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Functional Impairment as a Predictor of Spine Loading

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Study Design. Spine loadings during a variety of lifting exertions were compared with individual torso kinematic abilities. Relationships were evaluated between these measures.

Objective. To determine if trunk kinematic status (functional impairment) is indicative of spine loading increases in patients with low back pain (LBP) compared to asymptomatic individuals.

Summary of Background Data. Recurrent LBP is a common and costly problem that may be related to increased spine loads in those individuals with LBP. Previous studies suggest that patients with LBP had greater loading than their asymptomatic counterparts when performing work. However, we know little about how to identify when a patient with LBP can resume lifting tasks without having exaggerated spine loading.

Methods. Sixty-two patients with LBP and 61 who were asymptomatic were evaluated for signs of kinematic compromise (*i.e.*, inability to generate normal trunk kinematic patterns) during a prelift test. All subjects were then asked to perform a variety of lifting exertions that varied in lift origin (region), lift asymmetry position, and weight lifted. An electromyography-assisted model was used to evaluate spine loading in each subject during the lifting exertions. Statistical models were used to assess the relationship between kinematic compromise and spine loading.

Results. Patients with LBP had greater spine loading as well as greater kinematic compromise. The degree of kinematic compromise was related to the degree of spine loading increases in those individuals with LBP. A statistical model was developed that was able to describe 87% of the variability in compression, 61% in anteroposterior shear, and 65% in lateral shear.

Conclusions. Those patients with greater kinematic compromise used higher levels of antagonistic muscle coactivation that not only reduced trunk motion but also resulted in increases in spine loading. Given the degree of kinematic compromise and the lifting task conditions, a method has been devised to predict the increase in spine loading above and beyond that of an asymptomatic individual when performing typical materials handling tasks.

Key words: spinal loads, low back pain, low back disorder, electromyography, lifting biomechanics, musculoskeletal, rehabilitation, recurrent low back pain, secondary low back pain. **Spine 2005;30:729–737**

Few studies have evaluated the costs associated with recurrent low back pain (LBP). However, the limited literature that does exist suggests that recurrent LBP costs are substantial. In a descriptive study of recurrent LBP trends, MacDonald *et al*[1] report that median disability costs associated with recurrent back pain episodes were higher than those for nonrecurrent LBP. Similarly, a recent analysis of the Washington State Workers' Compensation data indicated that "gradual onset" (chronic) back injuries represent two-thirds of the award claims and 60% of lost workdays attributed to back injuries.[2] Likewise, a study performed on low back related workers' compensation claims in Ohio indicated that 16% of the back injuries accounted for 80% of back injury costs.[3] Further evaluations suggested that "these high cost back injuries often result from reinjury of an existing condition." Hence, recurrent low back injuries could represent a rather large and costly problem.

Because of the increased spine loading expected of patients with LBP during lifting exertions,[4,5] it would be desirable to predict the degree to which a particular patient with LBP would increase his/her spine loading given the LBP status so that activity limitations could be quantitatively prescribed. Traditionally, functional capacity assessments have been used to match the abilities of the patient with LBP with task demands to determine when an individual may return to physically demanding activities. A multitude of capacity measures, such as strength and range of motion, have been used to characterize the abilities of the patient with LBP to determine when abilities have returned to normal or determine when the abilities of the patient meet job demands.[6–11] However, these measures do not reflect the underlying changes in spine loading that occur in the individual with LBP that might potentially result in exacerbation of LBP. Thus, a void exists because we have no way to estimate how the extent of LBP impairment relates to the increases in spine loading associated with an exertion.

One potential measure reflecting the status of the patient with LBP and, potentially, spine loading might be trunk kinematics. Trunk kinematics has been related to occupational LBP risk[12–14] as well as spine loading[15–21] in asymptomatic subjects. In addition, during the last decade, there has been a substantial effort to understand the role of trunk kinematics in describing the extent of

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functional impairment associated with LBP.[22–25] These efforts have been able to show that torso *kinematic compromise* is a sensitive indicator of the degree of LBP impairment. The torso kinematic profile is monitored as a function of a patient controlled, free dynamic, flexion extension task exertions (while the trunk is *not* exposed to external loads, *e.g.*, not lifting) and is believed to reflect torso motor recruitment patterns adopted by the patient.[24–26] After adjusting the kinematic measures for individual gender and age, the measure quantitatively reflects the extent of kinematic compromise due to low back impairment. Previous studies have reported excellent sensitivity (92%) and specificity (97%) using these measures to identify patients with LBP.[24]

Thus, this review has indicated that torso kinematics is indicative of LBP impairment. In addition, trunk kinematics has also played a role in spine loading.[27] The goal of the current study was to investigate whether measures of kinematic compromise obtained from a simple kinematic assessment test[24] can be used to predict changes in spine loading (in patients with LBP compared to individuals who are asymptomatic) under realistic lifting exertions expected in a workplace. If successful, simple torso kinematic information might be used to help guide the return of patients with LBP to the workplace without increasing the risk of further back impairment.

■ Methods

Approach. To assess the relationship between individual kinematic status and spine loading, a study was performed in which a kinematic pretest evaluated patients with LBP and asymptomatic individuals for the degree of torso kinematic compromise using a validated kinematic testing methodology. A laboratory study using the same population of subjects evaluated spine loadings for both groups of subjects as they lifted a variety of loads from a spectrum of locations. Kinematic performance measures and lifting condition information were used to develop a model that predicted spine loads for all subjects.

Subjects. One hundred and twenty-three subjects participated in this study. Sixty-two of the subjects (32 males and 30 females) had LBP at testing and were recruited from several medical practices. This group had pain of muscular origin, with median pain duration of 5.5 months. The LBP characteristics of the group are summarized in Table 1. Patients were excluded from the study if physical examination showed signs of lower extremity deficit or hyperflexia. Within the LBP group, 35% reported local back pain only, 52% reported a distribution of 75% back pain and 25% leg pain, and 13% reported an equal distribution of pain between back and leg.

Sixty-one (31 males and 30 females) age-matched asymptomatic (during the previous year), individuals were recruited to perform in the study. Mean (standard deviation [SD]) height of the asymptomatic and LBP groups was 173 (10.7) and 172.9 (9.3) cm, respectively, whereas, mean weight was 77.1 (17.4) and 90.9 (21.1) Kg, respectively, indicating that the LBP and asymptomatic groups were nearly identical in average height but differed in weight and torso dimension, with the LBP group being heavier.

Table 1. Pain and SF (Short Form)-36 Health Survey Results for Patients with LBP

Impairment Measure	Mean	Standard Deviation
Pain level (0 to 10 scale)	5.0	1.9
Duration (months)	10.2	13.6
Million visual analog	68.4	26.6
SF-36 Physical functioning	20.7	5.5
SF-36 Role–Physical	4.8	1.3
SF-36 Bodily pain	6.1	2.2
SF-36 General health	17.9	5.1
SF-36 Vitality	12.2	4.1
SF-36 Social functioning	7.3	2.2
SF-36 Role emotional	4.5	1.3
SF-36 Mental health	20.9	4.9
SF-36 Reported health transition	3.3	0.8

Study Design. All subjects participated in a kinematic status assessment (pretest) as well as a spine loading assessment while lifting loads from a variety of locations.

Kinematic Status Assessment. All subjects performed a kinematic functional assessment test designed to document the trunk motions or kinematic capabilities of each subject. In this test, the trunk motion characteristics of the subjects were documented with a trunk goniometer as subjects flexed and extended their trunk within the sagittal plane at 5 different asymmetries (symmetric, 15° clockwise (CW), 15° counterclockwise (CCW), 30° CW, and 30° CCW) while maintaining their twist position within ± 2° (Figure 1). Visual (computer) feedback was provided to the subjects as they performed the test so that they could restrict motions to the desired plane of motion.

Measures of trunk instantaneous position, velocity, and acceleration were recorded and compared to a previously established normative database of trunk motions.[28] Previous studies have indicated that trunk kinematics, once adjusted for age and gender, are indicative of the degree of low back impairment.[23] In this study, kinematic compromise was operationally defined as the deficit of the subject in low back motion characteristics (kinematics) relative to the expected trunk motions (defined by the normative database) and adjusted as a function of subject gender and age. The kinematic compromise summary measure (*i.e.*, "probability of normal" or p[n]) was used to indicate concisely the degree of low back impairment of an individual compared to the normative database.[23,24] This measure is composed of a combination of sagittal plane range of motion, velocity, and acceleration characteristics, frontal plane and transverse plane motion, as well as the ability to complete the 5 conditions shown in Figure 1. The measure has been thoroughly described previously.[23] The assessment methodology has been independently validated, and reports good sensitivity (92%) and specificity (97%)[24] in the ability to distinguish between individuals with and without LBP, and is considered a quantifiable measure of the extent of a low back disorder impairment.[22–25]

Spine Loading Assessment. The spine loading assessment portion of this study consisted of a laboratory study designed to evaluate the spine loading for a specific subject as he/she lifted under a variety of experimental conditions representing the array of manual materials' handling conditions documented in industrial situations.[13] This phase used a repeated measures, within subject design. The *independent variables* in this study

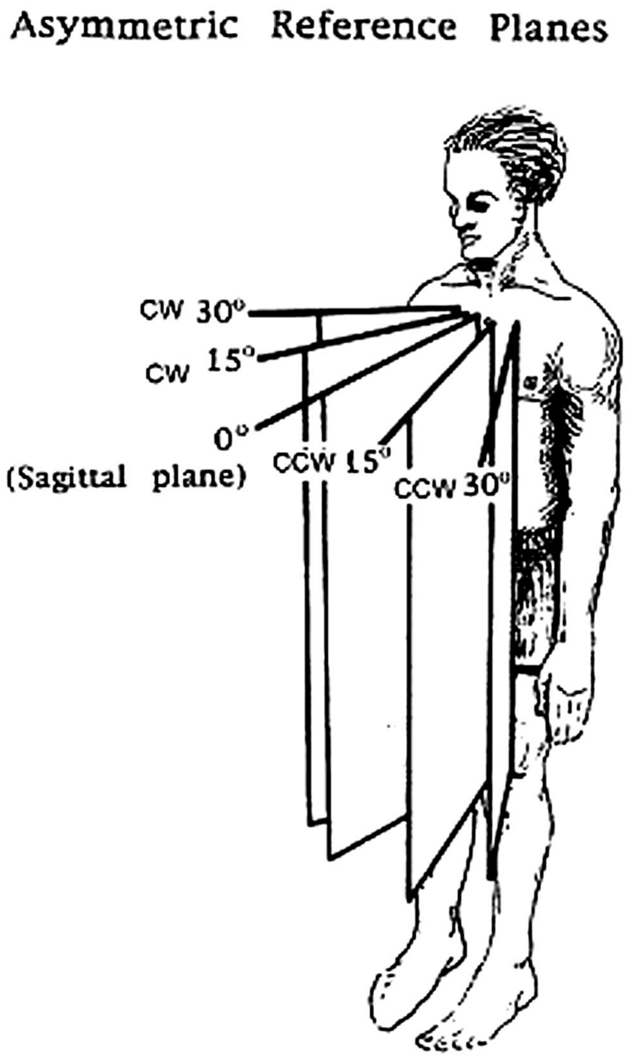

Figure 1. Asymmetric twisting positions for kinematic status assessment. CCW = counterclockwise; CW = clockwise.

were subject group membership (LBP *vs.* asymptomatic), weight lifted, lift origin region, and lift asymmetry position. Four *weights* (4.5, 6.8, 9.1, and 11.4 kg) were lifted under free-dynamic conditions starting from each of 5 *lift origin regions*, varying in vertical height and horizontal distance from the spine (shoulder height at a moment arm distance of 30.5 cm from the spine, waist height at a moment arm distance of 30.5 cm from the spine, knee height at a moment arm distance of 30.5 cm from the spine, far-waist height at a moment arm distance of 61 cm from the spine, and far-knee height at a moment arm distance of 61 cm from the spine (Figure 2). The lifts ended with the body in an upright position, with the weight located at elbow height (elbow angle about 90°). In addition, subjects performed each lift from 5 different symmetric and asymmetric (*lift asymmetry*) positions (Figure 3). The combination of weight lifted, lift origin region, and lift asymmetry were intended to represent the range of lift exertion variable combinations expected of a worker returning to the workplace.[12,13]

The *dependent variables* consisted of the electromyographic (EMG) activity of 10 trunk muscles, trunk and hip kinetic as well as kinematic information, and the resulting spinal loads.

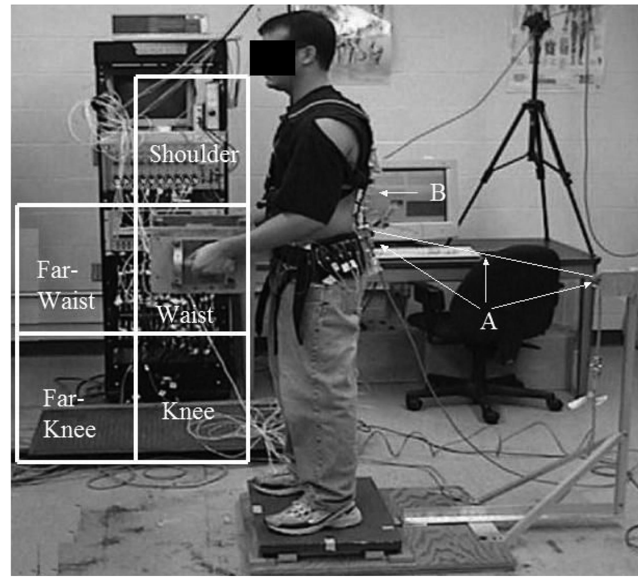

Figure 2. Definitions of the 5 lift origin regions. Subject instrumentation. A = Goniometric system for monitoring position of L5/S1 relative to the force plane. B = The lumbar motion monitor or LMM.

Apparatus. EMG activity was collected with bipolar silver-silver chloride electrodes that have a 4–mm diameter and were spaced approximately 3 cm apart. Electrodes recorded activity at the 10 major trunk muscle sites consisting of right and left muscle pairs of erector spinae, latissimus dorsi, rectus abdominus, external oblique, and internal oblique muscles. EMG preparations and electrode placements were previously described.[29] The raw EMG signals were preamplified, high-passed filtered at 30 Hz, low-passed filtered at 1000 Hz, rectified, and smoothed with a 20-ms sliding window filter. Skin impedances were maintained below 100 KΩ.

EMG calibration normalization was performed using an asymmetric reference frame that isolated the exertions and postures of the torso.[30] Pelvic and leg positions were also controlled using a pelvic support structure.[31] The asymmetric reference frame provided static resistance against the upper body and monitored torque production about L5/S1. The pelvic support structure was mounted to a force plate (Bertec 4060A, Worthington, Ohio). The forces and moments measured at the center of the force plate were mathematically translated and

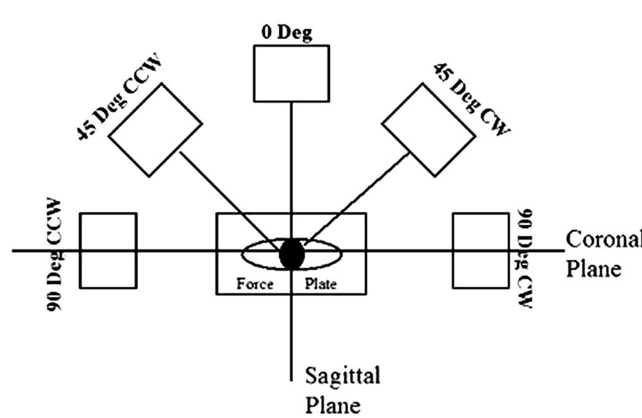

Figure 3. Asymmetric lift positions. CCW = counterclockwise; CW = clockwise; Deg = degree.

rotated to L_5/S_1.[31] A computer displayed real-time moment about L5/S1 to the subject and allowed them to control the exertion magnitude.

An EMG calibration (normalization) procedure was recently reported that does not require a maximum exertion to calibrate the EMG signal.[32] The EMG-force relationship was established through a series of low-level exertions performed in flexion, extension, and axial twisting. These test conditions produced a series of EMG-force relationship points from which a relationship slope was derived. A recent study[33] reported minor differences in EMG-assisted model results when comparing this normalization method *versus* maximum exertions to calibrate the EMG signal.

During both the kinematic assessment and the spine load assessment portions of this study, trunk kinematics was monitored with a triaxial goniometer (lumbar motion monitor or LMM). The device acts as an instrumented exoskeleton of the spine that measured instantaneous 3-dimensional position, velocity, and acceleration of the trunk. The device design, accuracy, and application have been reported previously.[34] During the spine loading study, ground reaction forces were monitored *via* a force plate, and trunk muscle EMG activities recorded as described previously. A set of electro-goniometers in conjunction with a force plate was used to document the moments and forces exerted about L_5/S_1[35] during these free dynamic lifts (Figure 2). The set of goniometers measured the position of L_5/S_1 as well as the pelvic orientation of the subject relative to the center of the force plate. Based on these relative positions, the 3-dimensional forces and moments measured at the force plate were mathematically translated and rotated up to L_5/S_1.

All signals were collected simultaneously through customized Windows™ (Microsoft Corporation, Redmond, WA)-based software developed in the Biodynamics Laboratory. The processed signals were collected at 100 Hz and recorded on a computer *via* an analog-to-digital converter.

Procedure. On arriving at the laboratory, the subjects were first informed about study procedures, the ability to refuse to complete a particular lift, and the need to inform experimenters about any further discomfort. Consent to participate was acquired *via* a document approved by the University Institutional Review Board. Second, subjects performed the kinematic functional assessment test described previously.

Next, subjects were prepared for the spine loading assessment testing. Anthropometric measurements were collected, and surface electrodes then were applied using standard placement procedures described previously[29] for muscles of interest. The subject was positioned in the experimental apparatus, and EMG calibration procedures were completed as described previously.

Following a rest period, the lifting exertions began. To ensure patient safety, all lift origin region conditions (Figure 2) were completed at each weight level before increasing to the next weight. Hence, lifts were performed in the least taxing positions (*e.g.*, lowest expected lift moment) first and then progressed to more demanding lifts (*e.g.*, higher expected lift moment) at each weight level. Asymmetry order presentation was counterbalanced between subjects. Subjects were required to keep the feet stationary on the force plate for force monitoring purposes but were free to move the rest of the body as they wished.

Spine Load Assessment. During the last 20 years, our laboratory has developed a 3-dimensional dynamic biomechanical model that can determine how the vertebral joint at L_5/S_1 is loaded during a dynamic motion.[36] The model yields subject and task specific spine loading information. Our model assumes that we can pass one imaginary transverse plane through the thorax and another imaginary transverse plane through the pelvis. According to the laws of physics, only muscles that pass through both of these planes are capable of imposing loads on the lumbar spine. EMG is used to monitor every major muscle group that passes through both of these 2 planes. The lumbar motion monitor tracks the positions of the 2 planes relative to one another, and permits the adjustment of muscle activity for muscle length and velocity. This information is used to assess the muscle force associated with each muscle. These forces are represented as vectors acting between these 2 imaginary planes. Magnetic resonance imaging data have been collected to ensure that origin and insertions of muscle vectors are anatomically realistic, and adjusted for gender differences and muscle fiber orientation.[37] Summation of muscle forces in each cardinal plane is used to compute spinal forces. Comparison of model predicted external moment with measured external moment is used as a validation measure. The model has been validated for forward bending,[38,39] lateral bending,[19] and twisting[21] exertions. Adjustments to muscle location and size were also made relative to the body mass index[40] of each subject since the LBP group was considerably heavier than the asymptomatic group yet similar in stature.

Analyses. Spine loading descriptive statistics were tested for statistical significance using mixed modeling procedures. For these analyses, the subject group (asymptomatic *vs.* symptomatic) was used as a fixed effect, as were lift origin region, weight, and asymmetric position. The random effect was the subject. The mixed procedure identified significant differences resulting from main effects of subject group, lift origin region, weight, asymmetry position, and all 2 and 3-way interactions. *Post hoc* Tukey tests were used to identify the significant differences within a group between task asymmetries, lift origin region, and weight levels.

Statistically significant relationships between kinematic assessment measures (p[n]) and spine loading measures (observed as a function of the experimental conditions) were evaluated using the statistical analysis system (SAS) mixed modeling procedures for the purposes of identifying model building parameters. However, instead of considering the subject groups as fixed effects, continuous measures of kinematics status were used to build the models. Kinematic status measures found to differentiate significantly between subject groups were used to develop several mixed models. The Akaike Information Criteria (AIC) model comparison criteria based on the likelihood function was used to assess model performance with smaller values of the AIC, indicating better-fitting models.[41] Model fidelity was also estimated by calculating an R^2 statistic according to the procedures described by Vonesh *et al.*[42]

■ Results

Kinematic (Pre-Lift Test) Status

Statistically significant differences were observed between participants with LBP and the asymptomatic group as a function of kinematic performance. Motion characteristics as described by p(n) of the participants with LBP were significantly lower than that of asymp-

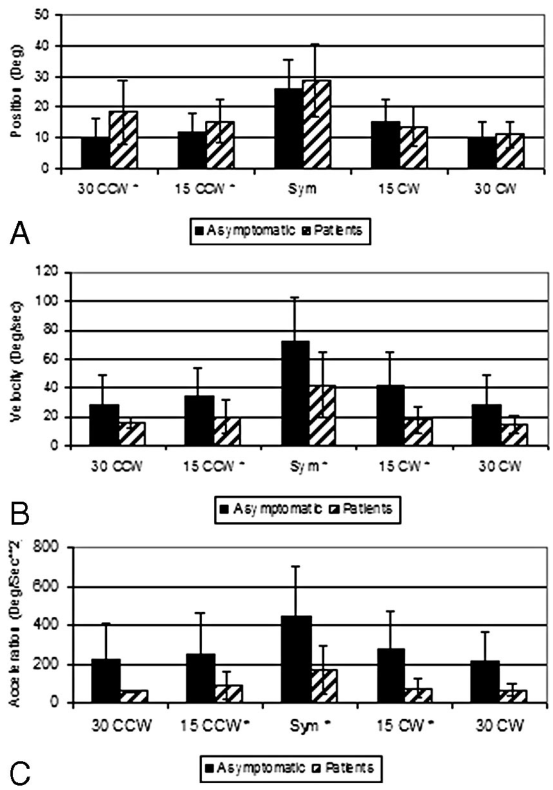

Figure 4. **A**, Kinematic status assessment summary for range of motion as a function of subject group. **B**, Kinematic status assessment summary for extension velocity as a function of subject group. **C**, Kinematic status assessment summary for extension acceleration as a function of subject group. *indicates significant difference between groups, $P < 0.05$. CCW = counterclockwise; CW = clockwise; Sym = symmetry.

tomatic individuals ($P < 0.01$). On average, the LBP group's motion patterns (p[n]) were about 12% (SD = 17%) of the expected motion values (adjusted for age and gender), whereas the asymptomatic group averaged 82% (SD = 25%) of the expected motion values (within normal range), indicating meaningful differences in functional musculoskeletal status between the 2 groups. Most of the individual kinematic measures were also significantly different between the 2 groups as a function of the various asymmetric conditions. All measures involving time derivatives (*e.g.*, velocity or acceleration) were significantly lower for participants with LBP ($P < 0.01$). The most dramatic differences occurred with the higher derivatives of motion (*e.g.*, acceleration) (Figure 4).

In general, greater differences between the LBP group and the asymptomatic group were observed under asymmetric conditions (it is noteworthy that less than 7% of participants with LBP were able to perform the 30 CCW or 30 CW conditions, whereas nearly all performed the remaining conditions). Few "range of motion" measures indicated differences between the 2 groups at the 0.05 level of significance, with patients actually having more range of motion under some CCW conditions. The distribution of p(n) among the subject population represented the spectrum of kinematic abilities expected in the general population, with values ranging from 0.004 to 0.999, with every decile of population capabilities being represented in the test sample. The p(n) measure reflected one of the more robust measures between the 2 groups.

Spine Loads

Spine loads were significantly ($P < 0.01$) higher in the LBP group compared to the asymptomatic group. Overall conditions and compression were, on average, about 11% greater and anteroposterior (A/P) shear about 18% greater in the patients with LBP. Statistically significant increases in spine loading *between subject groups* were noted as a function of lift origin region, lift asymmetry position, and interaction. Weight lifted was a significant factor for defining spine load for both subject groups. However, no differences between subject groups were noted as a function of the magnitude of the weight lifted. Compression and A/P shear values were of higher magnitude and greater relative difference than the lateral shear values. Table 2 displays descriptive statistics for these loadings as a function of the significant factors. It is noteworthy how the relative difference in spine loadings varied as a function of the region. Under the most biomechanically taxing lift origin region conditions, both compression and A/P shear average differences between the subject groups were the smallest observed (10% to 19%), whereas the average largest relative differences between the subject groups occurred at the least biomechanically taxing lift origin regions (24% to 35% difference in compression and A/P shear in the shoulder and waist regions).

Spine loading as a function of lift asymmetry also produced several significant findings (Table 2). It was noteworthy that spine compression was always higher for both patients with LBP and subjects who were asymptomatic in asymmetric (CW and CCW) conditions compared to the asymmetric conditions. However, an unexpected spine compression finding involved the statistically significant greater loads associated with CW 45 lifting conditions compared with CCW 45 conditions within the LBP population that was not present for the asymptomatic subjects. A complete discussion of spine loading trends can be found in another study.[5]

Kinematic Status as an Indicator of Spine Loading

The relationship between the kinematic performance measures (describing low back impairment) and the spine loading measures obtained during the lifting exertions were evaluated for evidence of significant relationships. Table 3 summarizes the statistically significant kinematic and load origin variables associated with spine loading compression, A/P shear, and lateral shear. This table indicates that p(n) and many of the interactions were significant for many dimensions of spine loading. The significant variables noted in Table 3 were used to develop a statistical model that described the relationship between p(n), the physical characteristics of the experimental condition (lift origin, asymmetry, and

Table 2. Spine Loading Descriptive Statistics as Well as Statistical Summary of Differences Between Asymptomatic and LBD Groups as a Function of Experimental Conditions

	Mean Shoulder (SD)	Mean Waist (SD)	Mean Knee (SD)	Mean Waist Far (SD)	Mean Knee Far (SD)
Compression					
Asymptomatic	1198.9* (419.3)	1419.4† (496.7)	3370.9‡ (1207.2)	2342.5§ (837.9)	4641.1¶ (1733.2)
LBP	1562.1* (660.0)	1771.8† (695.6)	3799.7‡ (1472.7)	2650.5§ (1070.2)	5124.1¶ (2169.0)
A/P shear					
Asymptomatic	470.0* (127.3)	428.2* (117.9)	555.7† (287.5)	444.4* (158.0)	860.1‡ (559.2)
LBP	635.7* (314.9)	530.0† (156.9)	630.6* (319.7)	527.9† (175.0)	956.1‡ (651.0)
Lateral shear					
Asymptomatic	52.7* (45.5)	60.2* (57.2)	241.1† (229.6)	141.9‡ (146.5)	420.7§ (368.6)
LBP	87.3* (81.1)	84.2* (87.0)	202.6† (171.3)	141.2‡ (144.2)	315.8§ (257.2)
	CCW 90	CCW 45	Symmetric	CW 45	CW 90
Compression					
Asymptomatic	2803.1†,§ (1687.6)	2656.9†,‡ (1582.4)	2181.3* (1473.4)	2693.7†,‡ (1693.2)	2838.0§ (1812.6)
LBP	2872.4‡,§ (1666.3)	2931.7‡ (1852.4)	2560.0* (1692.3)	3247.0† (2079.1)	3094.0†,§ (1753.7)
A/P shear					
Asymptomatic	582.2† (379.1)	555.3† (308.8)	505.0* (303.5)	555.9† (324.3)	582.3† (384.5)
LBP	633.3*,† (386.6)	664.7*,† (397.0)	610.7* (319.4)	682.1† (416.8)	653.0*,† (432.9)
Lateral shear					
Asymptomatic	271.6‡ (300.4)	195.5† (232.5)	75.9* (118.0)	180.5† (240.2)	247.7‡ (296.2)
LBP	206.6‡ (187.7)	174.5† (158.3)	87.2* (91.8)	187.2† (199.1)	220.8‡ (237.1)

There are significant differences at alpha = 0.05 between patients with LBP and those who are asymptomatic with the "Compression" and "A/P shear" experimental conditions.
Footnote symbols indicate statistically significant differences between conditions within the row.

weight) in predicting spine loading over the range of p(n) for each loading dimension.

AIC scores for spine compression, A/P shear, and lateral shear models were 112, 3245, and 16145, respectively. Pseudo R^2 values associated with these models have been estimated as 0.87, 0.61, and 0.65 for the compression, A/P shear, and lateral shear models, respectively (Table 3).

Figures 5 and 6 describe the compression and A/P shear behavior, respectively, for this model as a function of lift asymmetry and the p(n) measure for all lift origin regions. These figures indicate how spine loading is expected to vary as p(n) goes from 0 (fully impaired) to 1.0 (fully asymptomatic) for the combinations of different origins and asymmetries. As shown in Figure 5, compression could vary by more than 1000 N as kinematic capacity varies. Increases in spine loading in kinematically impaired subjects were as large as 79% over the range of p(n) under some conditions. In addition, much greater differences between asymptomatic and LBP spine compressions were observed when lifting from CW lift origins compared to CCW lift origins.

Table 3. Significance Summary of Model Parameters and Goodness of Fit for Each Spine Loading Measure

	P Values		
	Compression	A/P Shear	Lateral Shear
Region	0.0001	0.0001	0.0001
Weight	0.0001	0.0001	0.0001
Asymmetry	0.0001	0.0002	0.0001
P(n)	0.0001	0.0001	0.0020
Gender	0.0226	0.0001	0.5856
Region * P(n)	0.0001	0.0001	0.0001
Asymmetry * region	0.0001	0.0001	0.0001
Asymmetry * P(n)	0.0001	0.1117	0.0537
Gender * asymmetry	0.0043	0.0003	0.4020
Gender * region	0.0001	0.0001	0.0001
Gender * P(n)	0.2831	0.8506	0.9866
R^2	0.87	0.61	0.65

Figure 7 indicates how the p(n) variable interacts with the load weight lifted to yield differences in spine compression. In general, compression increased by 1% for every one pound increase in weight lifted. Similar relationships were developed for A/P and lateral shear forces. A/P shear increased by 1% for each unit increase in weight, whereas lateral shear force increased by 1.4% for every unit increase in weight lifted.

■ Discussion

This evaluation has been able to estimate the degree of increased spine loading expected as a function of the kinematic compromise and the physical characteristics of the lifting situation of a patient with LBP. Because the study contained an unusually large subject population (123 subjects) for a detailed biomechanical study, the statistical power permitted us to assess, in detail, the response of the musculoskeletal system.

Examination of the results indicated that when loading was increased in patients with LBP compared to asymptomatic individuals there was a "mismatch" between kinematic task demands and the kinematic abilities of the patient with LBP. The patient with LBP re-

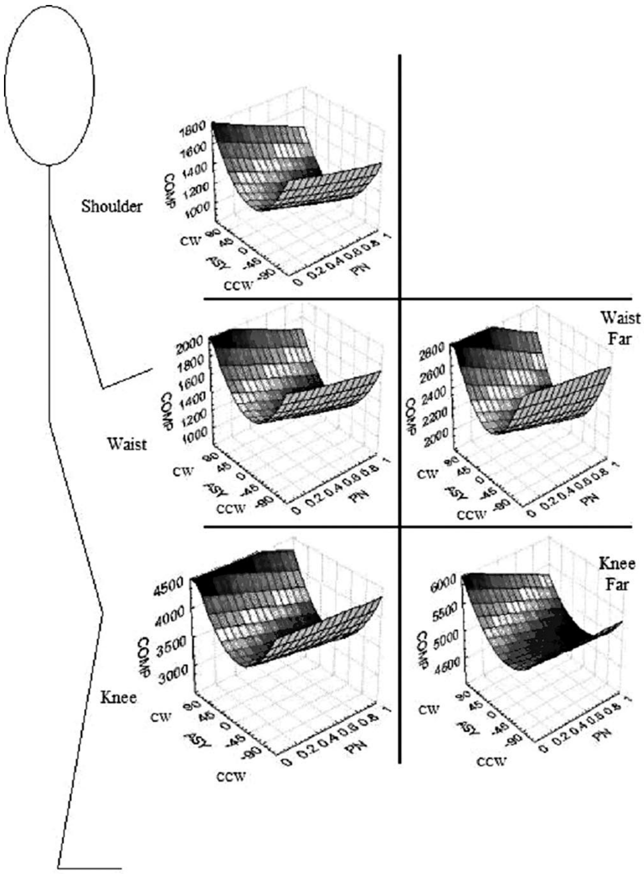

Figure 5. Compression as a function of p(n) and asymmetry for each lift region. ASY = asymmetry; CCW = counterclockwise; CW = clockwise.

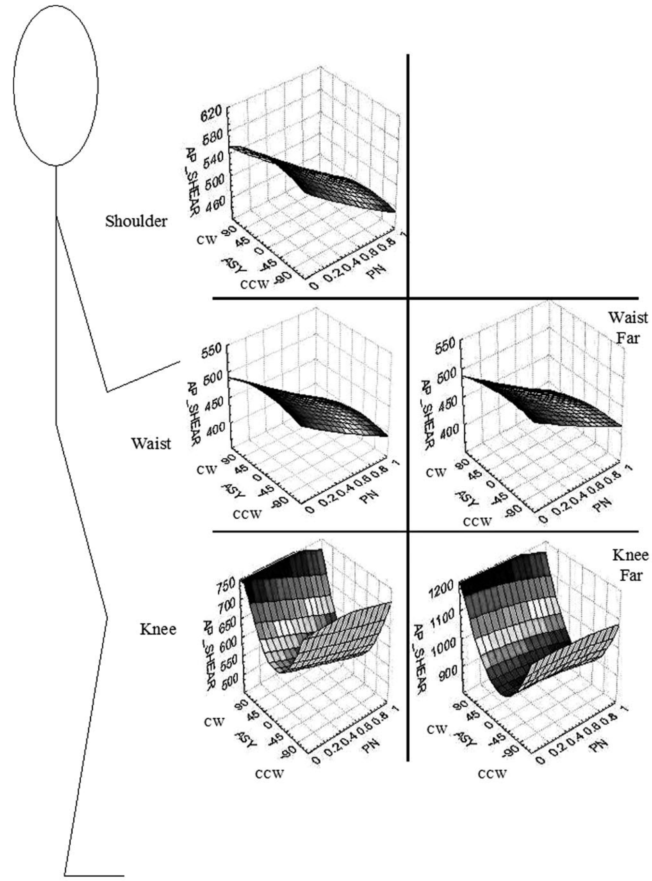

Figure 6. Anteroposterior (A/P) shear as a function of p(n) and asymmetry (ASY) for each lift region. CCW = counterclockwise; CW = clockwise.

sponded with increased torso muscle coactivation, resulting in significantly higher loading compared to an asymptomatic individual. For example, under many of the CW 45 lifting exertion conditions in which the largest differences in compressive loading between subject groups were noted (Figure 5), the average peak sagittal velocity during lifting for both groups were about the same. However, the kinematic capacity of the 2 subject groups observed during the kinematic status assessments were significantly different because Figure 4B indicated larger relative kinematic deficits in the CW movements of subjects with LBP (relative to the asymptomatic subjects) compared to CCW motion. Thus, a kinematic mismatch between task demands *versus* subject kinematic status appears to reflect the differences in spine loading between the LBP and asymptomatic group *via* a muscle coactivation mechanism.

Perhaps the most remarkable finding of this study was the ability to characterize these underlying mismatches and the subsequent effect on spine loading through a relatively simple model. The model reflects spine compression best (explaining 87% of the variability) and spine A/P shear least well (explaining 61% of the variability). This model can predict changes in spine loads (compared to an asymptomatic individual) given the lifting situation and the degree of kinematic compromise of a patient with LBP.

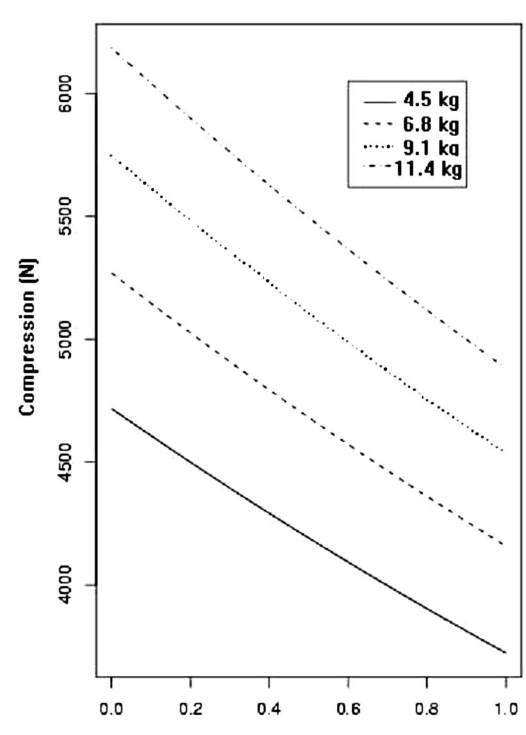

Figure 7. Compression as a function of p(n) for each weight.

These findings have significant implications for the return-to-work of individuals with LBP in that given the kinematic capabilities of a patient with LBP, it would be possible to determine quantitatively which specific work activities might compromise the rehabilitation of the patient. Thus, patients with LBP could return to work sooner if one could determine which specific tasks should be avoided. In addition, periodic remonitoring of the kinematic status of the patient would reveal when the patient with LBP would be able to return to more demanding tasks without the risk of excessive mechanical spine loading. Hence, these findings suggest that it is possible to minimize exposure to activities that might be responsible for a recurring back problem exacerbated by mechanical loading.

However, the capacity for trunk velocity and acceleration generation of the LBP group was compromised as noted by the kinematic status assessments (Figure 4). Hence, the LBP group was taxed at a higher percentage of the kinematic capacity relative to the asymptomatic group. Yet, kinematic status assessments indicated significant kinematic deficits in the LBP group when moving in CW positions (Figure 4).

Collectively, this study indicates that valuable information is contained within kinematic information relative to the recruitment pattern and functioning of the musculoskeletal system. Based on these results it is highly likely that trunk kinematic deficits are reflective of increase in trunk muscle coactivation that probably occur from a desire by the patient with LBP to increase guarding and stability but also result in greater loading. These findings also suggest that those jobs that would be expected to impose the least amount of risk may involve far more spine loading than expected. It appears that patients with LBP have higher levels of coactivity (compared to asymptomatic subjects) under conditions in which externally imposed loads are minimal. It is assumed the increase in coactivity is intended to increase stability in situations in which stability is marginal.

Several limitations should be acknowledged relative to these findings so that the study contribution could be viewed in perspective. First, this study only considered the mechanical spine loading contribution to low back disorders. The literature recognizes that back pain is multidimensional and involves many factors.[2,43] Second, not all the patients with LBP elected to perform all the exertions. Specifically, few subjects elected to perform the 90 CW or 90 CCW exertions when lifting the 9.1 and 11.4 Kg loads. Hence, the relationships observed in these extreme conditions might only reflect the less impaired subjects with LBP. Third, we elected not to normalize spine loading as a function of body weight in this study. A previous study[4] indicated that body mass normalization produces similar findings. However, the inclusion of such normalization would limit the applicability of the results. Hence, we elected to report the absolute spine loads because they would better reflect the loads expected during actual lifting exertions. Finally, the relationships described in this study involve subjects with LBP with LBP of muscular origin. It is unknown whether the relationship between kinematic status and LBP would be similar for LBP of structural origin.

■ Conclusions

Spine loading is greater in patients with LBP compared to asymptomatic individuals when performing similar lifting exertions. The difference in loading between LBP and asymptomatic individuals depends primarily on the lift origin and asymmetry location of the object lifted.

Lift origin locations located at the least biomechanically taxing positions resulted in the greatest difference in loading between individuals with LBP and those who are asymptomatic. CW asymmetric lifts (at 45° of asymmetry) yielded much greater spine loading in subjects with LBP compared to CCW lifts. The degree of kinematic compromise is directly related to increase in spine loading. Given individual kinematic deficit and the physical characteristics of a lifting task, it is possible to estimate the increase in spine loading during a lifting exertions compared to an asymptomatic individual.

■ Key Points

- Patients with LBP have greater spine loading as well as higher kinematic compromise compared to asymptomatic individuals performing the same task.
- The degree of kinematic compromise was related to the degree of spine loading increases in those patients with LBP.
- A statistical model was developed that was able to describe 87% of the variability in compression, 61% in A/P shear, and 65% in lateral shear.
- Those individuals with greater kinematic compromise used higher levels of antagonistic muscle coactivation that not only reduced trunk motion but also resulted in increases in spine loading.
- Given the degree of kinematic compromise and the lifting task conditions, a method has been devised to predict the increase in spine loading above and beyond that of an asymptomatic individual when performing typical materials' handling tasks.

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