Lumbar Lordosis and Pelvic Inclination in Adults With Chronic Low Back Pain

Background and Purpose. The causes of lumbopelvic imbalances in standing have been widely accepted by physical therapists, but there is a lack of scientific evidence available to support them. We examined the association between 9 variables and pelvic inclination and lumbar lordosis during relaxed standing. **Subjects.** Thirty men and 30 women with chronic low back pain (CLBP) for at least 4 months were examined (mean age=54.9 years, SD=9, range=40.4–69.8). **Methods.** Multiple linear regression modeling was used to assess the association of pelvic inclination and the magnitude of lumbar lordosis in standing with age, sex, body mass index (BMI), Oswestry Back Pain Disability Questionnaire (ODQ) scores, physical activity level, hip flexor muscle length, abdominal muscle force, and range of motion (ROM) for lumbar flexion and extension. **Results.** In women, age, BMI, and ODQ scores were associated univariately and multivariately with pelvic inclination. In men, lumbar extension ROM was related univariately to pelvic inclination; age, lumbar extension ROM, and ODQ scores were associated multivariately. Lumbar lordosis was associated univariately with only lumbar extension ROM for women and men. A weak correlation was found between angle of pelvic inclination and magnitude of lumbar lordosis in standing (r=.31 for women, r=.37 for men). **Conclusion and Discussion.** The odds ratio of having CLBP is increased if the score on the double-leg lowering test for abdominal muscles exceeds 50 degrees for men and 60 degrees for women. In patients with CLBP, the magnitude of the lumbar lordosis and pelvic inclination in standing is not associated with the force production of the abdominal muscles. [Youdas JW, Garrett TR, Egan KS, Therneau TM. Lumbar lordosis and pelvic inclination in adults with chronic low back pain. *Phys Ther.* 2000;80:261–275.]

Key Words: *Chronic low back pain, Kinesiology/biomechanics, Lumbar spine mobility, Muscle performance.*

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Physical therapists routinely assess relaxed standing posture to help identify possible problems with the spine or peripheral joints. For example, if a patient stood with an exaggerated lumbar lordosis, various authors[1–4] suggested that the patient's abdominal muscles were weak and elongated, whereas the erector muscles of the spine and the hip flexor muscles were supposed to be shortened. These lumbopelvic imbalances would be expected to produce an increased anterior tilt of the pelvis and an exaggerated lumbar lordosis during relaxed standing. These authors also contended that what they considered muscle imbalances recognized by observation of the patient's postural alignment can be verified by performing specific muscle force and length tests. The hypotheses generated by Kendall et al[1] and endorsed by others[2–4] regarding the causes of postural faults have been widely accepted by physical therapists, although there is a paucity of scientific information available to support them.

Several studies have questioned some of the relationships Kendall et al[1] and others[2–4] have described regarding faults observed during standing postural alignment. Walker et al[5] were the first investigators to examine the relationship between lumbar lordosis and pelvic inclination in standing and abdominal muscle performance. Repeated measurements were made of lumbar lordosis and pelvic tilt in standing on 31 physical therapist students without symptoms of low back pain (23 women and 8 men) between the ages of 20 and 33 years. Abdominal muscle force was assessed with the double-leg lowering test originally described by Kendall et al.[1] All measurements were reliable. Spearman rho correlation of abdominal muscle force measurements with pelvic tilt and with lumbar lordosis yielded values of .18 and .06, respectively. The Pearson product-moment correlation coefficient was .32 for the relationship between lordosis and pelvic tilt. Walker et al[5] concluded that no relationship existed between lumbar lordosis and pelvic inclination in a standing position and abdominal muscle force.

Similarly, Heino et al[6] examined the relationship between hip extension range of motion (ROM) and 3 determinants of standing postural alignment—standing pelvic tilt, depth of lumbar lordosis, and abdominal muscle force—in 25 adults without symptoms of low back pain (15 women and 10 men) between the ages of 21 and 49 years. The Pearson product-moment correlation coefficient was .01 for the relationship between lumbar lordosis and pelvic tilt. The Pearson product-moment correlation coefficient between abdominal muscle force and pelvic tilt was .30, whereas the correlation between abdominal muscle force and lumbar lordosis was .27. No relationship was found among clinical variables commonly observed by physical therapists during a standing postural evaluation of the lumbopelvic complex.

Youdas et al[7] sought to expand on the study by Walker et al[5] and to examine the association between pelvic inclination and lumbar lordosis during relaxed standing and 8 variables thought to contribute to standing postural alignment. Ninety subjects (45 women and 45 men) between the ages of 40 and 69 years and without back pain or a history of surgery were examined. Multiple linear regression modeling was used to assess the association of pelvic inclination and size of lumbar lordosis in standing with age, sex, body mass index

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Table 1.
Descriptive Statistics for Men With and Without Chronic Low Back Pain Regarding the Angle of Pelvic Inclination and Size of Lumbar Lordosis in Standing and Selected Explanatory Variables[a]

Variable	With Back Pain (n=30)			Without Back Pain (n=45)			Wilcoxon Rank Sum P
	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	
Age (y)	54.9	9.0	40.4–69.8	54.8	8.5	40.6–69.8	1.00
Height (cm)	178.5	6.5	163.8–190.5	175.3	7.4	163.8–192.4	.07
Weight (kg)	85.9	12.9	66–114.8	82.1	13.7	60.5–114.1	.22
Body mass index (kg/m^2)	26.9	3.6	21.2–37.4	26.6	3.5	21.3–36.1	.71
Oswestry Back Pain Disability Questionnaire (%)	15	9.5	0–48				
Pelvic inclination (°)	14.9	7.7	0–33	13.8	4.5	3–24	.34
Lumbar curve (°)							
Standing	39	8.1	26.5–59	37.5	11	14–58	.78
Sitting	28.6	6.6	13.5–40.5	31	5.7	17–43	.10
Prone	42.7	8.8	23.5–61	50.1	9.2	27–65	.0005
Supine trunk-thigh angle (°)							
Left	180.3	1.5	175–183	180.4	1.8	175–183	.17
Right	179.9	1.5	175–182.5	179.9	1.5	175–182	.69
Abdominal muscle force (°)	53.9	6.6	42–67.5	39.4	11.3	0–56	<.0001

[a] Data for subjects with back pain were unique to this study, whereas data for subjects without back pain were taken from previously published data (Youdas et al[7]).

(BMI), physical activity level, back and one-joint hip flexor muscle length, and force and length of abdominal muscles. Abdominal muscle force was associated with angle of pelvic inclination for women (R^2=.23) but not for men. Standing lumbar lordosis was associated with abdominal muscle length in women (R^2=.40); it was associated multivariately with length of abdominal and one-joint hip flexor muscle and physical activity level in men (R^2=.38). Youdas et al used joint range of motion to estimate or reflect muscle length; however, length was not measured directly. The correlation coefficient between pelvic inclination and size of lumbar lordosis was .06 for women and −.08 for men.

Evidence from these 3 studies[5–7] challenges the assumption that standing postural malalignments of the pelvis and lumbar spine in subjects without low back pain are linked to abdominal muscle force or tightness of the back and one-joint hip flexor muscles.

Investigators have claimed that anthropometric characteristics such as height and body weight,[8] increased lumbar lordosis,[9] diminished abdominal muscle force,[10] and reduced mobility of the lumbar spine[11] by themselves can increase the risk of chronic low back pain (CLBP). It would be important for physical therapists to know whether clusters of these characteristics, which can be objectively measured during a routine clinical examination, are commonly associated with CLBP.

The primary aims of this study were to expand on the study by Youdas et al[7] and to determine in patients with CLBP whether an association exists between pelvic inclination or lumbar lordosis during relaxed standing and the following 9 factors: age, sex, BMI, Oswestry Back Pain Disability Questionnaire (ODQ) scores, physical activity level, abdominal muscle force, lumbar extension ROM, lumbar flexion ROM, and one-joint hip flexor muscle length. Furthermore, using data gathered from 90 adults with healthy backs from a previous study,[7] we compared the subjects with and without CLBP on the basis of anthropometric characteristics, magnitude of lumbar lordosis, abdominal muscle force, lumbar spine mobility, and physical activity level. We hypothesized that subjects with CLBP would have larger BMIs; an increase in the magnitude of the lumbar lordosis and size of pelvic inclination; and reduced abdominal muscle force, lumbar spine ROM, and levels of physical activity compared with their counterparts without symptoms of low back pain.

Method

Subjects

The subjects were 60 volunteers (30 men and 30 women), aged 40 to 69 years, with CLBP. There were 20 subjects (10 men and 10 women) in each of 3 age groups (40–49 years, 50–59 years, and 60–69 years). These 3 decades were selected because they represent a range of men and women with CLBP who have varied occupations and 4 levels of physical activity. The summary statistics of the subjects' personal characteristics are presented in Tables 1 and 2. The median duration of back pain for the men was 18 years ($\overline{X}$=18.7 years, SD=14.3 years,

Table 2.
Descriptive Statistics for Women With and Without Chronic Low Back Pain Regarding the Angle of Pelvic Inclination and Size of Lumbar Lordosis in Standing and Selected Explanatory Variables[a]

Variable	With Back Pain (n=30) $\overline{X}$	SD	Range	Without Back Pain (n=45) $\overline{X}$	SD	Range	Wilcoxon Rank Sum *P*
Age (y)	54.9	8.5	41.6–68.8	53.4	8.8	40.4–69.3	1.00
Height (cm)	162.8	7.2	151.1–180.3	161.3	5.8	146.1–172.7	.56
Weight (kg)	76.7	16.6	46.7–112.7	67.8	13.4	46.8–100	.02
Body mass index (kg/m^2)	28.9	5.7	19.4–42.7	26.1	5	17.9–43	.04
Oswestry Back Pain Disability Questionnaire (%)	26.7	9.7	8–44				
Pelvic inclination (°)	25	7.3	5–46.5	22.8	7.6	9–46	.10
Lumbar curve (°)							
Standing	55.5	10.4	34.5–80.5	52.7	15.3	22–81	.33
Sitting	20.7	8.9	0–35.5	23	10.1	0–42	.31
Prone	56	12	29–83	56.5	10.4	37–86	.81
Supine trunk-thigh angle (°)							
Left	180.4	1.1	178–182.5	181.6	1.4	177–184	<.0001
Right	180.2	1.1	178–182.5	180.9	1	180–183	.02
Abdominal muscle force (°)	60.7	8.4	43–77	49.6	11.5	22–70	<.0001

[a] Data for subjects with back pain were unique to this study, whereas data for subjects without back pain were taken from previously published data (Youdas et al[7]).

range=6 months to 44.5 years), and the median duration of back pain for the women was 11 years ($\overline{X}$=15.4 years, SD=12.7 years, range=1–49 years).

We categorized subjects' occupations according to the Physical Demands Strength Rating.[12] This scheme describes the force requirements necessary for average, successful work performance according to the judgment of an occupational analyst. There are 5 categories of work: sedentary, light work, medium work, heavy work, and very heavy work. The criteria for each category are described in Appendix 1. Eleven subjects (18%) were classified as performing sedentary work, 31 subjects (52%) were classified as performing light work, 11 subjects (18%) were classified as performing medium work, 5 subjects (8%) were classified as performing heavy work, and 2 subjects (3%) were classified as performing very heavy work.

Subjects were recruited through advertisements placed weekly on bulletin boards at our institution, in monthly newsletters received by our employees, and in a local daily newspaper. All subjects were queried by one of the authors to confirm that they fulfilled each admission criterion: (1) were not currently receiving any treatment for their back pain, (2) had CLBP for at least 4 months,[13] (3) were free from major illness, (4) had no previous back surgery, and (5) lacked a spinal fracture, infection, or cancer or occult disease, as determined by plain radiographs, magnetic resonance imaging, or computed tomogram. Written informed consent was obtained from all subjects.

Questionnaires

To allow us to describe the sample more completely, each subject completed 2 brief questionnaires. In the first questionnaire, the Lipid Research Clinics Physical Activity Questionnaire,[14] subjects were asked to rate their level of physical activity relative to peers at work and at leisure and to indicate whether they regularly performed (ie, at least 3 times a week) strenuous exercise or hard physical labor (Appendix 2). Based on their answers to the questionnaire, subjects were classified as "very active" if they answered "yes" to questions 3 and 4, "moderately active" if they answered "yes" to question 3 and "no" to question 4, "low active" if they answered "no" to question 3 and rated themselves as active as their peers for questions 1 and 2, and "very low active" if they rated themselves as less active than their peers at work and outside of work and answered "no" to question 3. Ainsworth et al[14] reported that data obtained with the Lipid Research Clinics Physical Activity Questionnaire were reliable and valid for predicting cardiorespiratory fitness and body fat. Fifty percent of the women and 60% of the men who volunteered for this study reported engaging in strenuous exercise or hard physical labor at least once a week.

The second questionnaire was the ODQ.[15] This instrument was selected so that we could describe the disability level of our subjects with CLBP for the purpose of comparing our results with those of other studies. Subjects completed a self-report that resulted in an index of a patient's perceived disability based on 10 areas of limitation in performance. Each section was scored on a

6-point scale (0–5), with 0 indicating no limitation and 5 indicating maximal limitation. The combined subscales add up to a maximum score of 50. The score was doubled and interpreted as a percentage of patient-perceived disability: the higher the score, the greater the patient's disability. Although the ODQ is described as a disability index, the questionnaire enables the investigator to examine the measures of impairment (eg, pain), functional limitations (eg, sitting, standing, lifting), and disability (eg, personal care, sex life, traveling).

The reliability and validity of scores obtained with the ODQ have been described by Fairbank et al.[16] A group of 25 patients with an initial episode of acute low back pain demonstrated a near-linear decrease in their mean ODQ score in a 3-week interval. These authors suggested the ODQ yielded reliable estimates of back pain disability. Twenty-two patients with CLBP completed the ODQ at the same time on 2 consecutive days; the test-retest reliability was estimated by the Pearson product-moment correlation coefficient (r=.99). Grönblad et al[17] also examined the reliability for the ODQ in 20 patients with CLBP who completed the ODQ on 2 separate occasions 1 week apart. The test-retest reliability of the disability assessments was estimated by the intraclass correlation coefficient (ICC=.83). These findings suggest that the ODQ provides valid and reliable measurements for predicting disability due to low back pain.

Body Mass Index

We defined *body mass index* as the ratio of weight (in kilograms) divided by height squared (in square meters).[18] Subjects were classified as underweight if the BMI was less than or equal to 20, as having normal weight if the BMI was greater than 20 but less than or equal to 25, as overweight if the BMI was greater than 25 but less than or equal to 30, and as obese if the BMI was greater than 30.[19]

Physical Activity Status

The physical activity status is a categorical variable with 4 levels (very low, low active, moderate, and highly active). Because only 2 subjects rated themselves as very low active and 5 subjects rated themselves as moderately active, the stability of any model containing categorical variables for levels would be questionable. Therefore, the physical activity status was collapsed to 2 levels. Subjects were classified as either low active (very low to low active on the original scale) or active (moderately to highly active).

Examiners

Measurements were made by 2 of the authors (JWY and TRG), who each had at least 25 years of teaching and clinical experience in physical therapy. Some measurements required the combined effort of both examiners.

Procedure

After the questionnaires were completed, all subjects changed from their street attire into shorts (men) or shorts and a gown (women) to provide adequate exposure of the low back and abdomen. The body height (in inches) and weight (in pounds) of each subject were measured with a standard clinical scale.* The accuracy of this device was checked on a weekly basis. The 2 examiners then measured the following 6 variables: (1) angle of pelvic inclination in a standing position, (2) magnitude of the lumbar lordosis in a standing position, (3) lumbar flexion ROM in a sitting position, (4) lumbar extension ROM in a prone position, (5) length of anterior hip joint soft tissues in a supine position, and (6) force of abdominal muscles in a supine position. Youdas et al[7] described the specific procedure for obtaining measurements of each of these variables.

Measurement of pelvic inclination. Pelvic inclination was measured using an inclinometer (the Back Range of Motion [BROM] II†) and a platform device to control postural sway. Each subject stood barefoot on the platform and was asked to assume a comfortable, erect posture, with body weight evenly distributed between both feet.

Measurement of lumbar lordosis. Lumbar lordosis was measured with a flexible curve† molded to the contour of the subject's lumbosacral spine. Sites along the flexible curve that intersected with adhesive dots marking the spinous processes of T-12, L-4, and S-2 were marked with twist-ties attached to the flexible curve. The shape of the curve's outline was traced on a piece of posterboard, and marks corresponding to the spinous processes were made along the curve's contour. Quantification of the curve (in degrees) was done with a previously described technique that involved drawing tangent lines to the curve at the points representing the spinous processes of T-12, L-4, and S-2.[20] Intersections of the 3 tangent lines to the curve at the points representing the spinous processes of T-12, L-4, and S-2 were measured with a protractor, and the sum of the 2 angles was the estimate of the magnitude of the lumbar lordosis.[21]

Measurement of lumbar spine flexion. Peak lumbar flexion ROM was also obtained with the flexible curve. With feet flat on the floor and spread to shoulder width, each subject bent the trunk forward, attempting to place the head between the knees. The flexible curve was molded to the contour of the lumbar spine, and its shape subsequently transferred by tracing it onto a piece of posterboard. The curve was quantified (in degrees)

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* Continental Scale Corp, Bridgeview, IL 60455.

† Performance Attainment Associates, 958 Lydia Dr, Roseville, MN 55113.

using the technique of tangent lines and measuring the angle with a protractor.

Measurement of lumbar spine extension. Peak lumbar extension ROM was obtained with the subject positioned prone. The subject performed a press-up by placing the palms of the hands at shoulder width, pushing against the table, and passively extending the lumbar spine. The flexible curve was molded to the contour of the subject's lumbar spine. The magnitude of the lumbar extension ROM was obtained by tracing the curve on a piece of posterboard; drawing tangent lines to the marks for spinous processes T-12, L-4, and S-2; and calculating the angles (in degrees) with a protractor.

Measurement of length of one-joint hip flexor muscles. The procedure to reflect the length of the one-joint hip flexors was patterned after the procedure described by Kendall et al.[1] This angular measure was an indirect measurement of muscle length. The subject was initially positioned supine on the treatment table with the hips and knees straight and arms folded across the chest. When assessing the right-side one-joint hip flexors, the examiner passively flexed the subject's left knee so the calf rested against the posterior thigh. The right trunk-thigh angle was obtained with a 360-degree universal goniometer. The angle was used to reflect muscle length.

Measurement of abdominal muscle force. Abdominal muscle force was measured with the subject positioned supine on a padded wooden treatment table according to a technique originally described by Kendall et al[1] and subsequently used by other investigators.[5–7] An examiner passively elevated the subject's fully extended legs to a point not exceeding 90 degrees of hip flexion. The subject lowered the legs to the tabletop at the start of a 10-second count, using an eccentric contraction of the hip flexors. During leg lowering, the subject attempted to keep the lumbar spinous processes pressed tightly against the tabletop by maintaining the pelvis in a posterior tilt. Abdominal muscle force was reflected by the angle at the point where the lower back began to extend and the lumbar spinous processes were no longer in contact with the examiner's fingertips. We believe this position change indicated that the abdominal muscles could no longer hold the pelvis in a posterior tilt in response to the ever-increasing external extension moment acting on the lumbar spine primarily through the pull of the psoas major muscles.

For this study, 2 measurements, as described by Youdas et al,[7] of each variable were obtained from each subject to permit estimation of intratester reliability in the subjects with CLBP. The time between successive measurements was generally between 2 and 3 minutes. Red adhesive dots used to mark the spinous processes of T-12, L-4, and S-2 were removed after the first examination and replaced by fresh dots before the second examination. The measurement scale of the universal goniometer was blinded from the examiner, and the recorder wrote down the results without conveying any feedback to the examiner. The goniometric measurements did not require the examiner to make any marks on the subject's skin surface. A precursor to answering the main questions was the need to establish the reliability of measurements of the 6 major attributes described in this section.

Table 3.
Intratester Reliability for Measurements in Patients With Chronic Low Back Pain

Variable	ICC (1,1)[a]
Pelvic inclination	.97
Standing lumbar lordosis	.93
Lumbar extension range of motion	.90
Abdominal muscle force	.92
Lumbar flexion range of motion	.91
One-joint hip flexor muscle length	
Right	.60
Left	.54

[a] Intraclass correlation coefficient (ICC [1,1]) estimates the reliability of a single measurement made by the tester.

Except for the indirect measurement of length of the right and left one-joint hip flexors (.60 and .54, respectively), all ICCs were greater than .89 (Tab. 3). The ICC for lumbar extension ROM in the prone position was initially calculated as .73. However, this relationship was highly influenced by 4 outliers. These outliers occurred because the subjects' efforts were inconsistent between the first and second measurements of lumbar extension. Two subjects improved by 16 and 31 degrees, whereas 2 subjects became worse by 14 and 27 degrees. On eliminating these 4 measurements, the remaining 56 measurements yielded an ICC (1,1) of .90.

Estimates of the ICC depend on the heterogeneity of the individuals; greater heterogeneity gives larger values of the ICC. In this study, the range of values for hip flexor muscle length was narrow, so we augmented the ICC using a graphic technique proposed by Bland and Altman.[22,23] For each of the 60 subjects, we plotted the algebraic difference between the first and second measurements of hip flexor muscle length (y-axis) versus the mean value (x-axis) for the 2 measurements for the right extremity. For the right lower extremity, the length of the one-joint hip flexors obtained on the second measurement varied from 2 degrees above to 2 degrees below that of the first measurement. For the left lower extremity, the second measurement varied from 2 degrees above to 4 degrees below the value of the first

Table 4.
Descriptive Data for Men and Women With Chronic Low Back Pain Regarding Their Self-Reports of Levels of Physical Activity

		Men (n=30)		Women (n=30)	
Item	**Response**	**No.**	**%**	**No.**	**%**
Rate your level of physical activity	Very low active	2	7	3	10
	Low active	5	17	12	40
	Moderately active	5	17	4	13
	Very active	18	60	11	37

measurement. On the basis of the ICCs and the Bland-Altman graph, we found all measurements to be reproducible.

Data Analysis

Our study had 2 parts: (1) examining the relationships among variables for people with CLBP and (2) using an unmatched case-control study to determine the relationship of predictor variables to CLBP.

Relationships among variables for subjects with CLBP. Only the right trunk-thigh angle for estimating the lengths of the one-joint hip flexor muscles was used in the modeling, because the values for left and right sides were highly correlated (r=.66, P=.0001).

Sex was the strongest predictor of pelvic inclination and lumbar lordosis and was highly correlated (P<.0001) with the other independent variables. Therefore, assessment of what other variables might be associated with sizes of lumbar lordosis and pelvic inclination was performed separately for men and women.

The Pearson product-moment correlation coefficient was used to assess the association between lumbar lordosis and degree of pelvic inclination for both men and women. For men (n=30) and women (n=30), each dependent variable was plotted against the 2 measurements (pelvic inclination and lordosis). Following the suggestions of Chambers et al,[24] the plots were augmented with a smooth curve to help reveal the pattern of association. The Spearman rank order correlation and associated probability value were used to test for an association between the predictor and pelvic inclination or lumbar lordosis, respectively. Multivariate associations were examined using forward and backward stepwise regression. The study had 80% power to detect a correlation of .35 or greater between a covariate and the response.

Comparing subjects with and without CLBP. Descriptive statistics for men and women with and without CLBP were compared using the Wilcoxon rank sum test. To examine the relationship of predictor variables to the likelihood of CLBP, the current and prior data sets were analyzed together as an unmatched case-control study. We felt justified in combining the 2 data sets, because their inclusion criteria were identical except the second data set was composed of volunteers with CLBP. Both groups of men and women contained 75 subjects: 30 subjects with CLBP and 45 subjects with healthy backs.

Both univariate and multivariate relationships were examined using the logistic regression model[25]:

$$\begin{aligned} \textit{Log}\,(\mathrm{p}/1-\mathrm{p}) = {} & \beta_0 + \beta_1\,(\textit{weight}) + \beta_2\,(\textit{height}) \\ & + \beta_3\,(\textit{abdominal muscle force}) \\ & + \beta_4\,(\textit{standing lumbar lordosis}) \\ & + \beta_5\,(\textit{pelvic inclination}) \\ & + \beta_6\,(\textit{lumbar extension ROM}) \end{aligned}$$

where p is the probability that a subject is a member of the CLBP group, given a set of 6 covariates: weight, height, abdominal muscle force, standing lumbar lordosis, pelvic inclination, and lumbar extension ROM. The β_1 through β_6 coefficients quantify the relationship between each covariate and CLBP. Nonlinear relationships were explored using generalized additive models (GAMs), an extension of the logistic model in which selected linear terms, β_1 (weight) for example, are replaced by a smooth function S (weight), which can be displayed graphically.[23] The modest size of the study makes confidence limits on the smooth functions large. Nevertheless, investigation of possible nonlinearity is an important component of any data analysis.

The smooth functions, S(x), are based on splines. The amount of "wiggle" in the smooth function is controlled by the degrees of freedom (df) for the fit. For a fit with Kdf, place K push pins onto the plot of the data and then spread through them a resilient, flexible metal strip or "spline," attaching it to each of the pins. Two degrees of freedom (pins) lead to a straight line, 3 degrees of freedom lead to a curve with one bend, and *n* degrees of freedom lead to a curve that intersects every data point. In this analysis, we used 4 degrees of freedom for the smooth terms. All data analyses were performed using the SAS[‡] and S-PLUS[§] statistical packages.

[‡] SAS Institute Inc, PO Box 8000, Cary, NC 27511.

[§] MathSoft Inc, StatSci Division, 1700 Westlake Ave, Seattle, WA 98109.

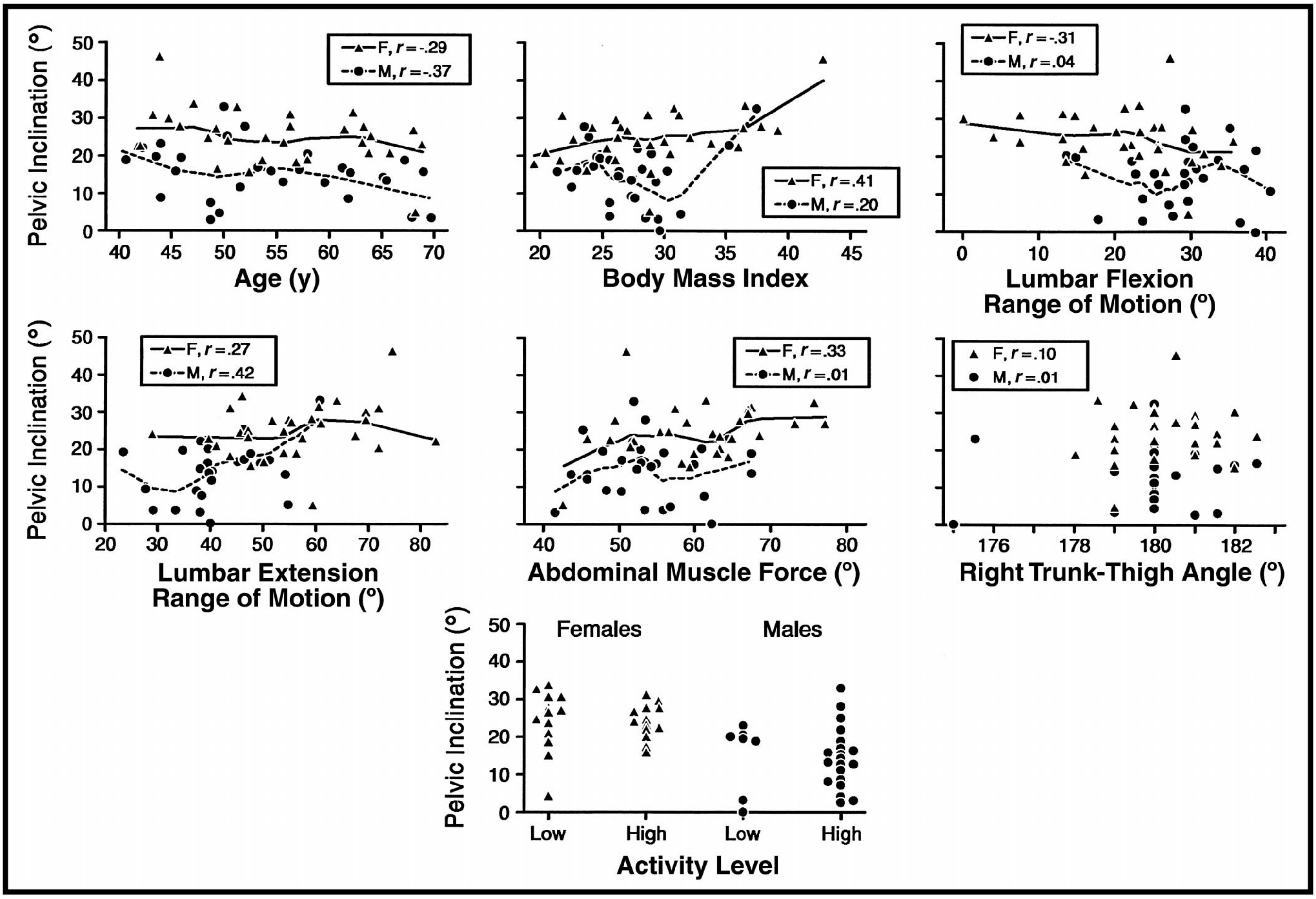

Figure 1.
Plot of standing pelvic inclination versus 7 independent variables for both men and women with chronic low back pain. Except for physical activity level, the Spearman rank order correlation coefficient estimates the relationship between standing pelvic inclination and each independent variable.

Results

Relationships Among Variables in Patients With CLBP

Physical activity level and ODQ scores. Descriptive data for both men and women about their responses to the self-report of physical activity are given in Table 4, and information about CLBP in men and women is given in Tables 1 and 2, respectively. The mean ODQ score was 15% (SD=9.5) for men, whereas the mean ODQ score was 26.7% (SD=9.7) for women. Frost et al[26] examined the effectiveness of a supervised fitness program in retarding physical and psychological deconditioning in patients with CLBP. The mean baseline ODQ score for the fitness group was 23.1% (SD=9.5%), whereas the control group had a mean baseline ODQ score of 24.9% (SD=12.8%). After 6 months of intervention, the mean ODQ score for the fitness group was 16.0% (SD=9.2%), whereas the mean ODQ score for the control group was 21.7% (SD=14.2%). These values are comparable to ours, which suggests that our data are generalizable to other reports of patients with CLBP.

Lumbar spine ROM/abdominal muscle force/length of hip flexors. Descriptive statistics of the measurements of standing lumbar lordosis and angle of pelvic inclination and the associated measurements of lumbar flexion and extension ROM, force of abdominal muscles, and length of hip flexor muscles for men and women are given in Tables 1 and 2, respectively.

Pelvic inclination versus predictor variables. Figure 1 illustrates the plot of standing pelvic inclination versus each independent variable for both men and women. The Spearman rank order correlation coefficients for men varied from .01 for both abdominal muscle performance and right trunk-thigh angle to .42 for lumbar extension ROM in the prone position. Age (r=.37) and lumbar extension ROM (r=.42) demonstrated an association with pelvic inclination. The correlation coefficients for women varied from .10 for right trunk-thigh angle to .41 for BMI; BMI (r=.41) showed an association with pelvic inclination. There was no observable relationship between standing pelvic inclination and physical activity level.

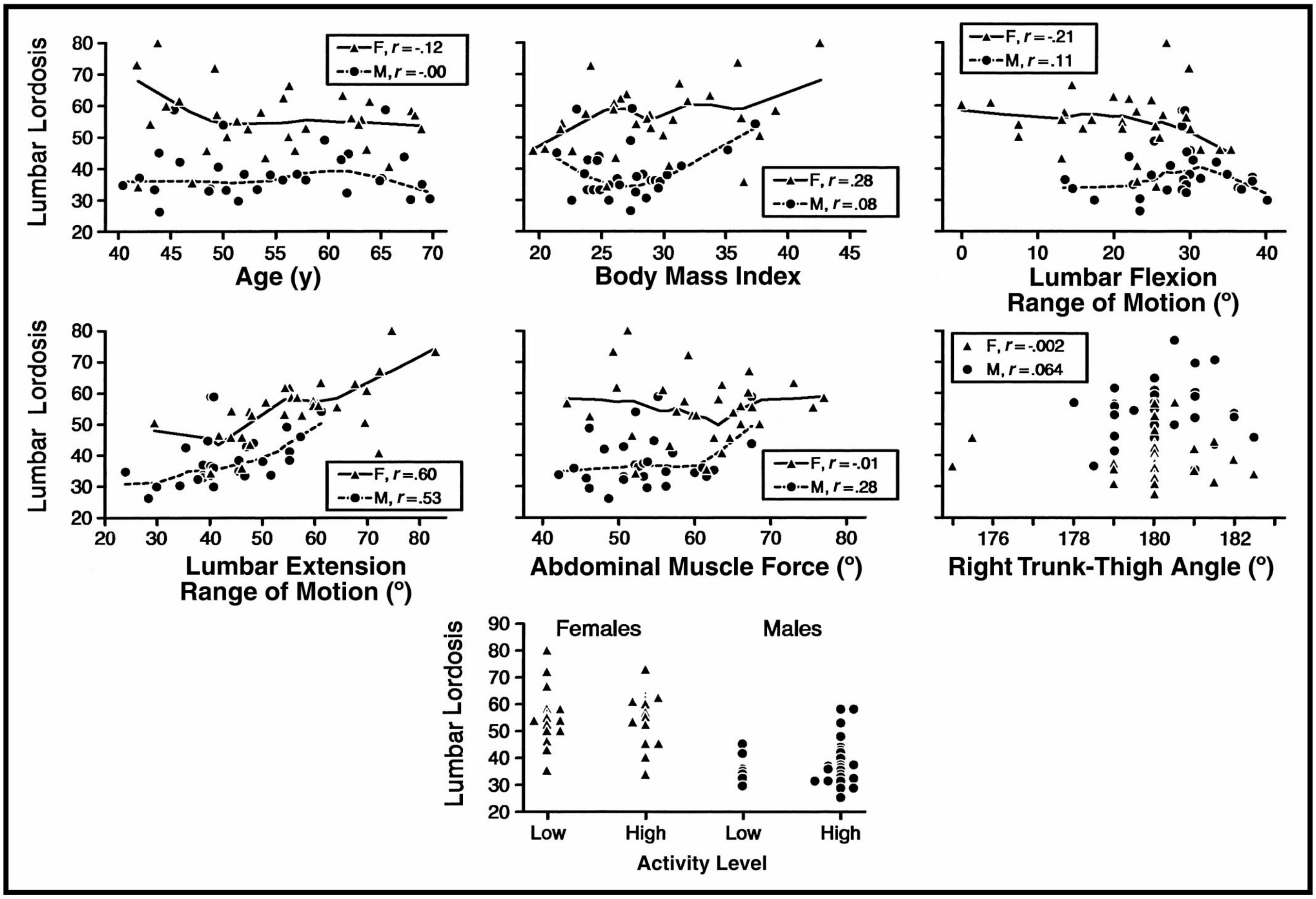

Figure 2.
Plot of standing lumbar lordosis versus 7 independent variables for both men and women with chronic low back pain. Except for physical activity level, the Spearman rank order correlation coefficient estimates the relationship between standing lumbar lordosis and each independent variable.

Standing lumbar lordosis versus predictor variables. Figure 2 displays the plot of standing lumbar lordosis versus each independent variable. Spearman rank-order correlation coefficients for men varied from 0 for age to .53 for lumbar extension ROM. The correlation coefficients for women varied from .002 for right trunk-thigh angle to .60 for lumbar extension ROM. For both men (r=.53) and women (r=.60), there was an association between lumbar extension ROM and lumbar lordosis. No relationship between standing lumbar lordosis and physical activity was found.

Univariate and stepwise models. Univariate and stepwise models were used for men and women separately for the dependent variables pelvic inclination and standing lumbar lordosis. The 8 independent variables under consideration were age, BMI, lumbar flexion ROM, lumbar extension ROM, abdominal muscle force, right trunk-thigh angle, physical activity level, and ODQ scores.

Pelvic inclination. In women, BMI, age, and ODQ scores were associated univariately and multivariately with pelvic inclination (Tab. 5). Once they were accounted for, however, no other variables were significant in the multiple regression model. In men, lumbar extension ROM was related to pelvic inclination. When lumbar extension ROM was accounted for, both age and ODQ scores were significant in the stepwise model.

Lumbar lordosis. For standing lumbar lordosis (Tab. 5) in men and women, lumbar extension ROM in the prone position was related univariately. When this was accounted for, no other variables were significant in the stepwise model. For men and women, the Pearson product-moment correlation coefficient was calculated to express the linear association between the angle of pelvic inclination and the standing lordotic curve (r=.31 for women, r=.37 for men).

Comparing Subjects With and Without CLBP

Descriptive statistics. Descriptive statistics for men with CLBP (n=30) and men without CLBP (n=45) were compared (Tab. 1) by the Wilcoxon rank sum test. The subjects with CLBP demonstrated weaker abdominal

Table 5.
Univariate and Multivariate Output for the Association of the Variables of Interest and Pelvic Inclination and Lumbar Lordosis in a Standing Position for Men and Women With Chronic Low Back Pain

	Pelvic Inclination				**Standing Lumbar Lordosis**	
	Univariate Model		**Multivariate Model**		**Univariate Model**	
Variable	R^2	P	R^2	P	R^2	P
Women						
Age	.135	.046	.469	.015	.016	.505
Body mass index	.215	.010		.010	.109	.074
Lumbar flexion range of motion	.048	.243		NS[a]	.027	.390
Lumbar extension range of motion	.070	.157		NS	.336	.001
Abdominal muscle force	.079	.134		NS	.004	.752
Trunk-thigh angle, right	.017	.487		NS	.007	.668
Physical activity level	.007	.652		NS	.005	.702
Oswestry Back Pain Disability Questionnaire	.165	.026		.039	.026	.396
Men						
Age	.127	.053	.428	.029	0	.993
Body mass index	.002	.801		NS	.030	.358
Lumbar flexion range of motion	.0001	.962		NS	.005	.722
Lumbar extension range of motion	.204	.012		.012	.199	.013
Abdominal muscle force	.0001	.960		NS	.101	.087
Trunk-thigh angle, right	.010	.604		NS	.001	.863
Physical activity level	.002	.820		NS	.009	.620
Oswestry Back Pain Disability Questionnaire	.046	.256		.050	.0003	.928

[a] NS=not significant.

muscles (from 53.9° to 39.4°) and had less lumbar extension ROM (from 42.7° to 50.1°) during a prone press-up than men without CLBP. The BMI (from 28.9 kg/m^2 to 26.1 kg/m^2) and weight (from 76.7 kg to 67.8 kg) were greater and right (from 180.2° to 180.9°) and left (from 180.4° to 181.6°) trunk-thigh angles and abdominal muscle force were less in women with CLBP (Tab. 2) than in women without CLBP.

Generalized additive models. The GAMs for men and women were studied separately using the variables weight, height, abdominal muscle force, lumbar lordosis, pelvic inclination, and lumbar extension ROM. Height and weight were selected rather than BMI because they had a greater effect than BMI alone. Right and left trunk-thigh angles were excluded because we failed to detect hip flexion deformity in either the control group or the experimental group. Age was excluded from the model because it was not related univariately to back pain for men or women. Figure 3 shows the plot of the odds ratio of CLBP versus each independent variable for the men. The final model for men was: $\log[P/(1-p)]=\alpha$ + weight + S (height) + abdominal muscle force + S (standing lumbar lordosis) + S (pelvic inclination) + lumbar extension ROM. Height, standing lumbar lordosis, and pelvic inclination demonstrated a nonlinear relationship. Figure 4 shows the plot of the odds ratio of CLBP versus each independent variable for the women. The final model for women was: $\log[P/(1-p)]=\alpha$ + weight + height + abdominal muscle force + standing lumbar lordosis + pelvic inclination + lumbar extension ROM. All relationships for women were linear. If the odds ratio is 1, then the control subjects are just as likely to experience back pain as those with CLBP. An odds ratio of less than 1 indicates that the subjects are less likely to experience back pain, whereas an odds ratio of greater than 1 indicates that subjects are more likely to have CLBP.

Discussion

Issues of Intratester Reliability for Patients With CLBP

The procedures we used for obtaining measurements of standing lumbar lordosis and abdominal muscle force were quite similar to those described by Heino et al,[6] although our measurements were obtained from patients with CLBP. Heino et al[6] reported ICCs of .89 and .94 for measurements of standing lumbar lordosis and abdominal muscle force, respectively. Initially, lumbar extension ROM in the prone position had an ICC of .73; however, this estimate was influenced by 4 outliers. Two subjects improved by 16 and 31 degrees between the first and second measurements, whereas another 2 subjects varied by −11 and −27 degrees between their first and second measurements. We attributed this large error component to the subjects' inconsistency in movement and not to tester error. We felt justified in elimi-

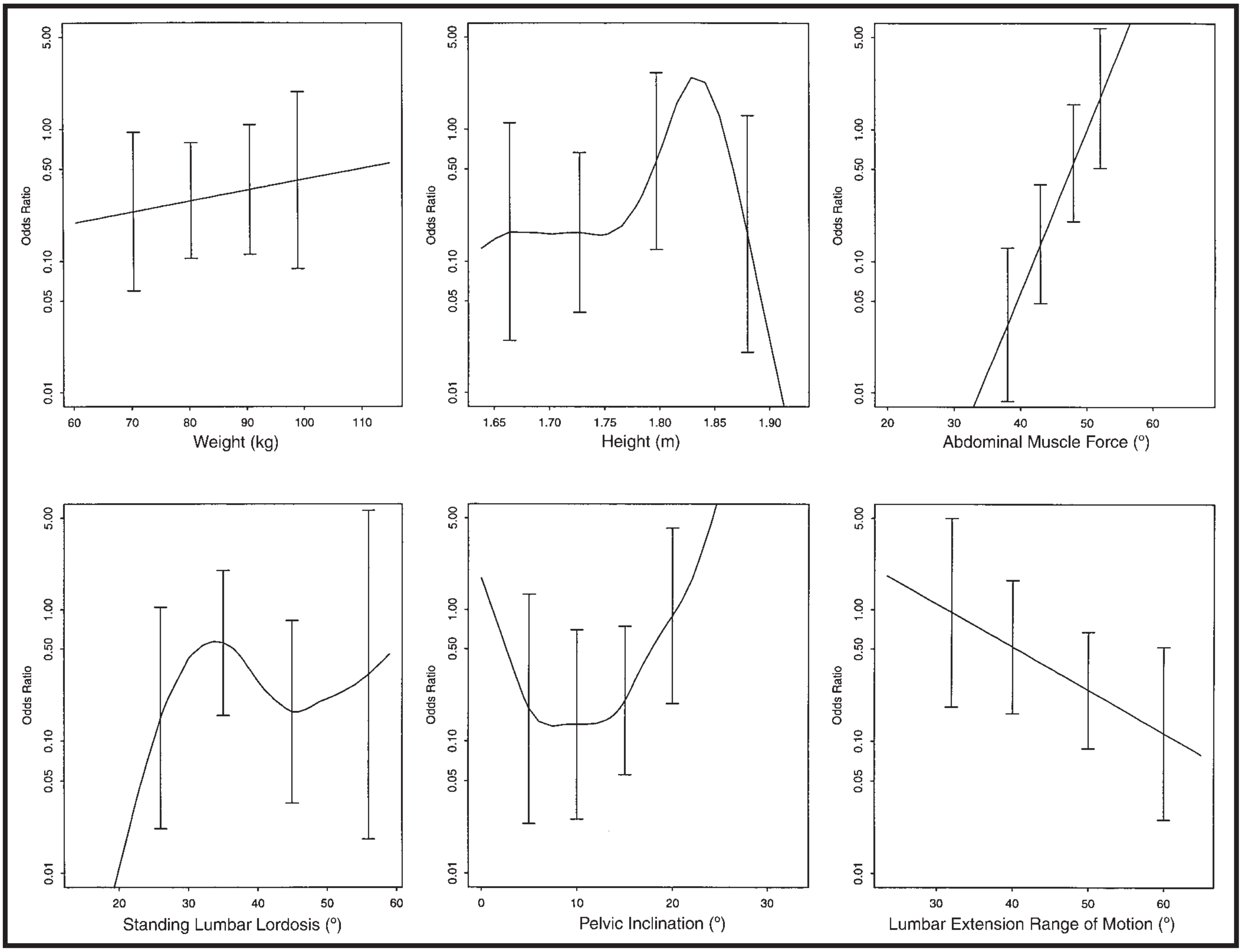

Figure 3.
Plot of the odds ratio of chronic low back pain (CLBP) versus 6 independent variables for men with CLBP (n=30) and without CLBP (n=45). The vertical lines represent the 95% confidence interval bars.

nating the 4 outliers from the calculation of ICC for lumbar extension ROM in the prone position.

Relationships Among Variables in Patients With CLBP

Issues involving the ODQ. The mean ODQ score for the men was 15%, which according to Fairbank et al[16] represents minimal disability due to CLBP, whereas the mean ODQ score for women was 26.7% and represents moderate disability. According to Fairbank et al,[16] the men in this study should be able to cope with the majority of daily activities (with proper education on how to lift and sit) and maintain a more active lifestyle. In contrast, the women, according to Fairbank et al,[16] should experience more pain with lifting, sitting, and standing and may miss work. Nevertheless, their CLBP usually can be managed by conservative treatment.

Issues involving abdominal muscle force. Contrary to often-expressed opinions,[1–4] our data failed to suggest an association between abdominal muscle force and angle of pelvic inclination or lumbar lordosis in relaxed standing in men and women with CLBP. This observation seems counterintuitive to the idea that the abdominal muscles, by pulling upward on the pelvis anteriorly, should have a major effect on the lumbar lordotic curve or angle of pelvic inclination. Some authors have suggested that weak abdominal muscles alter the normal standing postural alignment such that those patients with CLBP demonstrate a visible increase in the standing lumbar lordosis and pelvic inclination.[1–4]

We argue that assessment of standing postural alignment alone should not be used to prescribe therapeutic strengthening and stretching exercise programs for the trunk muscles in patients with CLBP. Instead, the physical therapist should perform additional tests and measurements to assess the force of the abdominal muscles and the ROM of the lumbar spine.

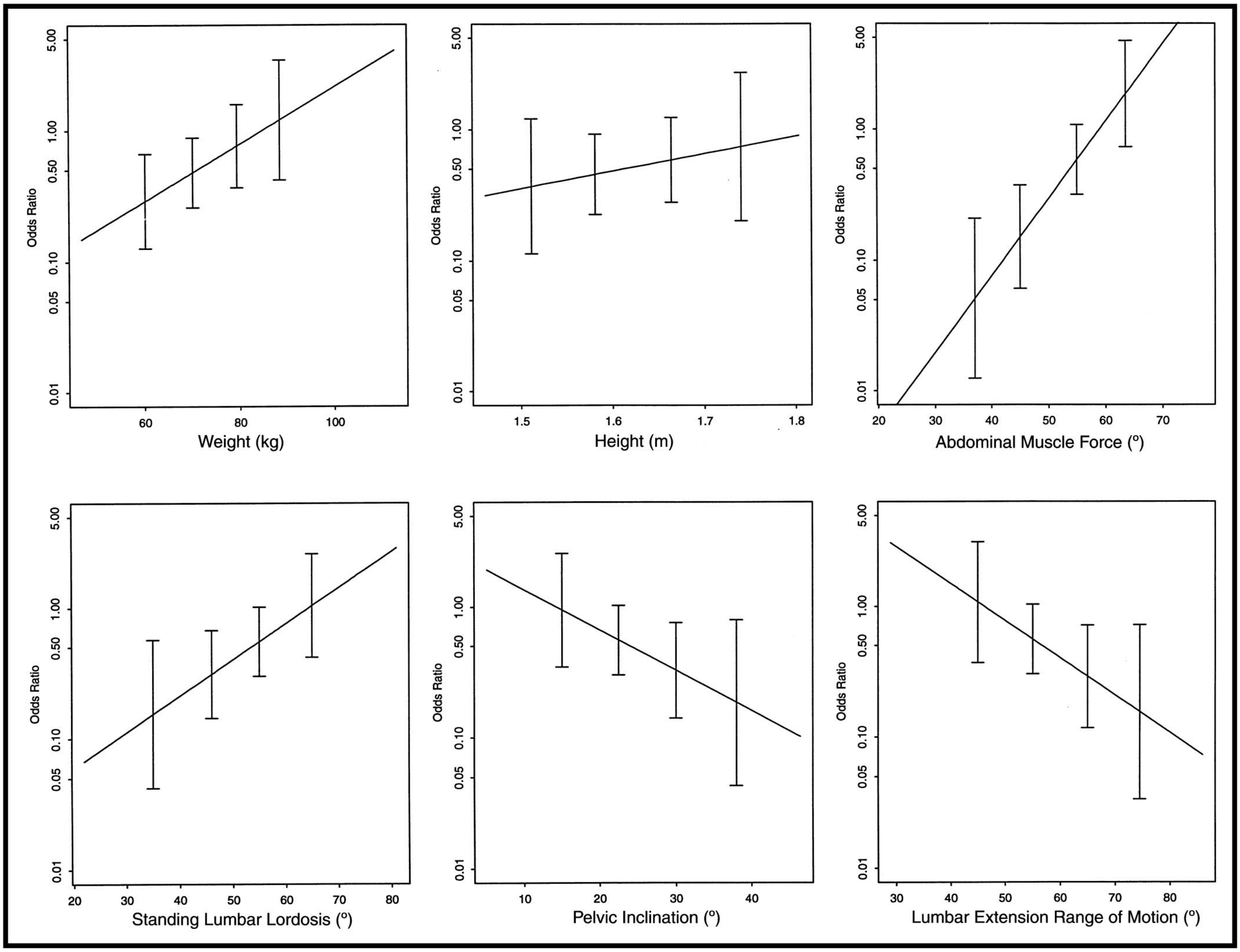

Figure 4.
Plot of the odds ratio of chronic low back pain (CLBP) versus 6 independent variables for women with CLBP (n=30) and without CLBP (n=45). The vertical lines represent the 95% confidence interval bars.

Issues involving standing lumbar lordosis and lumbar ROM. Peak prone lumbar extension ROM was univariately and multivariately associated with standing lumbar lordosis for both the men and women. For both groups, the magnitude of standing lumbar lordosis was generally equivalent to the amount of prone back extension. Our data suggest that, at least in patients with moderate disability due to CLBP, the magnitude of the standing lumbar lordosis is equivalent to peak passive lumbar extension in a prone position.

Descriptive Statistics for Comparisons of Subjects With and Without CLBP

Abdominal muscle force. According to our data, men and women with CLBP had weaker abdominal muscles than their counterparts without low back pain. This finding is consistent with other reports that documented weakness in the abdominal muscles of subjects with CLBP.[27–29] It is possible that the poor abdominal muscle force, as measured by the double-leg lowering test, was influenced by pain inhibition rather than being a true decrease in muscle force. This was a potential source of error in this study and is a limitation in any study that measures muscle force in patients with pain.

Standing lumbar lordosis. Neither the women nor the men with CLBP demonstrated an increased lumbar lordotic curve or angle of pelvic inclination compared with the control subjects. Day et al[30] also reported no difference in lumbar lordosis and pelvic inclination in relaxed standing between 32 men without low back pain and 15 men with at least a 3-year history of CLBP. Likewise, Pope et al[31] found no difference in the magnitude of lumbar lordosis between 106 adults without low back pain and 215 patients with CLBP.

According to our data, women had a larger mean value for standing lumbar lordosis than men. Using the flexible curve method, our mean value (±SD) for standing lumbar lordosis (37.5°±11°) in 30 men without low back pain, aged 40 to 69 years, was comparable to that from Link et al,[32] who examined 61 men without low back pain, aged 20 to 30 years, and reported a mean value of 34.4±9.85 degrees. Frey and Tecklin[33] also used the flexible curve technique and reported a mean value of 31.2±14.8 degrees for standing lumbar curvature in 44 subjects without low back pain (22 men and 22 women) whose mean age was 20±2 years. In contrast, the magnitude of lumbar lordosis as measured by the flexible curve is much smaller when compared with values obtained by radiographic techniques. Pope et al[31] reported a mean value of 54±11.9 degrees for standing lumbar curvature in 106 subjects without low back pain and a mean value of 53±8.8 degrees for standing lumbar curvature in 144 subjects with moderate low back pain, whereas Jackson and McManus[34] reported mean values (±SEM) of 60±12 degrees for 100 adults without low back pain and 56.3±12 degrees for 100 patients with CLBP.

Lumbar spinal mobility. The effect of CLBP on spinal ROM is not clear. Some investigators[35,36] have reported that spinal ROM is diminished in patients with CLBP. In contrast, Esola et al[37] reported that patients with CLBP had no less spinal flexion ROM than their counterparts without low back pain. Our results indicated that there was no difference in spinal flexion in both men and women between the subjects with CLBP and the control subjects. Furthermore, women with CLBP had no less lumbar extension ROM from a prone position than their counterparts without low back pain, yet men with CLBP had less lumbar extension ROM than the men without low back pain. This finding is consistent with results reported by Pope et al,[31] who also noted diminished lumbar extension ROM in 215 patients with CLBP compared with 106 control subjects. Our data also indicated that peak lumbar extension ROM for both subjects with CLBP and control subjects was considerably greater than peak flexion ROM. Our results are similar to values reported by Troup et al.[38]

Generalized Additive Models

Through the use of a graphically oriented analytic approach (GAM), we were able to demonstrate some clear patterns regarding the odds ratio of developing CLBP in subjects with minimal to moderate disability according to the ODQ. For both men (Fig. 3) and women (Fig. 4), the odds of developing CLBP decreased as body weight decreased. In terms of height, the odds of having CLBP increased considerably for both men and women above 1.8 m. This relationship was nonlinear for men, as the odds ratio for CLBP was greater than 1 for heights between 1.8 and 1.85 m; however, the ratio diminished sharply thereafter. Men were less likely to have CLBP if their abdominal muscle force, measured by the double-leg lowering test, was less than 50 degrees; for women, we found that the odds ratio of having CLBP was reduced when the abdominal muscle force was less than 60 degrees. These values indicate the point where the lower back began to extend and lumbar spinous processes were no longer in contact with the examiner's fingertips during the double-leg lowering test. In regard to standing lumbar lordosis, the odds ratio of CLBP in women increased once the lumbar curve exceeded 65 degrees. For men, this relationship was nonlinear and the peak lumbar lordosis for subjects with and without CLBP was 60 degrees. For both men and women, the odds of having CLBP was greater with angles of pelvic inclination near 0 degrees. According to our data, the odds ratio of not having CLBP increases in women if the angle of pelvic inclination is greater than 20 degrees. In contrast, for men, the odds ratio for having CLBP increases substantially if the angle of pelvic inclination is greater than 20 degrees. Lastly, both men and women are less likely to have CLBP as passive lumbar extension ROM in the prone position increases. The critical value for men was 30 degrees, whereas the critical value for women was 45 degrees.

Limitations

Our findings regarding the relationships between the independent variables and standing lumbar lordosis and pelvic inclination in patients with CLBP are based on findings from patients with minimal to moderate disability according to the ODQ. Subjects with more severe impairment may demonstrate a stronger relationship between abdominal muscle force and the dependent variables lumbar lordosis and pelvic inclination.

We chose the double-leg lowering test to assess abdominal muscle force because it is familiar to physical therapists. Previous investigators[5–7] used this test; although it is complex and requires good neuromuscular control, these investigators documented acceptable intratester reliability in patients with CLBP and their counterparts without low back pain. Nevertheless, physical therapists lack an estimate of the validity of measurements obtained with the double-leg lowering test if it is supposed to be used to predict the size of a subject's lumbar lordosis in standing knowing the grade assigned to the abdominal muscle force.[39] In our study, men and women with CLBP statistically demonstrated less force in the abdominal muscles than their counterparts without low back pain. Such weakness may be attributed to low back pain caused by increased abdominal pressure created during the double-leg lowering test.

Another limitation of our study was the use of subjects with CLBP who were not receiving medical treatment at the time the study was conducted. Patients with acute low back pain or CLBP who are receiving medical care may present different findings than our subjects. Furthermore, because our subjects had minimal (men) to moderate (women) disability as a result of CLBP, care must be taken not to generalize our findings to all patients with acute low back pain or CLBP. Furthermore, we also believe there are limitations to using multiple regression analysis with fewer than 10 subjects per covariate; we had 8 covariates and studied 30 men and 30 women. Out findings contribute new information to understanding muscle imbalances associated with standing posture. However, this information should not be considered definitive evidence until additional studies are conducted with larger numbers of subjects.

Conclusion

Repeated measurements of pelvic inclination, lumbar lordosis, abdominal muscle force, lumbar flexion and extension ROM, and length of the one-joint hip flexor muscles made by the same physical therapist using previously well-defined measurement procedures had excellent reliability in 60 subjects with mild to moderate disability due to CLBP. We concluded that these patients with CLBP had no more standing lumbar lordosis or pelvic inclination than their counterparts with healthy backs but that their abdominal muscle force was less than that of the control subjects. None of the linear regression models accounted for much of the variability in angle of pelvic inclination or magnitude of lumbar lordosis in a standing position. In standing subjects, we found a weak association between lumbar lordosis and pelvic inclination. Lumbar extension ROM had a univariate and multivariate association with the magnitude of the lumbar lordosis for both the men and women with CLBP.

Nevertheless, using the GAM analysis, we found that the odds of having CLBP are enhanced as body weight exceeds 100 kg in women and height exceeds 1.8 m for both men and women. Furthermore, the odds ratio of having CLBP is increased if the score on the double-leg lowering test for the abdominal muscles exceeds 50 degrees for men and 60 degrees for women. Additionally, the odds of having CLBP are diminished for both men and women if their passive lumbar extension ROM is greater than 40 degrees.

Abdominal muscle strengthening exercises are routinely recommended by physical therapists to correct faulty standing posture in patients with CLBP. These recommendations are often based on assessment of standing posture. We urge physical therapists to avoid prescribing therapeutic exercise programs of muscle strengthening of abdominal muscles in patients with CLBP based solely on assessment of relaxed standing posture.

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Appendix 1.

Physical Demands Strength Rating[a]

S–Sedentary Work—Exerting up to 10 pounds of force occasionally (occasionally: activity or condition exists up to ⅓ of the time) and/or a negligible amount of force frequently (frequently: activity or condition exists from ⅓ to ⅔ of the time) to lift, carry, push, pull, or otherwise move objects, including the human body. Sedentary work involves sitting most of the time, but may involve walking or standing for brief periods of time. Jobs are sedentary if walking and standing are required only occasionally and all other sedentary criteria are met.

L–Light Work—Exerting up to 20 pounds of force occasionally, and/or up to 10 pounds of force frequently, and/or a negligible amount of force constantly (constantly: activity or condition exists ⅔ or more of the time) to move objects. Physical demand requirements are in excess of those for Sedentary Work. Even though the weight lifted may be only a negligible amount, a job should be rated Light Work: (1) when it requires walking or standing to a significant degree; or (2) when it requires sitting most of the time but entails pushing and/or pulling of arm or leg controls; and/or (3) when the job requires working at a production rate pace entailing the constant pushing and/or pulling of materials even though the weight of those materials is negligible. NOTE: The constant stress and strain of maintaining a production rate pace, especially in an industrial setting, can be and is physically demanding of a worker even though the amount of force exerted is negligible.

M–Medium Work—Exerting 20 to 50 pounds of force occasionally, and/or 10 to 25 pounds of force frequently, and/or greater than negligible up to 10 pounds of force constantly to move objects. Physical Demand requirements are in excess of those for Light Work.

H–Heavy Work—Exerting 50 to 100 pounds of force occasionally, and/or 25 to 50 pounds of force frequently, and/or 10 to 20 pounds of force constantly to move objects. Physical Demand requirements are in excess of those for Medium Work.

V–Very Heavy Work—Exerting in excess of 100 pounds of force occasionally, and/or in excess of 50 pounds of force frequently, and/or in excess of 20 pounds of force constantly to move objects. Physical Demand requirements are in excess of those for Heavy Work.

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Appendix 2.

Lipid Research Clinics Physical Activity Questionnaire[a]

1. Thinking about the things you do at work, how would you rate yourself as to the amount of physical activity you get compared with others of your age and gender?
   a. Much more active
   b. Somewhat more active
   c. About the same
   d. Somewhat less active
   e. Much less active
   f. Not applicable
2. Now, thinking about the things you do outside of work, how would you rate yourself as to the amount of physical activity you get compared with others of your age and gender?
   a. Much more active
   b. Somewhat more active
   c. About the same
   d. Somewhat less active
   e. Much less active
3. Do you regularly engage in strenuous exercise or hard physical labor?
   a. Yes (answer question #4)
   b. No (stop)
4. Do you exercise or labor at least three times a week?
   a. Yes
   b. No

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[a] Reprinted by permisson of Lippincott-Williams & Wilkins from Ainsworth BE, Jacobs DR Jr, Leon AS. Validity and reliability of self-reported physical activity status: the Lipid Research Clinics Questionnaire. *Med Sci Sports Exerc.* 1993;25:92–98.