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Relating the Diers formetric measurements with the subjective severity of acute and chronic low back pain

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A B S T R A C T

Background context: Nonspecific low back pain (LBP) is a common disorder with a high economic, social and psychological burden. Many systems have been developed for evaluating the severity of LBP, though these are mainly based on scoring questionnaires for the functional status of the patients. Objective quantifiable methods relating LBP with anthropometric factors are scarce.
Purpose: To find the correlates of nonspecific LBP with spine shape variables and demographic characteristics. To investigate the possible relationship between the latter and the result of a questionnaire subjectively quantifying the severity of LBP.
Study Design/Setting: This is a pragmatic observational prospective cohort study.
Patient sample: 218 subjects participated in this study. A first group of participants were 160 patients consulting at an osteopathic outpatient clinic for back pain complaints. The second group consisted of 58 healthy pain-free volunteers.
Outcome measures: The Oswestry Disability Index (ODI) was used to quantify the degree of functional impairment due to low back pain. The surface topography of the back was registered statically with the Diers-4D formetric® system.
Methods: Multivariate analyses of the DIERS 4D formetric system recordings in the subjects with or without nonspecific, acute or chronic LBP.
Results: Different patterns between female and male subjects were found. Age, coronal and sagittal imbalance correlated with LBP in female subjects, whereas pelvic inclination, the trunk torsion and apical deviation correlated with LBP in male. Multivariate analyses allowed creating an algorithm to predict the functional disability (predicted LBP-score, PLBP), based on the above variables for females and males. Logistic stepwise regression analysis indicated the probability of a patient having a LBP-score above or below ODI 20 ($P = < 0.0001$), which is considered the clinically relevant threshold value for justifying absence from work.
Conclusions: In this study LBP was correlated with spine shape variables leading to an algorithm predicting the functional disability of a patient due to LBP. Discrepancies between the model and the ODI result may suggest elements that are clinically relevant.

Introduction

Low back pain (LBP) is a common health problem in the western society and may affect as many as 70% of the population in the course of life. LBP causes more global disability than any other condition with an increased overall burden in the last decade [1].

Specific causes of LBP are uncommon, accounting for less than 15% of all LBP cases. About 85% of patients with isolated LBP cannot be given a precise patho-anatomical diagnosis. Nonspecific LBP has been defined as tension, soreness, and/or stiffness in the lower back region for which it was not possible to identify a specific cause of pain [2]. An improper posture during the lifting of heavy objects, or an aberrant posture for a long period of time has been suggested to possibly cause lumbar disorders [3].

Since LBP is common in Western industrial societies, the economic consequences of LBP are enormous, and the effect on quality of life is substantial [2,4]. In a systematic review and meta-analysis Machado et al. [5] showed that simple analgesics fail to exert any clinically relevant effect as compared to placebo, whereas several non-pharmacologic therapies for primarily chronic LBP were found to be associated with a favourable effect on pain [6]. The Clinical Practice Guideline from the American College of Physicians therefore recommends that clinicians should initially select non-pharmacologic treatment for patients with chronic LBP [7]. Among treatments suggested for LBP, a randomized controlled trial (RCT) revealed substantial pain improvement with osteopathic manual treatment (OMT) [8,9]. Also, the systematic review and meta-analysis of Franke et al. (2014) indicated clinically relevant effects of OMT for reducing pain and improving the functional status of patients with acute and chronic nonspecific LBP. In addition, OMT was shown to influence several aspects of spine status [10]. In fact, LBP is the most common primary reason for consulting an osteopath [11].

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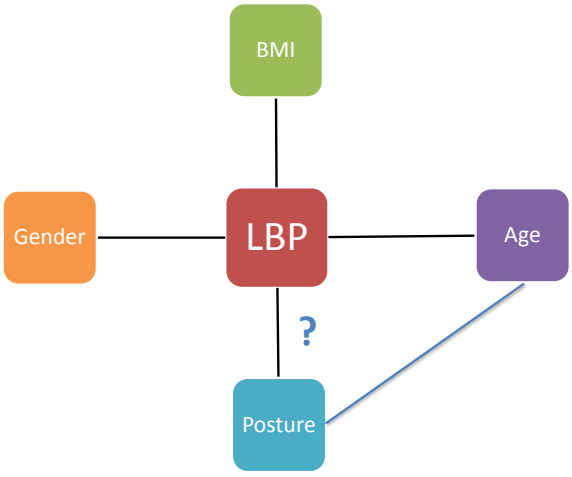

Fig. 1. Factors shown to be related with low back pain (LBP) (BMI: body mass index).

Although the cause of non-specific LBP is, by definition, unknown, several factors that can influence LBP have generally been accepted, as schematically presented in Fig. 1. Overweight and obesity have consistently been shown to be correlated with the occurrence of LBP [12,13], and gender differences influenced the time required for recovery after acute occupational LBP [14]. In elderly persons, LBP is recognized as one of the most common, poorly understood and potentially disabling conditions [15]. Postural changes seem to be associated with age such as a decrease in lumbar lordosis [16,17].

Clinical examination is essential for the identification of so-called "red flags" and for the exclusion of specific diseases [18]. However, the validity, reliability and diagnostic accuracy of the commonly used clinical tests for LBP is low. Though such tests have been claimed relevant for prognostic purposes, there is no consistent evidence for a predictive value for most of these [19].

It may be helpful to determine anthropometric markers that can identify risk factors for LBP using an objective and quantifiable method. Postural properties have already been correlated with LBP. Schroeder and Mattes using video raster stereography have reported spine shape variables to be associated with LBP [20]. Different variables were found to be relevant in female and male subjects. Trunk inclination and trunk imbalance together with pelvis variables were mainly found in women, whereas trunk inclination with trunk imbalance and the lumbar lordosis angle were considered relevant in men.

Formetric measurement technology provides objective, accurate and reproducible analysis of the spinal anatomy [21,22]. It allows for a radiation-free surface topography scanning, reliably and reproducibly generating a 3-dimensional reconstruction of the spine (Diers international Gmbh, Schlangenbad, Germany, [23]).

The present paper aims at finding objective correlates of the severity of low back pain by adding the findings of surface topography to the simple biological variables age, gender and BMI in well-defined subgroups of presentation of the disease. In addition, these discriminative factors may be clinically relevant for manual treatment practices, since general osteopathic treatment has already been proven to induce relevant postural changes [10].

Materials and methods

Subjects

The present pragmatic, real life, observational prospective cohort study included 218 subjects. A first group of participants were 160

Table 1
Epidemiological characteristics of the participants.

	n	Age (mean) min–max	BMI (mean) min–max	Weight (mean) min–max	Height (mean) min–max	ODI (Mean) min–max
All subjects	**218**	37.3 (16.9)	23.8 (3.7)	69.8 (12.3)	171.1 (9.3)	10.6 (11.7)
		18.0–78.0	*17.2–37.8*	*43.2–124.0*	*153.0–193.7*	*0.0–56.0*
ODI = 0	**58**	31.0 (14.8)	22.8 (2.4)	68.4 (10.2)	172.9 (9.4)	0.0 (0.0)
		18.0–78.0	*17.8–32.4*	*47.3–92.5*	*156.0–193.7*	-
ODI > 0	**160**	39.6 (17.0)	24.2 (4.0)	70.3 (13.0)	170.4 (9.1)	14.4 (11.5)
		18.0–77.0	*17.2–37.8*	*43.2–124.0*	*153.0–193.5*	*2.0–56.0*
ODI > 0 & acute LBP	**42**	36.1 (16.8)	23.1 (2.9)	67.6 (11.5)	170.6 (9.5)	6.0 (5.0)
		18.0–67.0	*17.2–29.5*	*43.2–94.0*	*153.7–189.0*	*2.0–18.0*
ODI > 0 & chronic LBP	**118**	40.8 (17.0)	24.6 (4.2)	71.3 (13.4)	170.4 (9.0)	17.4 (11.6)
		18.0–77.0	*17.8–37.8*	*47.3–124.0*	*153.0–193.5*	*2.0–56.0*
Women						
All	**134**	37.7 (16.5)	23.7 (3.9)	65.0 (10.6)	165.7 (6.1)	12.0 (12.0)
		18.0–78.0	*17.2–36.7*	*43.2–97.0*	*153.0–182.5*	*0.0–49.0*
ODI = 0	**31**	32.5 (16.7)	22.7 (2.9)	62.3 (8.8)	165.8 (5.5)	0.0 (0.0)
		18.0–78.0	*17.8–32.4*	*47.3–89.3*	*156.0–175.5*	-
ODI > 0	**103**	39.3 (16.2)	24.0 (4.1)	65.8 (11.0)	165.6 (6.3)	15.6 (11.5)
		18.0–69.0	*17.2–36.7*	*43.2–97.0*	*153.0–182.5*	*2.0–49.0*
ODI > 0 & acute LBP	**24**	39.3 (17.7)	22.5 (2.9)	60.6 (7.6)	164.2 (6.0)	6.6 (5.2)
		18.0–67.0	*17.2–29.5*	*43.2–72.3*	*153.7–174.0*	*2.0–18.0*
ODI > 0 & chronic LBP	**79**	39.3 (15.9)	24.5 (4.3)	67.37 (11.4)	166.1 (6.4)	18.3 (11.5)
		19.0–69.0	*17.8–36.7*	*47.3–97.0*	*153.0–182.5*	*2.0–49.0*
Men						
All	**84**	36.6 (17.4)	24.0 (3.4)	77.4 (11.0)	179.7 (6.5)	8.4 (10.9)
		18.0–77.0	*19.3–37.8*	*58.2–124.0*	*163.0–193.7*	*0.0–56.0*
ODI = 0	**27**	29.2 (12.4)	23.0 (1.7)	75.2 (6.9)	181.0 (5.6)	0.0 (0.0)
		19.0–68.0	*19.6–26.5*	*62.1–92.5*	*173.0–193.7*	-
ODI > 0	**57**	40.1 (18.4)	24.5 (3.8)	78.4 (12.4)	179.1 (6.8)	12.4 (12.2)
		18.0–77.0	*19.3–37.8*	*58.2–124.0*	*163.0–193.5*	*2.0–56.0*
ODI > 0 & acute LBP	**18**	31.8 (14.9)	23.8 (2.8)	76.4 (9.4)	179.2 (5.9)	5.1 (4.9)
		19.0–62.0	*19.3–27.6*	*58.2–94.0*	*169.0–189.0*	*2.0–18.0*
ODI > 0 & chronic LBP	**39**	44.0 (18.8)	24.8 (4.2)	79.4 (13.6)	179.0 (7.3)	15.7 (11.8)
		18.0–77.0	*19.4–37.8*	*60.9–124.0*	*163.0–193.5*	*2.0–56.0*

Age (Years); BMI (kg/m^2); Weight (kg); Height (cm); mean (SD). ODI: Oswestry Disability Index; LBP: low back pain; n: sample size; BMI: body mass index; SD: standard deviation.

consecutive patients consulting at an osteopathic outpatient clinic for LBP complaints over a period of 2 months. The second group consisted of 58 healthy pain-free volunteers. Conditions that could interfere with the raster-stereography of the DIERS measuring instrument were excluded, such as pregnancy, tattoos, prostheses or osteosynthetic materials, as well as severe spinal deformations such as in Bechterew and Scheuermann's diseases. Moreover, patients were excluded who were unable to stand upright for a few minutes, or used medication that could cause static imbalance, e.g. sedatives or sleeping pills. All participants gave written informed consent and the study was approved by the institutional review board of the International Academy of Osteopathy, as part of research leading to a master degree. Table 1 shows the epidemiological characteristics of the participants.

Low back pain classification

The 'Oswestry Low Back Pain Disability Questionnaire' or 'Oswestry Disability Index' (ODI; see Annex 1) [24,25] was used to identify patients with LBP, and to quantify the degree of functional impairment due to pain [26]. The ODI-score varies between 0 and 100, and is based on 10 sections related to the daily functioning (pain intensity, personal care, lifting, walking, sitting, standing, sleep, sex, social functioning and traveling). Each section contains six items that are scored from 0 (minimum degree of difficulty during that particular activity) to 5 (maximum degree of difficulty). The total score is obtained by summing up the scores of all sections, giving a maximum of 50 points. The ODI is calculated by doubling this sum. In agreement with Fairbanks [24] five classes of severity were introduced: from 0 to 20 indicating minimal disability; from 21 to 40 for moderate disability; from 41 to 60 for severe disability; from 61 to 80 for crippled; from 81 to 100 for patients being bed bound. An ODI score exceeding 20 has been related to a poor prognosis regarding the probability to return to work [27]. Table 1 shows de distribution of the subjects according to the ODI.

Subjects were also classified according the duration of the LBP. Chronic LBP was labelled when the duration exceeded 3 months, or occurred episodically within a 6-month period [28]. Duration lower than 3 months was labelled as acute LBP. The latter also included patients with recurrent LBP that occurred suddenly after a period of a minimum of 6 months without LBP.

Annex 1
Logit(p) back transformation table.

p	logit(p)	p	logit(p)	p	logit(p)	p	logit(p)
0.01	−4.5951	**0.26**	−1.0460	**0.51**	0.0400	**0.76**	1.1527
0.02	−3.8918	**0.27**	−0.9946	**0.52**	0.0800	**0.77**	1.2083
0.03	−3.4761	**0.28**	−0.9445	**0.53**	0.1201	**0.78**	1.2657
0.04	−3.1781	**0.29**	−0.8954	**0.54**	0.1603	**0.79**	1.3249
0.05	−2.9444	**0.30**	−0.8473	**0.55**	0.2007	**0.80**	1.3863
0.06	−2.7515	**0.31**	−0.8001	**0.56**	0.2412	**0.81**	1.4500
0.07	−2.5867	**0.32**	−0.7538	**0.57**	0.2819	**0.82**	1.5163
0.08	−2.4423	**0.33**	−0.7082	**0.58**	0.3228	**0.83**	1.5856
0.09	−2.3136	**0.34**	−0.6633	**0.59**	0.3640	**0.84**	1.6582
0.10	−2.1972	**0.35**	−0.6190	**0.60**	0.4055	**0.85**	1.7346
0.11	−2.0907	**0.36**	−0.5754	**0.61**	0.4473	**0.86**	1.8153
0.12	−1.9924	**0.37**	−0.5322	**0.62**	0.4895	**0.87**	1.9010
0.13	−1.9010	**0.38**	−0.4895	**0.63**	0.5322	**0.88**	1.9924
0.14	−1.8153	**0.39**	−0.4473	**0.64**	0.5754	**0.89**	2.0907
0.15	−1.7346	**0.40**	−0.4055	**0.65**	0.6190	**0.90**	2.1972
0.16	−1.6582	**0.41**	−0.3640	**0.66**	0.6633	**0.91**	2.3136
0.17	−1.5856	**0.42**	−0.3228	**0.67**	0.7082	**0.92**	2.4423
0.18	−1.5163	**0.43**	−0.2819	**0.68**	0.7538	**0.93**	2.5867
0.19	−1.4500	**0.44**	−0.2412	**0.69**	0.8001	**0.94**	2.7515
0.20	−1.3863	**0.45**	−0.2007	**0.70**	0.8473	**0.95**	2.9444
0.21	−1.3249	**0.46**	−0.1603	**0.71**	0.8954	**0.96**	3.1781
0.22	−1.2657	**0.47**	−0.1201	**0.72**	0.9445	**0.97**	3.4761
0.23	−1.2083	**0.48**	−0.0800	**0.73**	0.9946	**0.98**	3.8918
0.24	−1.1527	**0.49**	−0.0400	**0.74**	1.0460	**0.99**	4.5951
0.25	−1.0986	**0.50**	0.0000	**0.75**	1.0986		

Reproduced from: Schoonjans. Manual to the MedCalc statistical program (MedCalc Software, Ostend, Belgium).

Equipment

After completion of the questionnaire and measurement of weight and height, a static registration of the surface topography of the back was made based on the principle of Moiré, using the Diers-4D formetric® system (Fig. 2), as described elsewhere [10,21,29].

In short, volunteers were examined undressed, in a relaxed standing position, and breathing normally. The feet were placed on a fixed position drawn on the ground and anatomical landmarks were indicated with dots attached to the skin. While the person was standing at a distance of 2 metres (6.5 ft) in front of the height-adjustable 4D scanning device, the image of the back surface was captured in less than a one second by video raster stereography, and immediately processed. Spine shape parameters in the sagittal plane are illustrated in Fig. 3. All investigators were properly trained to work with the equipment, and the accuracy and reproducibility of measurement were assessed previously [21].

Statistical analysis

All data were recorded in an Excel spreadsheet and all clinically relevant parameters were analysed with SAS (version 9.2, SAS Institute Inc., Cary, NC, USA.) or MedCalc for Windows, version 17.2 (MedCalc Software, Ostend, Belgium) [31]. Summary statistics, including mean, standard deviation, minimum and maximum values, were calculated for all subjects combined, and separately for males and females in the following subgroups, relevant for a clinical practise: subjects without LBP (ODI = 0), subjects with LBP (ODI > 0), subjects with acute LBP, and subjects with chronic LBP. For all subgroups, and for males and females separately, stepwise multiple linear regression analyses were applied with as variable entry criterion $P < 0.15$, and as variable stay criterion $P < 0.1$. Variables included in the multiple linear regression models were BMI, age, sagittal imbalance (= trunk inclination), coronal imbalance, flèche cervicale, flèche lombaire, kyphotic angle, lordotic angle, pelvic inclination, pelvic torsion, pelvic obliquity, vertebral rotation (root mean square), trunk torsion, apical deviation (root mean square) and scoliotic angle. For each subgroup the overall P-value, the R^2, the intercept, and the coefficients of each variables the final algorithms are provided.

Based on different cut-off points for PLBP in the models, Receiver Operating Characteristics (ROC)-curves were generated based on ODI = 0 or ODI > 0. The Areas Under the Curves (AUC's) were calculated in order to allow for selecting the highest discrimination based on sensitivity and specificity. P-values were calculated to assess if each AUC was statistically different from the reference AUC = 0.5 (shown by the diagonal in the graph), representing pure random selection. Associated positive and negative likelihood ratios were calculated in order to compensate for the differences in number of subjects in the different subgroups. The criterion value for optimal discrimination between subjects without and with LBP was calculated as well as the highest combined sensitivity and specificity.

In view of the clinical relevance of the ODI for identifying serious levels of LBP probably associated with incapacity to work [27], logistic stepwise regression analysis for the groups of ODI > = 20 versus ODI < 20 were conducted. Since the statistical power for such analysis with a binary response is more limited, the preconditions were slightly relaxed: the P-value for entry into model was 0.25 (instead of 0.15) and the P-value for stay into the model was 0.20 (instead of 0.10 for stepwise multiple linear regression). The overall formula for applying logistic regression is $\text{logit}(p) = a_0 + a_1X_1 + a_2X_2 + \ldots$ where X_1, X_2, … are the symbols for the independent explanatory variables. The Odds ratio indicates the probability of an independent explanatory variable to increase or decrease the prediction for ODI > = 20. An odds ratio

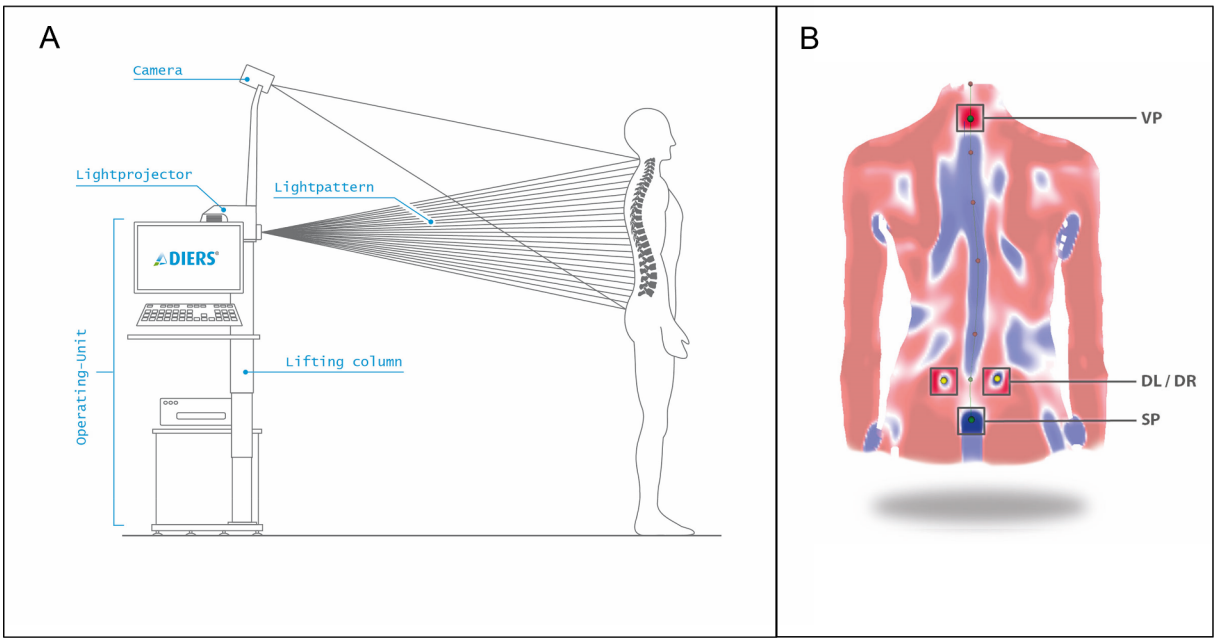

Fig. 2. The DIERS formetric 4D analysis system. Panel A illustrates the DIERS system showing the principle of triangulation. Panel B represents the 3D surface in mean curvature, showing the anatomical landmarks (VP: vertebra prominens, DL and DR: left and right lumbar dimples, SP: the sacrum point) (DIERS Formetric, Diers Medical Systems, Chicago, IL).

is > 1 shows a greater probability for an increased prediction of ODI > = 20. An odds ratio of < 1 shows that an increase in the value of variable results in a decreased prediction of ODI < 20. Based on the results of the stepwise logistic regression it is possible to calculate for each individual subject the probability (p) of having an ODI > = 20 by applying the formula logit(p) = ln(p/1 − p). Associated ROC curves can be drawn as well as the corresponding overall AUCs and the sensitivity, specificity, positive likelihood ratio and negative likelihood ration for each criterion value to be considered.

Results

All subjects filled out an Oswestry Low Back Pain Disability Questionnaire with an additional question about the duration of the LBP. The histograms in Fig. 4 show the distribution of the ODI among the participants.

Bivariate analyses were performed to explore possible correlations between the ODI, spine shape variables and demographic characteristics. A strong or weaker relationship is expressed in the Pearson correlation coefficients (r-values, see Table 2). A high r-value, either

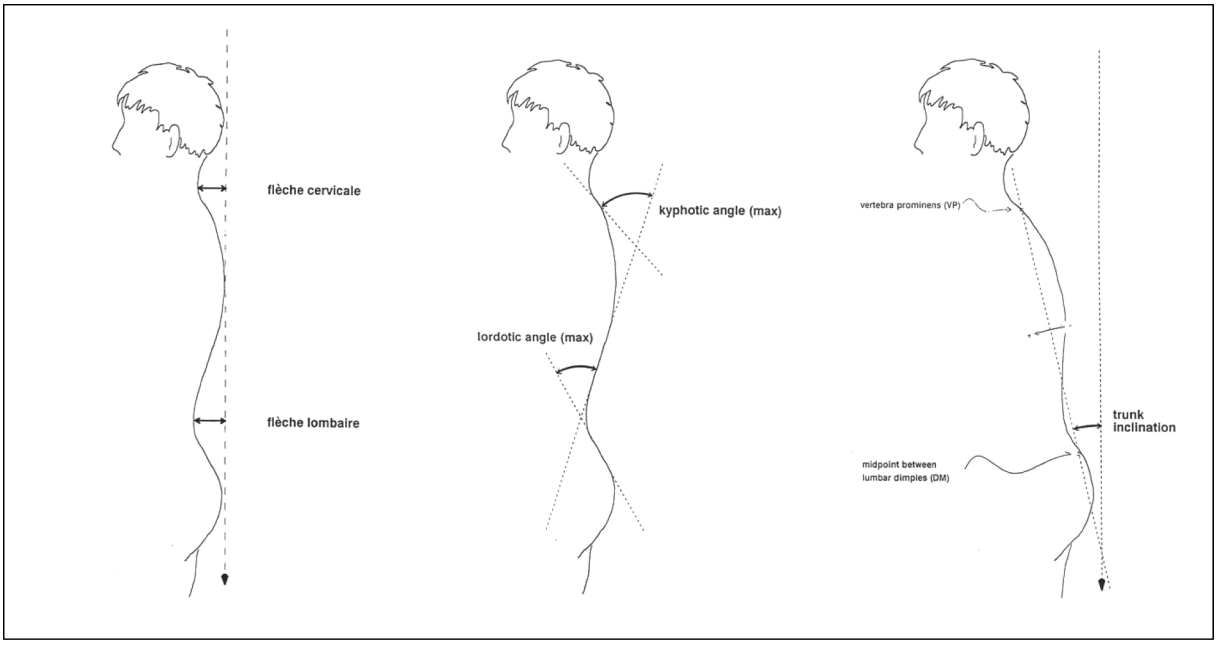

Fig. 3. Spine shape variables in the sagittal plane, measured with Diers (DIERS Formetric, Diers Medical Systems, Chicago, IL).

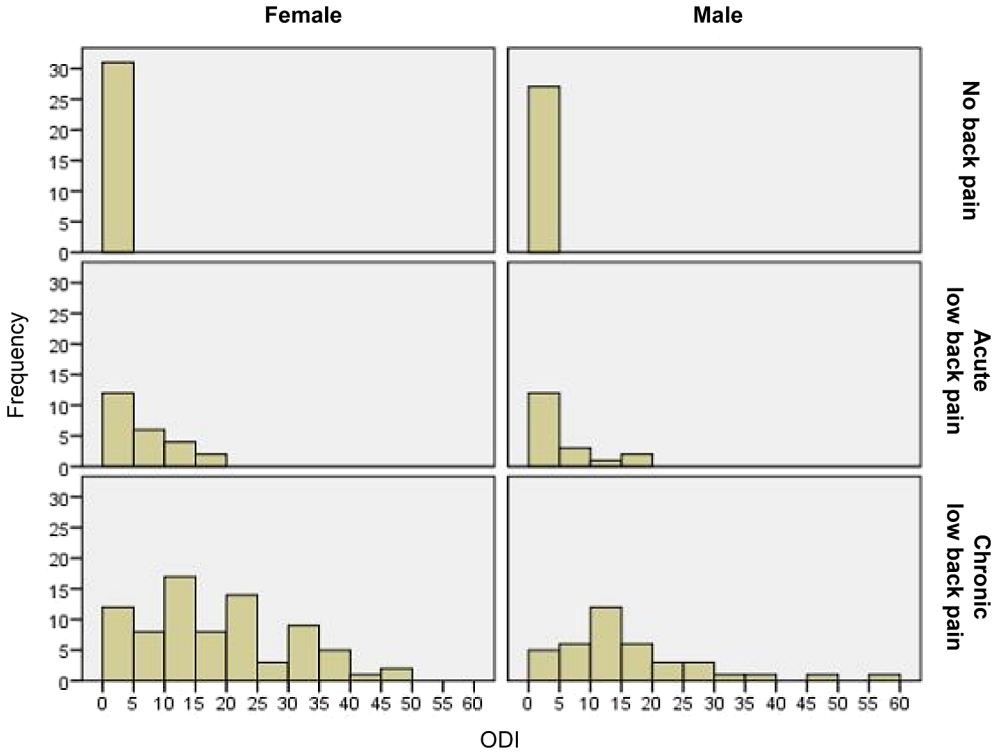

Fig. 4. Histograms of the ODI for all female (left column) and male (right column) subjects. The upper panel shows the number of subjects with no back pain, the middle panels subjects with acute LBP and the lower panel subjects with chronic LBP.

Table 2
Pearson correlation coefficients (r-values) as calculated from the bivariate analyses.

	ODI vs BMI		**ODI vs Age**	
	Female	Male	Female	Male
Acute	0.03 (P = 0.90; n = 24)	0.13 (P = 0.62; n = 18)	**0.43 (P = 0.03; n = 24)**	0.17 (P = 0.49; n = 18)
Chronic	**0.32 (P = 0.005; n = 79)**	0.31 (P = 0.05; n = 39)	**0.54 (P < 0.0001; n = 79)**	**0.34 (P = 0.04; n = 39)**
	ODI vs sagittal imbalance		**ODI vs Fléche cervicale**	
	Female	Male	Female	Male
Acute	0.08 (P = 0.69; n = 24)	0.19 (P = 0.44; n = 18)	0.016 (P = 0.46; n = 24)	0.24 (P = 0.33; n = 18)
Chronic	**0.33 (P = 0.003; n = 79)**	0.19 (P = 0.25; n = 39)	**0.25 (P = 0.02; n = 79)**	0.29 (P = 0.07; n = 39)
	ODI vs Kyphotic angle		**ODI vs Vertebral rotation**	
	Female	Male	Female	Male
Acute	−0.14 (P = 0.51; n = 24)	0.31 (P = 0.21; n = 18)	0.15 (P = 0.48; n = 24)	−0.13 (P = 0.59; n = 18)
Chronic	**0.36 (P = 0.001; n = 79)**	0.28 (P = 0.08; n = 39)	0.17 (P = 0.14; n = 79)	**0.44 (P = 0.005; n = 39)**
	ODI vs Trunk Torsion		**ODI vs Apical deviation**	
	Female	Male	Female	Male
Acute	−0.06 (P = 0.77; n = 24)	−0.46 (P = 0.053; n = 18)	**0.45 (P = 0.03; n = 24)**	0.034 (P = 0.89; n = 18)
Chronic	0.13 (P = 0.25; n = 79)	**−0.36 (P = 0.02; n = 39)**	0.03 (P = 0.79; n = 79)	**0.65 (P < 0.0001; n = 39)**
	ODI vs Scoliotic angle			
	Female	Male		
Acute	−0.045 (P = 0.84; n = 24)	−0.20 (P = 0.44; n = 18)		
Chronic	0.073 (P = 0.52; n = 79)	**−0.35 (P = 0.03; n = 39)**		

Age (years); BMI (kg/m^2); Fleche Cervicale (mm); Scoliotic Angle (mm); Kyphotic Angle (degrees); sagittal imbalance (degrees); vertebral rotation (degrees); Trunk Torsion (degrees); Apical deviation (mm). **Bold** indicates statistically significant (P-value < 0.05).

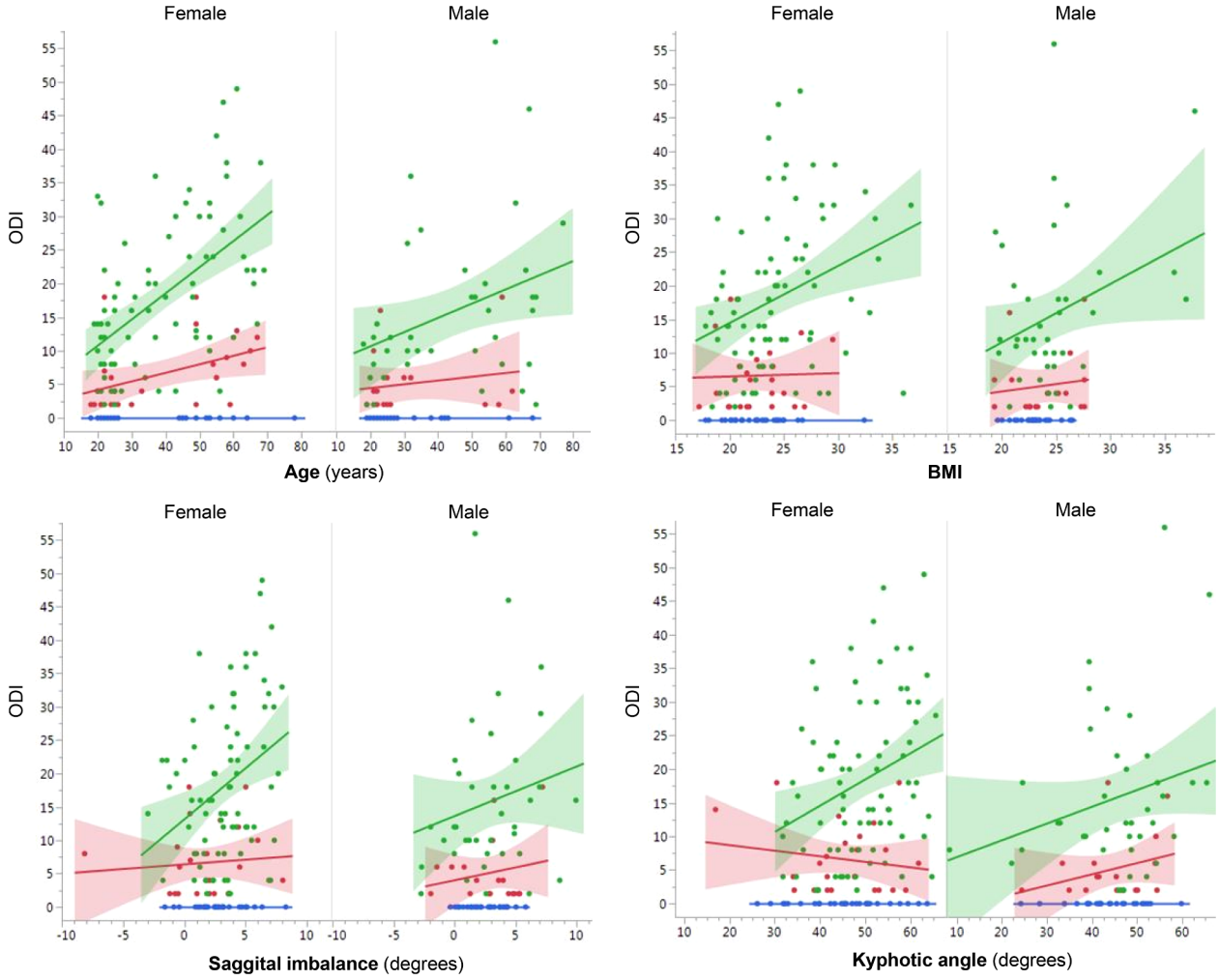

Fig. 5. Linear regression lines with 95% confidence intervals for acute and chronic LBP groups, females and males separately. ODI versus Age, BMI, sagittal imbalance and kyphotic angle are shown for subjects with no LBP (blue), acute LBP (red) or chronic LBP (green).

positive or negative, is suggestive of a significant contribution of this variable in the subsequent multiple regression analyses. Linear regression lines and their 95% confidence intervals were superimposed on the scatter plots in Fig. 5 for some of the variables for which at least one statistically significant correlation was found. Male and female groups express different patterns.

The above data allowed for developing an algorithm calculating the predicted LBP-score for patients with (or without) idiopathic LBP based on the spine shape variables and demographic characteristics. Multiple linear regression model calculations resulted in an algorithm for the "predicted LBP score" (PLBP) in different patient groups, women or men with either acute or chronic LBP (table 3). The R^2 expresses the percentage variability explained by the mathematical model.

The appropriateness of the models can be assessed with ROC curves. These and the corresponding dot diagrams are depicted for females and males with chronical LBP in Fig. 6. The associated analyses are summarized in Table 4.

Referring to the patient context, discrimination between ODI = < 20 or ODI > 20 is considered being a relevant threshold value related to work capacity or return to work within 3 months [27]. Therefore, logistic stepwise regression analysis was applied to calculate the probability for a subject to belong to the group of ODI > 20, based on the objectively measured posture parameters. Analysed were performed for any subject (total population: ODI ≥ 0) and for subjects having low back pain (ODI > 0).

Based on logistic regression (ODI score > = 20 versus ODI score < 20) for men with chronic LBP it appeared that trunk torsion and apical deviation are the significant variables. In women with chronic LBP, the significant variables are the pelvic torsion and apical deviation (see Table 5). In the group of persons with acute low back pain, there was no one with an ODI score > = 20.

To evaluate the outcomes of the formula, the associated ROC curves were calculated as well as the corresponding overall AUCs. Both AUCs are statistically highly significant ($p < 0.0001$).

The optimal criterion value together with the sensitivity, specificity, positive likelihood ratio and negative likelihood ration for each criterion value for the chronic female and male population is represented in Fig. 7 and Table 6.

Discussion

None of the subjects, presented with an ODI above 60% as shown in Fig. 3. This could be expected since all subjects were recruited from an osteopathic outpatient clinic. The degree of disability due to the low back pain should not have prevented them from coming to the clinic. At the other hand, an ODI of 20 was fixed as lower limit of clinical significance, since only scores above this threshold value would be associated with such degree of discomfort as to justify absenteeism [24,27]. Although slight variations in the response to the different items of the ODI questionnaire may occur, this score was proven to show good construct validity and high consistency and reproducibility [26].

Several variables were found to significant correlate with LBP. The

Table 3
Stepwise linear regression equations for the predicted LBP-values (PLBP) of the different subpopulations. The statistical coefficient (R^2) and p-values of independent variables of spine shape variables and demographic characteristics are listed.

	n	Predicted LBP (PLBP)	R^2	P-value
All women and men	218	−18.26 + 0.19(Age) + 0.53(BMI) + 0.47(Sagittal imbalance) − 3.10(gender) + 0.14(Kyphotic angle) + 0.58(Apical deviation)	0.2663	< 0.0001
ODI > 0	160	−7.78 + 0.20(Age) + 0.70(Sagittal imbalance) + 1.36(coronal imbalance) + 0.21(Kyphotic angle) − 0.28(Trunk torsion) + 0.49(Apical deviation)	0.2936	< 0.0001
Women				
all	134	−7.74 + 0.25(Age) + 1.42(Sagittal imbalance) + 1.52(Coronal imbalance) + 0.18 (fleche lombaire)	0.2713	< 0.0001
ODI = 0	31	/		
ODI > 0	103	2.46 + 0.27(Age) + 1.13(Sagittal imbalance) + 1.72(Coronal imbalance)	0.3142	< 0.0001
ODI > 0 & acute LBP	24	1.11 + 1.11(Apical deviation)	0.2001	0.0284
ODI > 0 & chronic LBP	79	1.70 + 0.35(Age) + 0.85 (Sagittal imbalance)	0.3202	< 0.0001
ODI = 0 + ODI > 0 & chronic LBP	110	− 10.08 + 0.29(Age) + 0.54(BMI) + 1.47(Coronal imbalance)	0.2630	< 0.0001
Men				
all	84	− 9.20 + 0.22(Age) − 0.67(Trunk torsion) + 0.99(Apical deviation) − 0.01(Scoliotic angle)	0.4368	< 0.0001
ODI = 0	27	/		
ODI > 0	57	4.35 + 0.13(Age) − 0.31(Pelvic inclination) − 0.89(Trunk torsion) + 1.52(Apical deviation)	0.5374	< 0.0001
ODI > 0 & acute LBP	18	6.19–0.45(Trunk torsion)	0.2140	0.0532
ODI > 0 & chronic LBP	39	8.84 + 2.13 (Apical deviation) − 0.75(Trunk torsion) − 0.35(Pelvic inclination)	0.5983	< 0.0001
ODI = 0 + ODI > 0 & chronic LBP	66	− 12.77 + 0.25(Age) + 1.30 (Apical deviation) − 0.56(Trunk torsion) − 0.02(Scoliotic angle)	0.4839	< 0.0001

Age (years); BMI (kg/m^2); Scoliotic Angle (mm); Kyphotic Angle (degrees); Apical deviation (mm); Trunk torsion (degrees); Coronal imbalance (mm); Pelvic inclination (degrees); sagittal imbalance (degrees); Fleche lombaire (mm).

bivariate analyses showed that age was an important factor for female patients suffering from acute and chronic LBP which is in agreement with the observations of Jones, Pandit and Lavy [15].

Different correlations of spine shape variables were found in female and male subjects. In women, the coronal imbalance (also named as trunk imbalance) and sagittal imbalance (also named as trunk

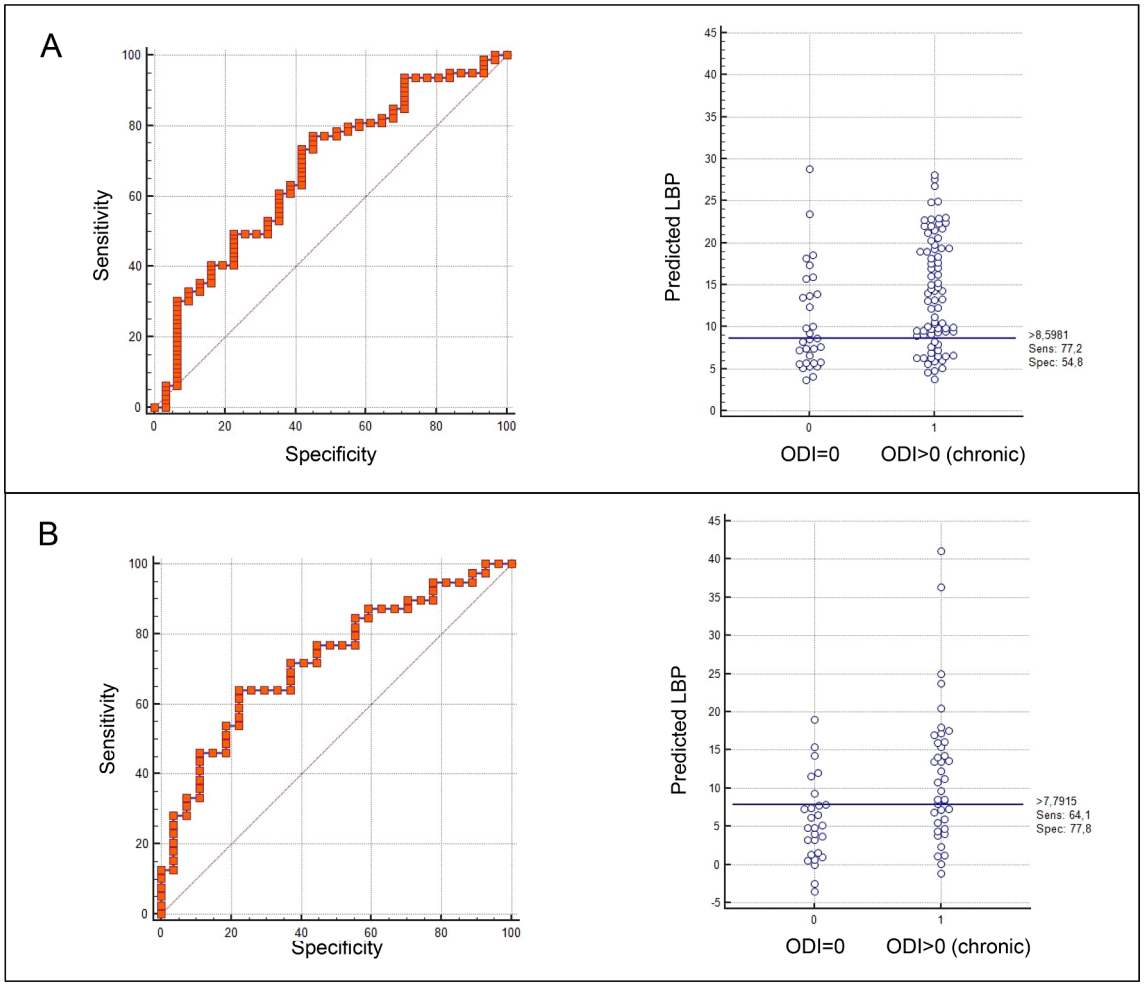

Fig. 6. ROC curves (left) and dot diagrams (right) for subjects with no low back pain (ODI = 0) or subjects with chronic low back pain. In panel A female subjects are shown, in panel B male subjects. The AUC for the female and male ROC curves are 0.673 and 0.726 respectively. The optimal criterion value, the sensitivity and specificity, for each cut-off value are indicated.

Table 4
Summary of ROC analyses for ODI = 0 or ODI > 0 (chronic).

	Female	Male
Sample size	110	66
Area under the ROC curve (AUC)	0,673	0.726
Significance level P (Area = 0.5)	0.0030	0.0003
Associated criterion	> 8.5981	> 7.7915
Sensitivity	77.22	64.10
Specificity	54.84	77.78
Positive likelihood ratio	1.71	2.88
Negative likelihood ratio	0.42	0.46

inclination) appeared to be contributing spine shape variables, as was equally reported by Schroeder and Mattes [20].

In men with LBP different variables, namely trunk torsion, pelvic inclination and apical deviation (also named lateral deviation) were shown to be significant. Neither the lordotic or the kyphotic angle, that are known to be mutually correlated [21], could be identified as predictors for the LBP.

Although some similarities between our results and those of previous studies were found, it should be underscored that the grading of the severity of LBP was based on different scoring systems. The present study aimed at assessing the relation between the expected and reported level of invalidity, respectively incapacity to work. Moreover, a differentiation between acute and chronic LBP was implemented, since these conditions may require a different therapeutic approach [30]. The study does not pretend to reveal the cause of the complaints, which may be related to complementary occupational, behavioural and other social factors.

The formula based on the logistic regression analysis with discrimination below or above ODI 20 provides an adequate prediction based on age, gender and objective measurements of the spine posture. The following formulas can be used for female and male subjects, respectively, with chronic LBP:

$$\text{Logit(p)} = -3.15 + 0.09\,(\text{Age}) - 0.16\,(\text{Pelvic torsion}) - 0.13\,(\text{Apical deviation})$$

$$\text{Logit(p)} = -4.35 - 0.27(\text{Trunk torsion}) + 0.51(\text{Apical deviation})$$

The logit(p) back transformation table (Annex 1, [31]) allows to predict the probability (p) for each group to have a LBP disability score likely to be above or equal to 20, which is most useful in assessing absenteeism. The accuracy of this prediction is similar in male and female persons, with area under the curve of approximately 0.83 (table 5), which is considered to be sufficient for biological variables.

The discriminating power of the predicted score should be considered biologically and clinically relevant. This implies that an important discrepancy between the predicted score (PLBP) based on the mathematical formulation, and ODI based on the questionnaire should either induce complementary investigations, or may suggest aggravation, particularly if the latter is much higher than the former.

In practise, the mathematically predicted LBP (PLBP) based on the formetric data and the ODI granted on the basis of information provided by the patient in the Oswestry questionnaire can be compared.

Table 5
Summary of the logistic stepwise regression analysis for the groups of ODI ≤ 20 or ODI > 20. The data are represented for all women and men together and gender specific, including patients with LBP (ODI > 0) or without LBP (ODI = 0).

Population	n	Variable (X)	Estimated value (a_1, a_2, …)	Odds Ratio	95% Wald Confidence Limits odds ratio	P-value
All women and men (ODI ≥ 0)	218	a_0	− 6.27			< 0.0001
		Age	+ 0.05	1.050	1.025–1.075	< 0.0001
		BMI	+ 0.13	1.139	1.034–1.255	0.0085
		Gender	− 1.13	0.322	0.136–0.758	0.0095
ODI > 0	160	a_0	− 5.45			< 0.0001
		Age	+ 0.05	1.049	1.023–1.077	0.0002
		BMI	+ 0.11	1.118	1.014–1.234	0.0256
		Gender	− 1.18	0.309	0.125–0.764	0.0110
Women						
all	134	a_0	− 6.12			< 0.0001
		Age	+ 0.05	1.050	1.020–1.081	0.0009
		BMI	+ 0.11	1.116	0.988–1.261	0.078
		Sagittal imbalance	+ 0.14	1.150	0.950–1.393	0.15
		Coronal imbalance	+ 0.21	1.238	0.897–1.707	0.19
ODI > 0	103	a_0	−5.80			0.0002
		Age	+ 0.05	1.051	1.019–1.085	0.0016
		BMI	+ 0.10	1.110	0.979–1.259	0.1042
		Sagittal imbalance	+ 0.14	1.145	0.940–1.395	0.1796
ODI > 0 & chronic LBP	79	a_0	− 3.15			0.0003
		Age	+ 0.09	1.095	1.051–1.140	< 0.0001
		Pelvic torsion	− 0.16	0.850	0.678–1.066	0.1602
		Apical deviation	− 0.13	0.875	0.726–1.055	0.1627
Men						
all	84	a_0	−7.0624			< 0.0001
		Age	+ 0.0688	1.071	1.015–1.131	0.013
		Pelvic obliquity	−0.2975	0.743	0.521–1.059	0.101
		Trunk torsion	−0.2423	0.785	0.640–0.962	0.020
		Apical deviation	+ 0.2715	1.312	1.010–1.704	0.042
ODI > 0	57	a_0	− 6.40			0.0006
		Age	+ 0.05	1.048	0.992–1.108	0.0949
		Pelvic obliquity	− 0.27	0.762	0.526–1.106	0.1524
		Trunk torsion	− 0.28	0.756	0.596–0.959	0.0210
		Apical deviation	+ 0.39	1.479	1.037–2.109	0.0309
ODI > 0 & chronic LBP	39	a_0	− 4.35			0.0026
		Trunk torsion	− 0.27	0.767	0.603–0.976	0.0309
		Apical deviation	+ 0.51	1.670	1.111–2.512	0.0138

Age (years); BMI (kg/m^2); Gender (Female = 0, male = 1); Apical deviation (mm); Trunk torsion (degrees); Pelvic obliquity (degrees); Pelvic torsion (degrees); sagittal imbalance (degrees); Coronal imbalance (mm).

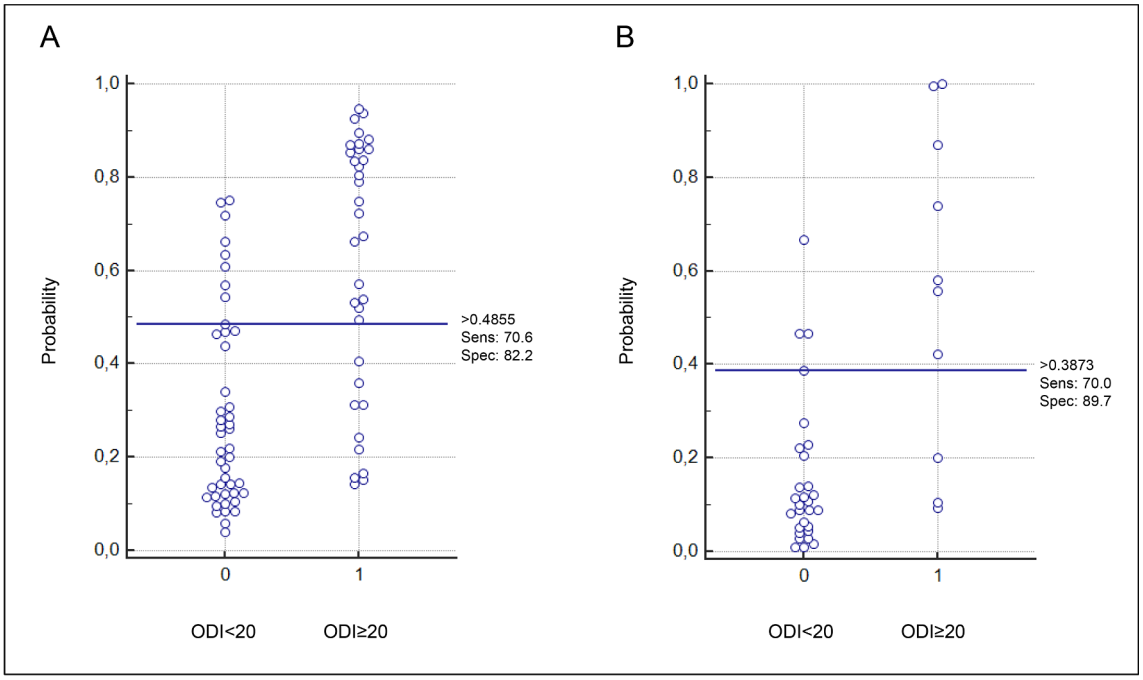

Fig. 7. Dot diagram of the probability that the ODI is equal or greater to 20 for the chronic female (A) and male (B) population. The optimal criterion value, the sensitivity and specificity, for each cut-off value are indicated.

Table 6
Summary of ROC analyses of the probability for female and male subjects with chronic low back pain to have an ODI ≥ 20.

	Female	Male
Sample size	79	39
Area under the ROC curve (AUC)	0.831	0.855
Significance level P (Area = 0.5)	< 0,0001	< 0,0001
Associated criterion	> 0.4855	> 0.3873
Sensitivity	70.6	70.00
Specificity	82.2	89.70
Positive likelihood ratio	3.97	6.77
Negative likelihood ratio	0.36	0.33

Inconsistency between the two scores may signal further investigations to be indicated in order to reveal severe organic pathology. The inconsistency may also indicate an aggravation by the patient concerned.

Conclusion

It has been found feasible to identify objective variables that are relevant to the severity of low back pain. The variables included in the algorithm predicting the latter are obtained from history taking and from the measurement of the static aspects of the spine, using the Diers Formetric equipment. Though application of the findings is relevant for the osteopathic treatment and follow-up of patients, more detailed information can probably be gained from the individual assessment of the spine profile using the percentile values of specific measurements.

Another important clinically relevant application of our study relates to the prediction and quantification of the level of invalidity caused by the LBP. This may contribute to a more reliable and objective assessment of capacity or incapacity to resume work, particularly among persons with chronic LBP. Further prospective multicentre trials including larger numbers of cases are in progress to sustain our findings.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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