angle – height of lordosis that are independent, sacral angle – wedged vertebrae that are independent, reversion angle - age are independent, reversion angle - lumbar spinal index that are dependent, degree of lordosis - age, etc. Other variables achieved very low reliability obtaining a value of independency between -1 and 1.

2. Line of best fit test, has confirmed the initial proposed hypothesis affirming that the variables such as sacral angle, reversion angle and degree of lordosis fit to a model of Normal probability distribution (figures 2, 3 & 4). This test is very relevant as it allows characterizing a sample and later on proceed to its comparison to other samples with different characteristics.

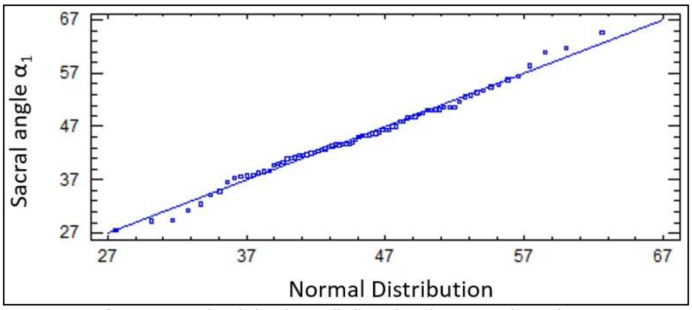

Fig. 2. Graph of the best fit line for the sacral angle α_1

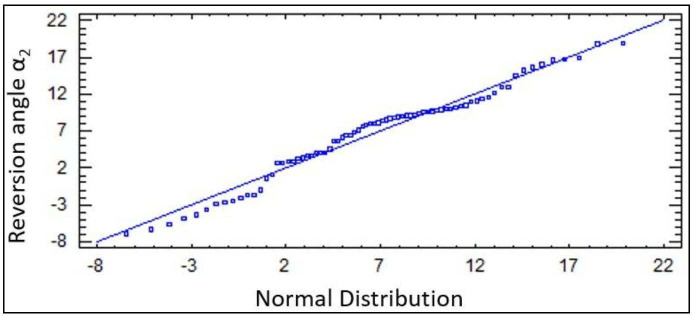

Fig. 3. Graph of the best fit line for reversion angle α_2

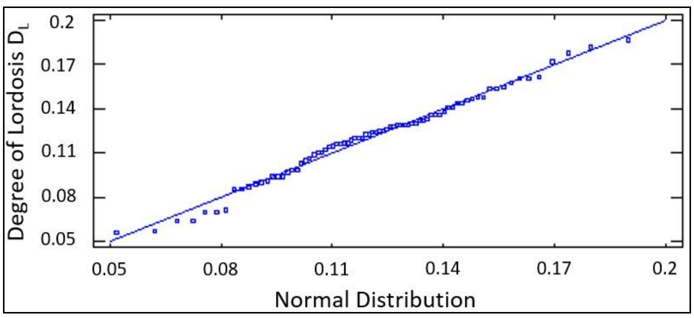

Fig. 4. Graph of the best fit line for the degree of lordosis D_L

In the histograms shown in figures 5, 6 & 7, a good fit of the data for the sacral angle α_1, reversion angle α_2 and degree of lordosis D_L to Normal distribution can be seen by comparing the two distributions quantiles. The solid line corresponds to the normal distribution and points to the values of α_1 achieved.

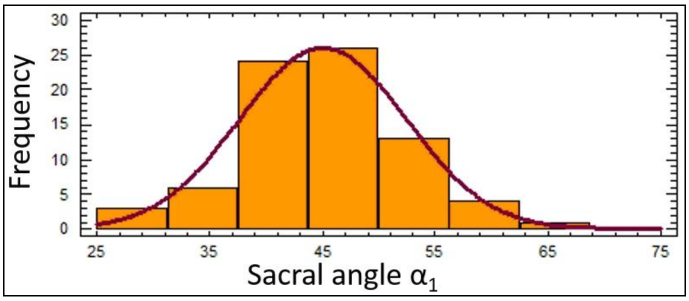

Fig. 5. Histogram of sacral angle α_1 and Normal density

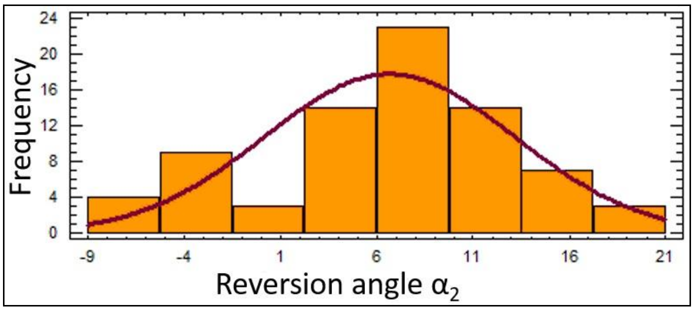

Fig. 6. Histogram of reversion angle α_2 and Normal density

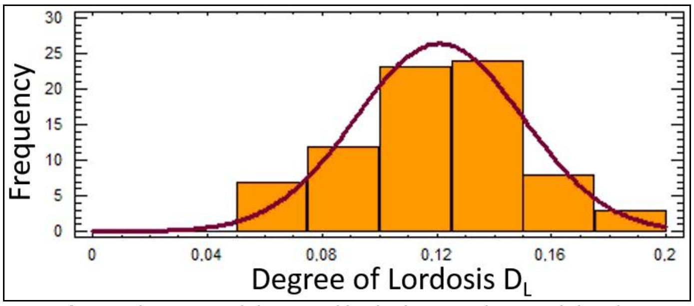

Fig. 7. Histogram of degree of lordosis D_L and Normal density

The results obtained in the proposed models are relevant for the systemization and postural modelization of the individual, once possible dependency relations are established, extending the study to other regions and acquiring fundamental concepts for the analysis of overall posture. Our geometric and mathematical models can be of interest for methodological usefulness for all professionals who focus on the study and measurement of the spine in different aspects: biomechanics, geometric, diagnosis, medical, physiotherapy, sports, etc.

Discussion:

Back pain in the lumbar region is the most frequent injury in sports[2,6]. Presently due to early sports specialization and great development in competitive sports, problems of acute lumbar back pain are encountered in adolescents who at such a young age sometimes require a surgery, the most common being spondylolysis[4,12,13]. Generally, the cause of these injuries is overtraining of the lumbosacral column and cartilage avulsion may occur in the vertebrae.

There are several situations involving an overload of the lumbar spine in sports like weightlifting because of fast intensive training and workout for competitions, in order to achieve maximum performance on columns. However, sometimes due to the age of the individual, the vertebral columns have not yet reached to the maximum or sufficient level of development, and are not prepared to bear this burden either[14,15].

In some occasions, a very painful accident can occur in the vertebral plate, which can be serious because of using weights of inappropriate loads, similarly the workouts that involve rotation or lateral inclination, which is mostly treated as a position attained in disequilibrium with poor proprioceptive control of the lumbar spine. A herniated disc often causes this acute condition[3].

Therefore, the geometric and mathematical study that we have applied on the subjects who practice the sport of weightlifting will permit the evaluation and graphical characterization of lumbar spine in sagittal plane in order to define it and analyse the angles of spine. This will be done by comparing with the history of same athlete as well as with others practicing the same discipline. Furthermore, it will also enable to predict the behaviour in the individuals interested in the

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practice of this sport modality, which undoubtedly will have an impact on the prevention of possible injuries of the lumbar region in the subjects[16]. In this way, a geometric and mathematical study of the vertebral column will allow carrying out a concrete determination of the safety limits in weightlifting by comparing the stress. These are calculated based on the biomechanical models using maximum loads and observing the specific tissues of the column involved in experimental mode.

When the calculated internal stress exceeds the capacity of the tissues, an injury can be expected to occur. Therefore, biomechanical models can be used for development or justification of risk control strategies that minimize the calculated stress, maintaining a safety zone during uplifting of the weights.

The National Institute for Occupational Safety and Health (NIOSH) establishes criteria for the safety levels in weightlifting. The equation of NIOSH employs the following biomechanics criteria; firstly it points out that the joint between L_5 and S_1 is at level where major force is implied during lifting, being the compressive force at this level and constituting the vector of critical stress, secondly the criteria points out that the compression force that establishes an increase in the risk is 350 kg.

Several studies have shown that carrying a compressive load of 350 kg on the lumbar spine starts producing microfractures in the vertebral plates at least in 25% of the weightlifting athletes[2,6]. The mechanism of the spinal injuries under compressive loads is produced by the disorder of the vertebral plates and the underlying trabeculae in accordance with the nucleus pulposus which is pressed in upper or lower direction. It is unlikely that the magnitude of the compressive forces during a single lifting causes just one fracture in the vertebral plate and it has been reported that it is more probable that injuries of this type are more cumulative.

The developed procedure will allow its practical application to the performance of sports and in sports medicine, not only in the speciality of weightlifting but could also be extended to other related sports modalities, by designing the protocols for the correction of overall posture and establishing compensatory guidelines of action on two levels. First one of preventive character, involving the application of this protocol in a programed fashion to the training of the sport thus avoiding deviations and imbalances that can exceed the healthy and performance limits, and therefore preventing irreversible morphological disorders or characteristic injuries. Second level of action would be through sports medicine, where these methods can be applicable to the rehabilitation of top athletes which by its protocol systematization would be feasible in case of getting mathematical modeling[16].

Moreover, the developed geometric and mathematical model can extend its methodology to pelvis-vertebral column as a whole in order to obtain a postural model with a higher level of comprehensiveness and totality and therefore possessing the capacity of a complete individual biomechanical analysis. This approach includes the study of the postural compensation hypothesis of spinal curves.

Having a good geometric and mathematical model of the lumbar spine, as we have developed in our work, will help improving the sports techniques, formulate behavioral guidelines about individuals´ postural patterns, prevent disorders in the vertebral column, improve orthopedic and support systems to people with disabilities, and optimize ergonomics and postural simulation in the field of industrial design.

A working methodology should be developed that analyzes the presented hypothesis to establish the possible relationship between the postural attitude and practicing a particular sport. In this way, it can be found out if there exists any specific type of morphology of the spine for a sample of individuals who practice professionally selected different sports.

In case that the mentioned relation exists, a specific typology could be characterized for every sport discipline and establish countervailing guidelines for action in the training itself that would avoid deviations or imbalances that exceed the health or performance limits and therefore avoid irreversible damage or characteristic injuries.

References

1. Santiago, F. R., Álvarez, L. G., Moreno, M. T. and González, P. N. (2010). La radiografía simple en el estudio del dolor de la columna vertebral. Radiología, 52(2), 126-137.
2. Samuel, P. C. Lesiones de la columna lumbar en el deportista. Revista Médica Clínica Las Condes 2012;23(3): 275-282.
3. Peña, G., Heredia, J. R., Lloret, C., Martín, M. and Da Silva-Grigoletto, M. E. Iniciación al entrenamiento de fuerza en edades tempranas: revisión. Revista andaluza de Medicina del Deporte(2016);9(1)
4. Mitnitski, A. B., Yahia, L. H., Newman, N. M., Gracovetsky, S. A. and Feldman, A. G. (1998). Coordination between the lumbar spine lordosis and trunk angle during weight lifting. Clinical Biomechanics, 13(2), 121-127.
5. Anselmi, H. (2007). Actualizaciones sobre entrenamiento de la potencia. Anselmi, Buenos Aires, 2007.
6. Rochcongar, P. (2014). Lesiones crónicas del aparato locomotor en el deportista. EMC-Aparato Locomotor, 47(2), 1-10.
7. Álvarez, G. R., Grigoletto, M. D. S. and Manso, J. G. La Halterofilia aplicada al deporte: Su enseñanza, uso y aplicación. Wanceulen SL2015.
8. Angulo Escobar, P. V., Cáceres Flores, B. I. and Cuenca Villa, M. A. (2015). Eficacia de la intervención educativa sobre ergonomía física, aplicada en el despegue de la modalidad de arranque en los niños, niñas y adolescentes que practican halterofilia en La Federación Deportiva del Azuay. Cuenca.
9. Hernández Corvo R. (2000). Halterofilia y Movimiento. 1ª ed. Madrid: B.O.C.M..

10. Gutiérrez, J. J. A., del Amo, J. L. L. and Evrard, M. M. (2014). Caracterización del tiempo de vuelo en relación con variables biomecánicas del tirón en la arrancada de halterofilia. Apunts. Educación física y deportes, 4(118), 68-78.
11. Pérez, F. G., and García, M. T. F. (2013). Exploración del raquis lumbar y articulaciones sacroilíacas. FMC-Formación Médica Continuada en Atención Primaria, 20(8), 468-472
12. Granata, K. P., Marras, W. S. and Davis, K. G. (1997). Biomechanical assessment of lifting dynamics, muscle activity and spinal loads while using three different styles of lifting belt. Clinical Biomechanics, 12(2), 107-115.
13. Fees, M., Decker, T., Snyder-Mackler, L. and Axe, M. J. (1998). Upper Extremity Weight-Training Modifications for the Injured Athlete A Clinical Perspective. The American journal of sports medicine, 26(5), 732-742.
14. Pope, M. H. and Novotny, J. E. (1993). Spinal biomechanics. Journal of Biomechanical engineering, 115(4B), 569-574.
15. Arabatzi, F., Kellis, E. and De Villarreal, E. S. S. (2010). Vertical jump biomechanics after plyometric, weight lifting, and combined (weight lifting+ plyometric) training. The Journal of Strength & Conditioning Research, 24(9), 2440-2448.
16. San Pedro Orozco, P. (2012). Modelo geométrico y matemático de medición de variables posturales del raquis lumbar. Aplicación a la biomecánica del deporte de élite: Halterofilia. 2012. Doctoral thesis. Universidad Alfonso X El Sabio.