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BIOMECHANICS

Reliability and Validity of a New Objective Tool for Low Back Pain Functional Assessment

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Study Design. Classification and functional assessment model for nonspecific low back pain (LBP) patients and controls on the basis of kinematic analysis parameters.

Objective. Develop a logistic regression model using kinematic analysis variables to (1) discriminate between LBP patients and controls and (2) obtain objective parameters for LBP functional assessment.

Summary of Background Data. Functional assessment of spinal disorders has been carried out traditionally by means of subjective scales. Objective functional techniques have been developed, which usually involve the application of external loads or the analysis of highly standardized trunk flexion-extension maneuvers. Few studies have used everyday activities such as sit-to-stand or lifting an object from the ground. They have shown that the motion patterns of LBP patients differ from those of healthy subjects. Nevertheless, very few studies have tried to correlate objective findings to the results of subjective scales, and no previous study has developed a LBP classification and functional assessment model on the basis of kinematic analysis of everyday activities.

Methods. Sixteen controls and 39 LBP patients performed a sit-to-stand task, and lifted three different weights from a standing position. The vertical forces exerted and the relative positions of the lower limb and the cervical, thoracic, lumbar, and sacroiliac regions were recorded. Reliability was determined from repetitions of the tests performed by the control group. Binary logistic regression analyses were computed. The results of the selected regression equation were correlated to the Oswestry Disability Index scale results, to check the validity of the procedure for the measurement of functional disability.

Results. Reliability of the parameters was good. The selected regression model used two variables, and correctly classified 97.3% of the patients. High correlations were found between the results of this regression equation and the Oswestry Disability Index scale.

Conclusion. It is possible to distinguish LBP patients from healthy subjects by means of the biomechanical analysis of everyday tasks. This kind of analysis can produce objective and reliable indexes about the patients' degree of functional impairment.

Key words: classification, functional assessment, low back pain, motion analysis. **Spine 2011;36:1279–1288**

Low back disorders are a major health burden. Four to thirty-three percent of the population is suffering low back pain (LBP) at any particular point of time, and its lifetime prevalence is 58% to 84%.[1] Its annual incidence has been estimated in 28 episodes per 1000 persons, with the highest incidence seen in those aged 25 to 64 years,[1] this is to say, prime-age workers. This is why LBP is also a major socioeconomic problem in western countries.

One of the most difficult tasks associated with the management of low back disorders is their clinical assessment. The diagnoses of spinal disorders and the corresponding classification systems are rarely based on quantitative indicators. We are not able to easily assess and diagnose spinal disorders. Rating of the lesions varies above 70% range with the current systems.[2] Spratt *et al*[3] estimated that in 80% to 90% of all musculoskeletal disorders involving patient disability the precise diagnosis is not known. These data reflect the scarce quantitative means available for objectively establishing the magnitude of the problem. Things get even more difficult when apart from the clinical assessment of LBP, we try to analyze the functional status of a patient or we try to assess the functional results obtained after a therapeutic intervention. It is difficult to find objective, valid, reliable, and sensitive parameters for this kind of assessment.

The assessment and classification of spinal disorders have been carried out in different ways. Patients have been classified according to the purportedly injured or painful structure. Imaging techniques are used (magnetic resonance imaging, computed tomography, myelography) to determine the affected structure. A pathologic-anatomic diagnosis is established in only 10% to 15% of all patients with disorders of the lumbar region.[1,4] In some studies, it has been found that 20% to 25% of all healthy and asymptomatic individuals

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younger than 60 years may present a disc herniation image as established by magnetic resonance imaging.[5] Diagnoses on the basis of the anatomy are then neither sensitive nor specific.

Imaging techniques do not provide evidence about the functional state of the patient, which has been traditionally studied by means of functional assessment scales. They typically comprise a series of questions for patients, who in turn answer from their own personal perspective or point of view. This is the case of the Oswestry LBP disability questionnaire,[6] the Roland and Morris scale,[7] the Waddell and Main disability index,[8] and the Million questionnaire.[9]

Alternatively, several functional tests have been developed to make an objective assessment of LBP patients. One option has been the use of force tests. These tests aim to measure the forces generated by the patient under isometric, isokinetic, and isodynamic conditions. The patient is often asked to perform maximum voluntary contractions against resistance to supposedly generate a maximum force. Despite their use even in recent studies,[10–12] these techniques present some questionable aspects. There is no objective way to confirm that all the motor units of the muscle groups have been activated,[10] and the force measurement protocols usually require maximum strength efforts that may be limited not so much by the true capacity of the patient to generate force but rather by tolerance of pain—an element that varies greatly among individuals.[13] In turn, by requiring maximum force against resistance, they add an external load to the spine; as a result, the test itself constitutes a risk for the spine.[14] Last, by executing the test against resistance, the coordinated pattern of the neuromuscular control system found under everyday or natural conditions is no longer elicited.[15]

Nevertheless, force measurements can be recorded during natural trunk movements with no external loading. These techniques involve an analysis of the force in the three spatial axes (x, y, z) generated by movement. A dynamometric platform is used to this effect. An example would be the three-dimensional analysis of the floor reaction forces during foot support in the context of different activities such as walking, rising from a chair, or lifting a weight. They offer information on the nature of support and possible unloading on a limb or extremity in the case of pain, this is to say, the symmetry of support. These techniques have been used to assess movement strategy in response to different diseases associated with pain or strength deficiencies.[16–18]

Another useful technique is kinematic analysis, with measurements of positions, angles, velocities, and accelerations from which other physical magnitudes in turn are derived. Motion analysis plays an important role in functional analysis, as it allows us to study movements in the context of the different activities of the patient. To this end, different techniques have been used: goniometers and inclinometers,[19] electrogoniometers,[20] and video analysis or photogrammetry.[21,22]

The pattern of motion in terms of angular velocity has been studied by a number of authors in patients with a history of LBP.[15,20,23–25] These authors found the mean angular velocity of the trunk or the lumbar spine during flexion-extension cycles to be significantly lower during flexion and extension,[15,20,23,24] or greater in the first 25% of the extension phase.[22] Paquet *et al*,[20] in patients with a history of LBP, reported a reduction in mean angular displacement during flexion, whereas Esola *et al*[21] found no differences in any of the phases or quartiles 0%–25% to 50%–75% to 100% of flexion.

In general, these studies have shown that the motion patterns of patients with a history of LBP differ from those seen in healthy subjects.[15,20–27] The results obtained are not uniform, however, and this makes it difficult to draw firm conclusions. Some authors[25–27] have studied not only patients with a history of LBP but also with specific spinal disease diagnoses. However, they failed to obtain parameters sensitive enough to differentiate between specific diagnostic groups. Marras *et al*,[15,23,24] on the basis of angular velocity and acceleration measurements, were able to distinguish among groups of patients with specific diagnoses. More recently, Dankaerts *et al*[28] were able to discriminate healthy subjects and two subgroups of nonspecific LBP patients using kinematic and electromyographic variables.

These studies were mostly focused on highly standardized trunk flexion-extension maneuvers. Other authors, however, have performed similar biomechanical analysis in movements with also a great functional importance but more usual in everyday life, such as sit-to-stand[17,18] or lifting an object from the ground.[18] Motion patterns in this kind of movements showed differences between healthy subjects and patients with LBP. Moreover, lumbar-pelvic coordination patterns during lifting tasks have also shown differences according to the amount of weight lifted,[29,30] which made these authors recommend the inclusion of different load conditions in the clinical evaluations of spinal kinematics.[30]

One conclusion can be extracted from all the studies commented above: it may be possible to get different diagnostic classifications of LBP patients on the basis of the biomechanical analysis of different tasks. There are authors who have even correlated some parameters obtained from this kind of analysis (mostly lumbar range of motion) with the subjective indexes obtained from functional assessment scales, such as the Oswestry LBP disability questionnaire.[19,31] Nevertheless, these studies have only worked with a very limited number of kinematic variables, and none of them have managed to elaborate a functional disability index from the parameters generated by a biomechanical analysis. It should be possible to obtain a simple index similar to those provided by functional assessment scales, generated by an objective procedure.

In this study, we have performed a biomechanical characterization of the most representative kinematic and kinetic variables obtained from usual movements in everyday life. Using these data, we calculated an objective functional index, which was additionally validated through the study of its reliability and its correlation with other functional assessment indexes. In this way, we will try to answer the following research questions: (1) Is it possible to accurately distinguish LBP patients from healthy subjects by means of the biomechanical analysis of everyday tasks? (2) Can valid and reliable indexes about the patients' degree of functional impairment be obtained by means of this kind of analysis?

MATERIALS AND METHODS

Experimental Protocol

A group of healthy volunteers were subjected to three measurement sessions on two separate days, to check the within-day and between-day reliability of the measurements. A second group of LBP patients underwent one measurement session. The sessions required the subjects to perform a sit-to-stand task, and to lift three different weights from a standing position. All tests were carried out at least 2 hour after the subjects had risen from bed to minimize the effects of diurnal variations in spinal mechanics.[32] During these tasks, the relative positions of the lower limb and the cervical, thoracic, lumbar, and sacroiliac regions were recorded by means of a photogrammetry system, as were the vertical forces exerted on two dynamometric platforms.

Subjects

Thirty-nine patients and 16 controls participated in this study. The inclusion criteria, for patients, were: (1) primary LBP, without sciatica and neurologic deficits, with repeated episodes of pain on the lumbar region during the last month; (2) disability directly caused by the LBP condition (time off work because of LBP in the last 6 months); (3) radiologic findings of normal or slightly degenerative changes without any gross spinal pathology such as tumor, infection, osteoporosis, spondylolysis, and spondylolisthesis; (4) no history of low back surgery; (5) absence of psychiatric pathology (depressive, bipolar, anxiety, somatoform, or factitious disorders); (6) no involvement with workers' compensation, litigation, or disability insurance. The control group consisted of subjects who had never suffered from LBP or any other kind of low back disorders. The independent *t* test did not find significant differences in terms of age, body mass, height, and body mass index between both groups (control *vs*. LBP, average ± standard deviation: age 39 ± 11 *vs*. 45 ± 11 years; weight 72.4 ± 15.5 *vs*. 75.0 ± 14.6 kg; height 1.7 ± 0.1 *vs*. 1.7 ± 0.1 m; body mass index 25.0 ± 4.0 *vs*. 24.9 ± 3.0). All the subjects rated their degree of disability on an Oswestry Disability Index scale,[6] which showed a zero score for all the controls, and an average score of 33.7 ± 13.2 for the patients. Two patients got an Oswestry score lower than 10, and were excluded from the study because their degree of functional affectation was considered too low.

Written consent to participate in the investigation was obtained from the subjects after they had been informed about the study. The procedure for this project was approved by an institutional review board. All the procedures were conducted in accordance with the principles of the World Medical Association's Declaration of Helsinki.

Measurement System

Kinematic analysis was performed by means of a three-dimensional video photogrammetric system (Kinescan/IBV, Instituto de Biomecánica de Valencia, Valencia, Spain),[33,34] which includes four cameras Pulnix TM-6740CL with a resolution of 1024 × 768 pixels and a frequency of 50 Hz. Kinetic analysis was performed by means of the dynamometric platform system Dinascan/IBV (Instituto de Biomecánica de Valencia, Valencia, Spain).[33] This system consists of two dynamometric platforms installed in parallel at ground level, which can measure ground reaction forces and the trajectory of the centers-of-pressure generated by both feet supports. A synchronic signal generated at the beginning of each measurement sent simultaneously a "start recording" order to both the cameras and the force plates.

The kinematic model developed for this study intended to represent the whole spine, and also thigh and leg segments to characterize hip and knee motion (Figure 1). This model was implemented by means of reflective markers (25-mm diameter balls, except on the thoracic and lumbar regions, where 15-mm markers were used to avoid overlapping during the digitalization process). The markers on C7 spinous process and leg (fibular midline) were applied by means of rigid structures held in place by straps, to minimize the effect of skin artifacts. Markers were placed after a standardized protocol based on the palpation of characteristic anatomic landmarks by experimented observers.

The angular variables for the kinematic analysis of the tasks were defined as follows (Figure 1, Table 1) Angles projected on the sagittal plane (XZ). Hip motion: angle formed by the intersection of the line between iliac crest and sacrum markers (pelvis) and the line between femoral condyle and femoral midline markers. Lower limb motion: similarly calculated from the intersection of the line between the markers on femoral condyle and femoral midline and the structure over the fibula. Lumbar motion: angle formed by the intersection of the line between T12 and L3 markers and the line between L5 and sacrum. Pelvic angle: intersection of the line between L5 and sacrum with *X* axis. Thoracic angle: intersection of

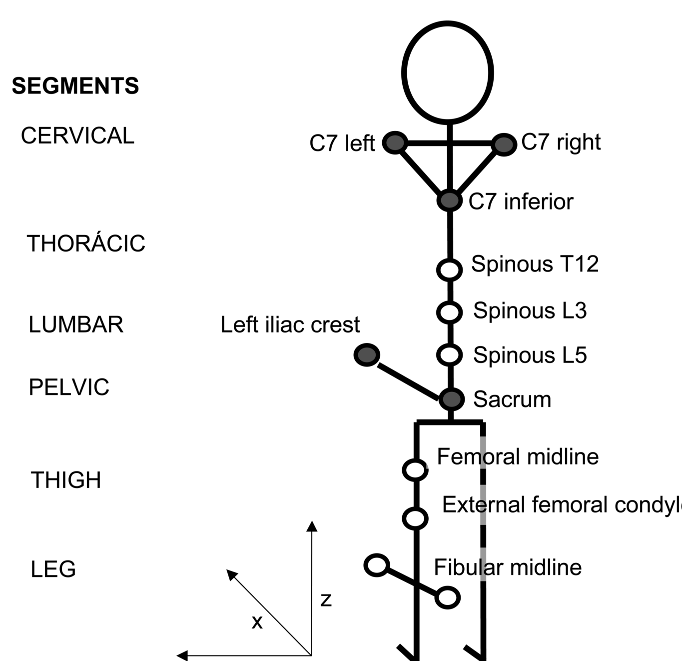

Figure 1. Schematic representation of the kinematic model with circles representing the position of the reflective markers.

TABLE 1. Variables

	Sit-to-stand		Lifting (0, 5, 10 kg)	
	Flexion	Extension	Flexion	Extension
Overall time: duration of the task(s)	X*		X†	
Minimum vertical force: normalized as a percentage of body weight (%)	X			
Maximum vertical force: normalized as a percentage of body weight (%)	X*		X*	
Forces asymmetry: difference between the normalized maximum vertical forces of both force plates (%)	X		X	
Lower limb range of motion (°)	X		X*	
Trunk range of motion (°)	X		X	
Lumbar range of motion (°)	X*		X†	
Thoracic range of motion (°)	X		X†	
Pelvic range of motion (°)	X		X	
Thoracic rotation (°)	X		X	
Trunk maximal angular velocity (°/s)	X†	X*	X†	X†
Trunk average angular velocity (°/s)	X†	X*	X†	X†
Lower limb maximal angular velocity (°/s)		X†		
Lower limb average angular velocity (°/s)		X*		
Trunk maximal angular acceleration (°/s^2)	X†	X†	X†	X†
Lower limb maximal angular acceleration (°/s^2)		X†	X	X*
Lower limb minimal angular acceleration (°/s^2)		X†		

Significant differences for the lifting task were the same for the three loads, with the exception of lower limb maximal angular acceleration during the extension phase of the 10-kg lifting task with $P < 0.005$.

**$P < 0.05$ (the significantly different variables according to MANOVA).*

†$P < 0.01$ (the significantly different variables according to MANOVA).

the line between C7_inferior and a virtual marker placed in the middle point between C7_right and C7_left with *X* axis. (2) Angles projected on the horizontal plane (XY). Thoracic rotation: intersection of the line between C7_left and C7_right with *Y* axis. Pelvic rotation: intersection of the line between iliac crest and sacrum markers with *Y* axis.

Measurement Protocol

Subjects performed a sit-to-stand task, and lifted three different weights (an empty box and the same box with 5 and 10 kg loads) from a standing position.

Sit-to-stand task

Once all the markers were in place, the subjects stood on the force plates, and were told to follow these instructions: "When you hear our signal, sit without looking back, with your arms crossed over your chest. When you hear a new signal, stand up, with no help of your arms, and remain standing. Once the measurements are started, you must not move your feet from the platform. You will perform this movement in what you consider a normal way, at your own preferred speed."[33]

Subjects performed five repetitions of this test, on a stool the height of which was regulated to allow the subjects to keep 90° of knee flexion when seated. Only the standing phase of the task was analyzed (from the seated position to a stabilized standing position), as it was considered the most demanding for the lumbar spine.

Lifting Task

Subjects stood on the force plates, looking forward with arms crossed over their chests. They had a table on their right. The box to be lifted was placed on the floor just in front of them. Then they were told to follow these instructions (Figure 2): "When you hear our signal, you will bend, get the box in front of you and lift it to the level of your abdomen. Then you will turn right and leave the box on the table, returning afterwards to the starting position. When you hear a new signal, you will have to repeat the task with the next two boxes (which we will have placed in front of you). Once the measurements are started, you must not move your feet from the platform. You will perform this movement in what you consider a normal way, at your own preferred speed."

Figure 2. One subject at the moment of getting the box during the lifting task. Note the positions of the reflective markers and the force plates.

Both tasks were divided in flexion and extension phases. In the sit-to-stand task, the flexion phase comprised from the beginning of trunk flexion to its maximum, and extension phase comprised from maximum flexion to the complete extension of both trunk and lower limb. In the lifting task, the flexion phase comprised from the beginning of the movement to maximum trunk flexion when the subject got the box, whereas the extension phase comprised the lifting of the load and ended with the complete extension of both trunk and lower limb.

The variables calculated for each task are shown in Table 1. Seventy-one variables were calculated for each subject, taking into account the three-fold calculations for the three different loads of the lifting task.

Statistical Analysis

The reliability of all the parameters recorded by the system was determined using a repeated measures analysis of variance (ANOVA) to calculate the (2,1) intra-class correlation coefficient (ICC),[1,2] according to the nomenclature proposed by Shrout and Fleiss.[35] Data for ICC calculations were obtained from the repetitions of the tests performed by the control group. Within-day and intraobserver reliability were determined by comparing values obtained in two repeated tests several minutes apart carried out by the same observer. Day-to-day and interobserver reliability were determined by comparing the results of two tests repeated at least 15 days apart, with different observers.[35–37] The standard error of measurement (SEM)[38] was calculated as a further measure of reliability.

Multivariate analysis of variance (MANOVA) was used to assess the significance of each of the 71 variables in the discrimination between healthy subjects and LBP patients.

To obtain an index that allowed distinguishing between healthy subjects and LBP patients, binary logistic regression analyses were computed.[39] Variables showing significance in the MANOVA were entered as independent variables. The dichotomous dependent variable (healthy/LBP) reflected the inclusion of the subjects either in the healthy or the LBP group. The analysis was performed with a forward selection of variables according to the Wald statistic, and the overall fit of the models was assessed by means of the Hosmer-Lemeshow and deviance χ^2 goodness-of-fit statistics.[39] Odds ratios were computed for the resulting variables, showing the independent effect of each factor.

The obtained regression models were cross validated by means of the leave-one-out (LOO) method. With this method, models were calculated leaving one patient of the analysis but using the same covariates; in this way, the probability for that patient diagnosis was predicted using the logistic regression equation.[40–42] This procedure was repeated for each patient.

To check the validity of the procedure for the measurement of functional disability, the results of the equation of the selected regression model were correlated to the results of the Oswestry Disability Index scale. The Oswestry results were expressed both as a continuous variable (correlations were calculated with the Pearson product-moment correlation coefficient) and as a categorical one, separating the Oswestry scores into minimal (less than 20%), moderate (20%–40%) and severe (>40%) disability[6] (correlations were calculated with the Spearman rank correlation coefficient).

SPSS for Windows (version 16.0.1, SPSS Inc-IBM Corporation, New York, USA) was used for all statistical analyses, except the crossed validation of the logistic regression equations, which was calculated by means of a MATLAB 2009b function. Significance was accepted at an α level of 0.05.

RESULTS

SEM values were very low, and ICC values were between 0.70 and 0.99, indicating fair to good reliability.[37,38] The only exceptions were ICC values for the forces asymmetry, which ranged from 0.50 to 0.61 for the sitting and three weight-lifting tasks. ICC and SEM values for the most representative variables are shown in Tables 2 and 3.

MANOVA showed significant differences ($P < 0.05$, $P < 0.01$) between both groups in 38 variables (Tables 1 and 4).

The results of the logistic regression analysis are presented in Table 5. The analysis produced three possible regression

TABLE 2. Reliability of the Variables from the Sit-to-Stand Task

	Vertical Force (% Weight)			Range of Motion (°)			Average Speed (°/s)		
	Minimum	Maximum	Lower Limb	Trunk	Lumbar	Thorax	Trunk (Flexion)	Trunk (Extension)	Lower Limb
Trial 1	10.9 ± 3.3	122.6 ± 4.6	89.1 ± 5.4	113.1 ± 8.2	32.6 ± 6.6	32.5 ± 6.6	35.8 ± 4.3	69.9 ± 6.7	−36.6 ± 2.9
Trial 2	11.5 ± 3.1	123.8 ± 5.0	87.0 ± 5.8	113.7 ± 7.9	31.7 ± 5.5	34.3 ± 7.1	35.1 ± 4.4	69.9 ± 6.8	−35.5 ± 3.4
Trial 3	10.6 ± 3.0	123.5 ± 7.6	89.0 ± 6.8	113.8 ± 7.1	29.5 ± 6.9	30.7 ± 5.4	36.0 ± 8.4	69.9 ± 5.8	−37.0 ± 3.4
ICC (WD)	0.94	0.94	0.96	0.97	0.78	0.94	0.80	0.89	0.80
SEM (WD)	0.82	1.22	1.16	1.41	2.81	1.69	1.93	2.23	1.40
ICC (BD)	0.90	0.91	0.70	0.83	0.80	0.83	0.70	0.77	0.80
SEM (BD)	1.01	1.83	3.39	3.12	3.02	2.47	3.48	2.97	1.50

Average ± standard deviation values in 16 pain-free controls. WD values were calculated from trials 1 and 2 (performed on the same day by the same observer). BD values were calculated from trials 1 and 3 (performed at least 15 days apart by different observers).

ICC stands for intraclass correlation coefficient; SEM, standard error of the measurement; WD, within-day; and BD, between-day.

models, involving respectively one, two, and three variables. To identify potential colinearity, the degree of interrelationship of the various risk factors selected for the regression analyses was verified using Pearson product-moment correlation coefficients. It was found that two of the variables used in the three-variable model were significantly correlated (average trunk velocity in flexion when lifting without load and average trunk velocity in extension during the sit-to-stand test, $r = -0.44$, $P < 0.01$), so this model was discarded. From the other two models, the two-variable one (lumbar range of motion when lifting a 5-kg load and average trunk velocity in flexion when lifting without load) offered both the best prediction values (it predicted 97.3% of the patients to be included in the LBP group, this is to say, all the patients but one) and the highest goodness of fit according to the results of the Hosmer-Lemeshow and deviance χ^2 statistics.

LOO cross-validation of the two first equations was carried out. The one-variable model showed 79.2% accuracy, whereas the two-variable model had 94.3% accuracy in the LOO cross-validation. This is to say, both equations showed good stability, but the two-variable model had a greater accuracy, so it was the one finally selected.

High and significant correlations were found between the results of this regression equation and the Oswestry Disability Index scale, expressed either as a continuous measurement (Pearson product-moment correlation coefficient $r = 0.65$, $P < 0.01$) or as a categorical scale (Spearman's rank correlation coefficient $\rho = 0.70$, $P < 0.01$).

DISCUSSION

The results support the hypothesis of this study: it is possible to distinguish LBP patients from healthy subjects with high accuracy by means of the biomechanical analysis of everyday tasks. This kind of analysis can produce objective and reliable indexes about the patients' degree of functional impairment.

TABLE 3. Reliability of the Variables from the Weight Lifting Task (5 kg)

	Maximum Vertical Force (% Weight)	Range of Motion (°)				Average Speed (°/s)	
		Lower Limb	Trunk	Lumbar	Thorax	Trunk (Flexion)	Trunk (Extension)
Trial 1	129.8 ± 7.9	72.3 ± 31.6	106.6 ± 8.2	41.1 ± 8.6	67.5 ± 19.2	72.4 ± 9.1	68.5 ± 7.8
Trial 2	128.9 ± 8.0	73.0 ± 30.2	105.3 ± 10.7	39.0 ± 8.5	67.6 ± 19.7	68.0 ± 9.8	65.8 ± 7.5
Trial 3	128.7 ± 7.6	76.1 ± 29.8	110.4 ± 8.6	37.2 ± 8.3	64.7 ± 22.1	67.6 ± 13.5	65.5 ± 7.4
ICC (WD)	0.97	0.97	0.92	0.92	0.98	0.90	0.92
SEM (WD)	1.33	5.35	2.67	2.38	2.61	3.07	2.19
ICC (BD)	0.94	0.96	0.91	0.82	0.98	0.79	0.73
SEM (BD)	1.93	6.51	2.52	3.63	2.85	5.25	3.86

Average ± standard deviation values in 16 pain-free controls. WD values were calculated from trials 1 and 2 (performed on the same day by the same observer). BD values were calculated from trials 1 and 3 (performed at least 15 days apart by different observers).

BD, between-day; ICC stands for intra-class correlation coefficient; SEM, standard error of the measurement; WD, within-day.

TABLE 4. LBP Patients *vs.* Healthy Controls

	Maximum Vertical Force (% Weight)	Range of Motion (°)			Average Speed (°/s)		Maximum Acceleration (°/s²)	
		Thorax	Trunk	Lumbar	Trunk (Flexion)	Trunk (Extension)	Trunk (Flexion)	Trunk (Extension)
Sit-to-stand								
Control	122.6 ± 4.6	32.5 ± 6.6	113.1 ± 8.2	32.6 ± 6.6	35.8 ± 4.3	69.9 ± 6.7	203.3 ± 43.5	474.7 ± 52.5
LBP	118.7 ± 6.9*	32.8 ± 11.1	111.4 ± 10.1	25.8 ± 9.6†	30.4 ± 6.8†	60.8 ± 11.8*	150.9 ± 45.6†	373.2 ± 118.9†
Lifting (0 kg)								
Control	127.0 ± 12.5	68.4 ± 19.9	104.9 ± 11.5	38.1 ± 10.7	73.4 ± 10.9	69.2 ± 10.5	337.1 ± 94.4	348.2 ± 62.6
LBP	119.8 ± 6.3*	45.0 ± 21.2†	107.7 ± 10.0	28.0 ± 8.2†	58.1 ± 11.4†	56.7 ± 12.5†	266.0 ± 71.3†	235.9 ± 71.9†
Lifting (5 kg)								
Control	129.8 ± 7.9	67.5 ± 19.2	106.6 ± 8.2	41.1 ± 8.6	72.4 ± 9.1	68.5 ± 7.8	316.3 ± 85.8	294.9 ± 49.6
LBP	124.6 ± 5.7*	43.8 ± 18.8†	106.8 ± 10.5	26.9 ± 8.3†	54.4 ± 12.1†	53.4 ± 10.2†	251.3 ± 76.6†	214.4 ± 62.5†
Lifting (10 kg)								
Control	133.9 ± 11.4	67.1 ± 18.3	104.1 ± 11.3	38.9 ± 10.7	72.7 ± 12.3	66.4 ± 10.5	342.7 ± 87.0	293.1 ± 74.1
LBP	128.5 ± 6.0*	45.8 ± 20.6†	105.8 ± 10.0	27.0 ± 9.2†	55.0 ± 13.2†	49.7 ± 14.1†	272.8 ± 73.5†	196.1 ± 66.5†

Average values ± standard deviation.

**P* < 0.05.

†*P* < 0.01.

Reliability of the parameters used to assess reflex activation was generally good, with the exception of the forces asymmetry. This variable was included in the measurement protocol because it is considered, together with other parameters related to postural stability, useful for the clinical assessment of LBP patients.[43] Nevertheless, it is a questionable variable from a statistical point of view: Reiser *et al*[44] showed that, to reach an acceptable statistical power for the categorization as symmetrical or asymmetrical of vertical ground reaction forces during quiet stance, a minimum number of 10 trials with a duration of at least 5 seconds each was needed. This kind of measurement did not fit in the protocol of this study. Anyhow, forces asymmetry was not included in any of the calculated regression models.

Both of the variables selected by the logistic regression process for the classification of the subjects came for the lifting tasks, specifically from the flexion phase parameters (lumbar range of motion and average trunk velocity). Many previous works have shown that both trunk velocity during flexion and lumbar range of motion are altered in LBP subjects. A decrease in lumbar range of motion has been observed in patients with a history of unspecific LBP,[19,25,45] disc herniation,[15,23–25] and spondylolisthesis.[27,46] Other authors, however, did not observe such a decrease.[20–22,47] In many LBP patients, the mechanical behavior of spinal tissues may be altered because of tissular damage, which provokes a decrease in distensibility and consequently a decrease in the range of flexion.[48] Subjects can also limit their range of flexion because of fear-avoidance behaviors, caused by fear to provoke or exacerbate pain.[49] It is also important to keep in mind that trunk range of motion depends on the flexibility of the subject, and its measurement is not only affected by the limitations of each specific measurement technique, but also affected by several additional factors, such as the motivation of the subject, the quality of performance of the movements or the anatomic landmarks used as references.[47] This is why the validity of the degrees of maximum lumbar flexion as a specific referent to distinguish between healthy subjects and LBP patients has been disputed by several authors.[23,25] Our results show that it can be a useful parameter, but it should be combined with other variables such as the flexion velocity.

Paquet *et al*[20] found that the mean amplitude of lumbar motion during flexion was reduced in patients with a history of LBP. Marras and Wongsam[50] observed a lower angular velocity during flexion also. It is true that several previous works have also shown changes in the mean amplitudes and the angular velocities of motion during trunk extension, changes which in many cases were considered more intense than the changes in the flexion phase.[25,50] In our study, we found significant differences between healthy subjects and LBP patients in several kinematic variables also during the extension phase,

TABLE 5. Regression Model

Variable	Coefficient (*B*)	Odds Ratio
Lumbar range of motion (5 kg)	−1.227	0.293
Average trunk velocity in flexion (0 kg)	−1.127	0.324

although they were not taken into account by the logistic regression procedure.

Several previous studies have used logistic regression models to distinguish between healthy subjects and LBP patients. These studies were focused mainly on sociodemographic or psychosocial variables, often recorded by means of questionnaires. Variables from clinical exploration, such as the presence of signs of radiculopathy,[51] or variables describing the movements and postures adopted during the working day[52] have also been associated to this kind of analysis. Nevertheless, there are very few previous works in the literature that have applied this kind of regression methods to objective variables obtained through kinematic analysis.

The results of the selected regression equation have shown a good correlation with the results of the Oswestry Disability Index scale. This is to say, this model may be useful to assess the degree of functional impairment in LBP patients. Such correlations between kinematic measurements and subjective functional indicators are difficult to find in the literature, and they are limited to specific variables, such as the lumbar range of motion.[19,31] In this study, we have not only defined a new indicator of functional impairment by means of the analysis of multiple kinematic variables, but also validated this indicator through the study of its reliability and validity. We believe this kind of analysis could be useful in clinical practice, maybe even providing an objective alternative to functional assessment scales such as the Oswestry Disability Index. The main disadvantage of these scales is their inherent subjectiveness. In many cases, the physician is unable to avoid a certain degree of subjectiveness in establishing an assessment, and the same applies to the patient answering the questions. This conditions quantification and is difficult to control. The difficulty of assessing certain elements conforming damage or injury also must be considered. Many elements are strongly influenced by subjectiveness and emotional factors on the part of the patient—a clear example being pain, which is a symptom impossible to quantify in the context of body damage assessments. An objective approach to functional assessment on the basis of kinematic analysis may help to avoid these problems.

Only 2 variables out of the 38 that showed significant differences between groups were included in the selected logistic regression equation. It is obvious that many of those 38 variables were partially redundant. Nevertheless, provided that steps are taken to avoid possible colinearities during the analysis process, the information obtained from the protocol of this study could allow the design of new regression models that include different variables. Such models may be able to classify subjects according to other criteria, such as their specific kind of lumbar pathology. Some studies suggest there could be different and specific patterns of motion, velocity, and acceleration in specific groups of spine pathologies.[25–27] Marras *et al*[15,23,24] managed to distinguish between groups of LBP patients with specific diagnosis, by means of the analysis of angular velocity and acceleration during several tasks. However, as the same authors suggest, the complexity of their models makes them difficult to apply in everyday clinical practice. Dankaerts *et al*[28] also distinguished between specific groups of LBP patients by means of a discriminant analysis of several biomechanical variables. Nevertheless, their protocol included not only kinematics but also an electromyographic analysis, which makes it more difficult and expensive to implement in everyday practice. Besides, their classification system of LBP subjects was developed by the same authors and it is not widely used. We believe that the analysis model presented in our study could shed new light in this field.

According to the "ten events per parameter" rule stated by Peduzzi *et al*,[53] in this study the number of subjects with and without LBP is the minimum number of individuals necessary to compute a model such as the one we selected, with only two parameters. Nevertheless, the main limitation of this work is the number of subjects. Future studies should work with bigger groups if regression models including more parameters or taking into account new factors (such as sex or age) are to be generated.

The observers of this study were not blinded to whether subjects did or did not have LBP. However, our kinematic model leaves little space for subjectiveness, given that the analysis of the motion and force data are entirely automatic, and there is no subjective preselection of subjects or variables to be included in the statistical processes.We believe then that with this kind of data analysis there is little necessity for a blinded study.

Regardless of the ability of logistic regression models or other alternatives such as principal component analysis or discriminant analysis to classify LBP subjects, the main conclusion of our study is that the characterization of functional movements by means of a kinematic and kinetic analysis can provide interesting information to objectively assess the functional impairment of LBP patients. The data obtained from these techniques appear to be sensitive and reliable, and may be useful in clinical tasks such as the orientation of a functional rehabilitation procedure or the assessment of the result of a surgical procedure.

➢ Key Points

- ❑ The aim of the study was to obtain objective parameters for LBP functional assessment and to discriminate between LBP patients and controls.
- ❑ A logistic regression model was developed using kinematic analysis variables from two everyday tasks.
- ❑ The selected regression model correctly classified 97.3% of the patients, and high correlations were found between the results of this regression equation and the Oswestry Disability Index scale.

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