Clinical Study

Lumbar motion changes in chronic low back pain patients: a secondary analysis of data from a randomized clinical trial

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Abstract

BACKGROUND CONTEXT: Several therapies have been used in the treatment of chronic low back pain (LBP), including various exercise strategies and spinal manipulative therapy (SMT). A common belief is that spinal motion changes in particular ways in direct response to specific interventions, such as exercise or spinal manipulation.

PURPOSE: The purpose of this study was to assess changes in lumbar region motion for more than 12 weeks by evaluating four motion parameters in the sagittal plane and two in the horizontal plane in LBP patients treated with either exercise therapy or spinal manipulation.

STUDY DESIGN/SETTING: Secondary analysis of a subset of participants from a randomized clinical trial.

PATIENT SAMPLE: One hundred ninety-nine study participants with LBP of more than 6 weeks’ duration who had spinal motion measures obtained before and after the period of intervention.

OUTCOME MEASURES: Lumbar region spinal kinematics sampled using a six-degree-of-freedom instrumented spatial linkage system.

METHODS: Trained therapists collected regional lumbar spinal motion data at baseline and 12 weeks of follow-up. The lumbar region spinal motion data were analyzed as a total cohort and relative to treatment modality (high dose, supervised low-tech trunk exercise, SMT, and a short course of home exercise and self-care advice). The study was supported by grants from Health Resources and Services Administration, Danish Agency for Science Technology and Innovation, Danish Chiropractors Research Foundation, and the University of Southern Denmark. No conflicts of interest reported.

RESULTS: For the cohort as a whole, lumbar region motion parameters were altered over the 12-week period, except for the jerk index parameter. The group receiving spinal manipulation changed significantly in all, and the exercise groups in half, the motion parameters included in the analysis. The spinal manipulation group changed to a smoother motion pattern (reduced jerk index), whereas the exercise groups did not.

FDA device/drug status: Not applicable.

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Introduction

For many years, researchers and clinicians have sought to measure back problems objectively, primarily to attempt to determine the origin of pain, and subsequently, to measure whether given types of treatment evoke a biologically or biomechanically measurable change [1,2]. There is a tradition of basing diagnoses on the results of imaging techniques, such as conventional X-ray, computed tomography, or magnetic resonance imaging. Ascribing a patient’s low back pain (LBP) to a presumed injured or painful structure (ie, a pathoanatomical source) is often inaccurate even when based on advanced imaging techniques. In many cases, LBP patients may show no identifiable pathoanatomical source. Conversely, it is not a rare observation that asymptomatic individuals demonstrate spinal pathologies evident on imaging [3,4]. Consequently, it has been proposed that spinal physical impairment and disability are better evaluated by assessing measurements of the movement pattern in specific motor tasks and/or recording of maximal muscle strength/power to determine the patient’s functional ability [5,6]. Functional capacity assessments addressing strength and endurance of trunk musculature can be performed to monitor the problem of LBP impairment. However, they are limited in that they measure extreme capacity, which often goes beyond normal trunk function needed for typical activities of daily living [6].

Traditionally in the clinic, spinal movement is quantified by measuring, for example, range of motion (ROM) or Schobers index [7]. Such low-tech measurements describe the full functional range of joint excursion but little about the quality of the motion. Research has indicated that simple ROM measurements have limited use as a measure of treatment outcomes or as a stand-alone measure of disability [8,9]. It has been proposed that a link between lumbar motion and lumbar pain may be found by addressing the patterns of the motion rather than the end ranges of motion [10]. More advanced motion parameters derived from high-tech three-dimensional (3D) motion devices may contribute to describing patient movement and movement changes.

Several motion parameters can be derived from real-time 3D spinal motion analysis, for example, angular velocity, acceleration, and smoothness of motion, respectively [11]. The development of advanced techniques to measure trunk motion characteristics during unloaded free dynamic activities represents an attempt to remedy existing deficiencies in the quantification of LBP impairment. However, the actual usefulness of regional lumbar motion measurements remains controversial. Lumbar motion measurements are probably influenced by several subjective factors, such as the patient’s agenda, motivation, effort, fear and other psychosocial states, as well as actual physical capabilities.

Many hypotheses and theories exist about how different treatment modalities such as exercise or spinal manipulation affect biomechanical spine function [12,13]. Several specific therapies have demonstrated positive effect on patient-reported outcomes [14–17], but little is known about the change in spinal movement characteristics after treatment. When a therapist treats a patient, a common belief is that spinal motion changes in particular ways in direct response to specific interventions, such as exercises or manual therapy. However, there seems to be a lack of science-based knowledge on this important aspect of clinical rehabilitation.

The overall aim of the present study was to analyze changes in lumbar region motion for more than 12 weeks by describing pre-to-post treatment changes in the entire study population, as well as treatment group differences, by evaluating four motion parameters in the sagittal plane and two in the horizontal plane.

Specifically, we wanted to analyze the change in spinal ROM, maximum flexion velocity, phase-plot area, jerk index (smoothness of motion), and two circumduction area motion parameters in 199 chronic LBP patients over a 12-week intervention period and analyze the effect of 12 weeks of spinal manipulation therapy, supervised trunk exercise, or home exercise on spinal lumbar motion ability.

Materials and methods

Design

This spinal motion analysis study is a secondary analysis of a subset of study participants from an observer-blinded, parallel-group, randomized clinical trial [15]. Subjects were recruited over a period of 3 years at the Wolfe Harris Center for Clinical Studies at Northwestern Health Sciences University, Minneapolis, USA. The institutional review boards of the Northwestern Health Sciences University, the Minneapolis Medical Research Foundation, and the University of Minnesota approved the study, and written informed consent was obtained from all study participants. Spinal motion recordings were measured at two baseline (PRE) visits (separated by 7–14 days) and one follow-up visit after 12 weeks of intervention (POST). To illustrate the stability of pain intensity in the overall cohort, pain intensity levels

CONCLUSION: This study provides evidence that spinal motion changes can occur in chronic LBP patients over a 12-week period and that these changes are associated with the type of treatment. © 2014 Elsevier Inc. All rights reserved.

Keywords: Low back pain; Spine; Measurement; Motion analysis; Biomechanics; Nonsurgical; Manipulation; Exercise
presented in Table 1. The treatment of chronic axial and mechanical low back pain frequently involves referrals for physical therapy, exercise, and spinal manipulation. The extent to which these interventions improve spinal motion changes remains controversial. In this context, the authors endeavored to perform a secondary analysis of data collected from a randomized prospective trial, comparing changes in lumbar motion between patients treated with exercise therapy or spinal manipulation.

**Context**
The number of patients who could not be included in the secondary analysis. The authors concluded that spinal motion changes do occur in patients treated with spinal manipulation and exercise therapy. However, those treated with spinal manipulation demonstrated changes in all parameters assessed, whereas those treated with exercise therapy changed in only three of the six areas evaluated.

**Implications**
As a post hoc analysis of heterogeneity of treatment effects between groups, this investigation is unable to present the same level of evidence as a true randomized trial. Moreover, given the design of the original study, including limitations on follow-up, the likelihood of observed changes in spinal motion being sustained and translating into long-term clinical benefit cannot really be established. Other limitations are correctly identified by the authors in their discussion, including the possibility of measurement bias and confounding due to the number of patients who could not be included in the secondary analysis.

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**Contribution**
Approximately 2/3 (n=199) of individuals included in the original study were able to be considered in the secondary analysis. The authors concluded that spinal motion changes do occur in patients treated with spinal manipulation and exercise therapy. However, those treated with spinal manipulation demonstrated changes in all parameters assessed, whereas those treated with exercise therapy changed in only three of the six areas evaluated.

**Randomization and blinding**
In the original study, restricted randomization using a 1:1:1 allocation ratio was applied using four strata: patients with and without radiating symptoms, LBP 6 to 12 weeks' duration, and LBP for more than 12 weeks. Before enrollment, the project statistician generated a randomization list using randomly mixed permuted blocks of different sizes. Objective outcome assessment was performed by examiners masked to treatment allocation. Detailed information on randomization, recruitment, and blinding procedures is reported in another publication [15].

**Interventions (12 weeks)**
Clinicians used standardized forms to document the events and procedures of each treatment visit, including patient-reported side effects. A minimum of 80% attendance at their scheduled visits was required. The following intervention modalities were used.

**Spinal manipulative therapy**
The number of treatments and the schedule of care were determined by one of the nine treating chiropractors. Treatment typically involved two encounters per week lasting 15 to 30 minutes that could include manual spinal manipulation, with light soft-tissue massage, with the assistance of a flexion/distraction table if required. Activity modification was prescribed as necessary. The vertebral levels treated were determined by the individual clinicians by static and/or motion palpation. Specific spinal manipulation was performed as follows: patients were positioned on a treatment table in either the prone,
supine, or side-lying position. For each spinal manipulation, the chiropractor’s contact hand would be placed over an osseous process, muscle, or ligament and the vertebral or sacroiliac joint of interest would be taken to the end of its physiological ROM. The chiropractor would then apply a high velocity, low-amplitude impulse to the joint, carrying it beyond the normal physiological ROM. Participants were discharged from care if the treating clinician felt that maximum clinical benefit had been obtained.

Supervised exercise therapy

Supervised high-dose exercise in small groups of patients (3–4) was provided (one-on-one supervision) by 15 exercise therapists trained in the study protocol. The main focus was dynamic trunk strengthening exercises (trunk extensions and leg extensions) and abdominal exercises using low-tech methods. In addition, a core strengthening program and static stretches (series of six) with a focus on the lumbar, gluteal, and hamstring musculature before and after strengthening. Each stretch was done once, with the patients instructed to hold each stretch for three deep breaths. Over the 12-week period, patients were asked to attend 20 one-hour sessions involving a high number of repetitions (two to three sets of 15–30 repetitions for each exercise) and a progressive increase in muscle load (achieved by altering the patient’s center of gravity when possible). The patients were instructed to perform repetitions until they could no longer do so using proper form. The study protocol was based on the dynamic trunk strengthening protocol described by Manniche et al. [19], which includes trunk extensions and leg extensions and has, in part, been tested in a previous trial [20].

Home exercise and advice

Eleven therapists trained in the study protocol provided counseling on self-care education. Two 1-hour sessions were conducted on self-care measures and ergonomics associated with work and activities of daily living. These included postural instructions and practical demonstrations of proper body mechanics performed with patient participation.

A more comprehensive description of the various intervention modalities has been published elsewhere [15].

Outcomes and measurements

A comprehensive description and analysis has been undertaken of patient-rated outcomes as well as descriptions of instrumentation, attachment, measurement procedure, data processing and analysis, and reliability [11,15].

In short, evaluation was conducted during baseline assessment and 12 weeks after randomization. Self-report questionnaires were completed at each time point, independent of study providers and investigators. Objective outcome assessments (lumbar kinematics including both sagittal and coronal plane motions, as well as rotation and circumduction, trunk muscle strength, and endurance) were collected by a blinded examiner at both baseline assessments and at Week 12. As described in detail previously [11], lumbar spine kinematics were sampled during a standardized motion test using a six-degree-of-freedom instrumented spatial linkage system with a sampling rate...
of 100 Hz (CA 6000 Spine Motion Analyzer; OSI, Union City, CA, USA). The instrument was calibrated against an inclinometer at the beginning of each test day, and zero setting was performed for each subject in the neutral position before their first test. Each participant wore a loose T-shirt and trousers. The instrument was attached to the patient when standing in a neutral position with arms relaxed. The fixed extremity of the device was mounted on the sacral crest (S2) using a manufacturer-supplied belt. The mobile end of the device was mounted at the level of T7 using a manufacturer-supplied chest harness, and the top edge of the horizontal metal pieces was aligned evenly with the inferior angles of the scapulae (which is level with the T7 spinous process). The pelvic harness was applied so that the binding posts were level with the posterior superior iliac spines. Neutral position was defined as the patient standing with eyes open, facing forward, with the feet positioned a shoulder width apart and arms hanging freely at their side with the low back in a comfortable position. Each patient then performed several trial runs as a warm up. Two recordings were obtained at each test session that needed to display a total ROM variability of $4^\circ$ or less. The testing time duration for the complete protocol was approximately 10 minutes.

A custom-made MatLab program was used to reduce the 3D data into single numbered motion parameters [11]. The following motion parameters were determined:

1. **ROM** was calculated as the total angular range of spine motion in the sagittal plane expressed in degrees from maximum extension to maximum flexion [11] (intraclass correlation coefficient [ICC]$_{(1,1)}=0.69$).

2. **Maximum flexion velocity** ($^\circ$/s) was calculated as the peak angular speed in the forward bending motion reached from full extension position to full flexion position [11] (ICC$_{(1,1)}=0.69$).

3. **Phase-plot area** ($^\circ^2$/s) was defined as the area composed by the phase plot of sagittal flexion-extension angular motion versus velocity. Phase-plot area was calculated based on cross-product calculations between vectors drawn from the neutral position to each coordinate point in the phase plot [11] (ICC$_{(1,1)}=0.74$).

4. **Jerk index** was calculated from maximum flexion to maximum flexion position as the mean spectral frequency of the first derivative of the angular acceleration signal multiplied by movement duration [11]. This parameter indicates the number of changes in acceleration, that is, the smoothness of the motion (ICC$_{(1,1)}=0.55$).

5. **Two-dimensional (2D) circumduction area** ($^\circ^2$) was defined as the 2D surface area of the angular phase plot formed by the frontal and sagittal motions (Fig. 1). The area was calculated based on cross-product calculations between vectors drawn from the neutral position to each coordinate measurement point in the circumduction motion (ICC=0.81).

6. **3D circumduction area** ($cm^2$) was defined as the curved 3D surface formed by the translatory motion from the point (0,0,0) to each point formed by (x, y, z) coordinates. The area was calculated based on cross-product calculations between vectors drawn from the neutral position to each coordinate measurement point in the circumduction motion (ICC$_{(1,1)}=0.68$).

The ICC values presented after each measurement represent the reliability of pain intensity stable patients with a pain level defined as a maximum change of $\pm 1$ on the numeric rating scale during the previous week between the two baselines.

Reliability and measurement error for 3D lumbar region measurements in general [21] and for present group of

![Fig. 1. Clockwise circumduction motion in a typical patient before and after treatment. The area increased after treatment.](image-url)
subjects in particular (sagittal motion only) have been reported elsewhere [11]. The reliability coefficient $IC(1,1)$ for circumduction motion calculated for the entire cohort ($n=199$) was 0.82 (95% confidence interval [CI], 0.77–0.87) for 2D circumduction and 0.69 (95% CI, 0.61–0.76) for 3D circumduction. Limits of agreements ranged from −40% to +72% for 2D circumduction and −59% to 148% for 3D circumduction.

**Statistical analysis**

We first determined if those study participants who completed the motion tests were different from those who did not. Independent $t$ tests or chi-square tests were conducted on the following parameters: age, sex, body mass index (BMI) [22], duration of pain, baseline physical component score, baseline mental component score, baseline depression score (Center for Epidemiologic Studies Depression Scale), diagnostic group, and intervention group.

All lumbar motion parameters except for ROM were non-normally distributed. Various transformations were applied to the parameters, and non-normal distribution still existed. Paired $t$ test (ROM) or Wilcoxon signed rank test were used for comparison between paired data, and Wilcoxon rank sum (Mann-Whitney $U$) test was used for comparison of unpaired data. For comparison of differences in pre-to-post changes between the three treatment groups, the Kruskal-Wallis test was used. For descriptive reasons and to estimate the individual change in each motion parameter, we calculated the individual percent change.

Two statistical tools were used to assess test-retest reliability and measurement error. Based on the study design, that is, each target was rated by a different set of the nine examiners (considered to be randomly selected from a larger population of judges) and because we aim to generalize to individual ratings the ICC ($IC(1,1)$) were calculated to assess reliability [23]. To evaluate measurement error, Bland-Altman limits of agreement with 95% CIs were calculated [24]. These analyses were based on logarithmic transformed data to fit formal statistical assumptions.

**Results**

A total of 630 individuals were evaluated for the study, of which 329 were excluded because they did not meet the exclusion criteria specified in the primary article [15]. Therefore, 301 patients were randomized, but because of technical problems with the equipment at baseline or follow-up (80 patients) and dropouts (22 patients), a total of 199 complete patient recordings were obtained.

Overall, adherence to study interventions was high. The number of patients who did not receive or discontinued intervention for each treatment group were four for home exercise and advice (HEA) (refused to participate [$n=3$] and time commitment [$n=1$]), four for spinal manipulative therapy (SMT) (refused to participate [$n=3$] and competing comorbidity [$n=1$]), and 14 for the supervised exercise therapy (SET) (unknown reason [$n=2$], increase in pain [$n=3$], refused to participate [$n=3$], moved [$n=1$], time commitment [$n=1$], and personal conflict [$n=3$]). More details about the adherence have been reported in the primary article [15]. The individuals not available for analysis were significantly younger (Table 1), but there were no differences in the other baseline characteristics, such as BMI, gender, duration of pain, back/leg pain intensity, and RMDQ score or depression score. Table 1 summarizes the demographic and clinical characteristics of the study participants. For the regional lumbar motion evaluation, 199 persons had complete motion data at baseline and Week 12.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test</th>
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<th>Mean</th>
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<td>Velocity</td>
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LBP, low back pain; CI, confidence interval; phase plot, phase-plot area ($\pi^{2}$/s); BL, baseline; Wk 12, Week 12; velocity, maximum flexion velocity ($\pi$/s); Jerk index, number of changes in acceleration from full extension to full flexion; ROM, range of motion ($\pi$); 2D, two-dimensional circumduction area ($\pi^{2}$); 3D, three-dimensional circumduction area (cm$^2$).

### Table 2

Motion parameters recorded during voluntary lumbar sagittal plane and circumduction motion for 199 chronic LBP patients

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<tr>
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### Table 3

Motion parameters percent change recorded during voluntary lumbar sagittal plane and circumduction motion for 199 chronic LBP patients

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LBP, low back pain; CI, confidence interval; phase plot, phase-plot area ($\pi^{2}$/s); BL, baseline; Wk 12, Week 12; velocity, maximum flexion velocity ($\pi$/s); Jerk index, number of changes in acceleration from full extension to full flexion; ROM, range of motion ($\pi$); 2D, two-dimensional circumduction area ($\pi^{2}$); 3D, three-dimensional circumduction area (cm$^2$).
The two exercise groups increased on three of six motion parameters (Table 4). The pre-to-post change in jerk index differed between treatments (p = .0031), with the spinal manipulation group changing to a smoother motion (Fig. 2).

**Discussion**

Using a 3D regional spinal motion instrument, we tested two theories: first, that in chronic LBP patients, commonly used treatments actually change spinal motion by modulating spinal biomechanics, and second that specific treatment modalities may affect spinal motion differently.

For the whole cohort, it was observed that spinal motion parameters (except for Jerk index) increased after the 12-week intervention period; however, differences were found between treatments. Thus, it would appear that changes in lumbar region spinal motion can occur in chronic LBP patients after exercise and spinal manipulation, and these changes are potentially different between the interventions.

Spinal ROM can be measured in the sagittal, frontal, or horizontal planes, respectively, and is possibly the most commonly used assessment of physical impairment in LBP patients in both clinical and research settings [25,26]. Specifically, sagittal plane motion (spinal extension and flexion ROM) represents a highly used measure in the clinical setting [25]. A lot of research has focused on creating normative databases to identify age, gender, and ethnic differences in healthy subjects and to make a distinction between people suffering from LBP and healthy individuals based on their ROM [27–29]. In general, there is evidence for a gradual decline in most ROM directions with increased age, but the subject-to-subject variation in all groups (age and gender) is very large and thus, the ability to discriminate LBP patients from healthy individuals based on ROM is poor [30]. Although LBP patients on average demonstrate lower ROM [28], a specific patient with decreased mobility relative to their normal mobility may fit well within the range of normal subjects. Furthermore, research has indicated that the correlation between ROM and disability (as measured by condition-specific spinal outcome questionnaires, eg, Roland-Morris Disability questionnaire [RMDQ]) is weak or even nonexistent [8,9,31,32]. In an effort to improve the capacity to discriminate between LBP patients and healthy subjects, more complex methods to assess spinal biomechanical function using higher order kinematics have been attempted [6,33]. These studies indicate that more complex tasks are needed for discrimination to be achievable, and it may be that such complex motion parameters are better for evaluative purposes as well.

The spinal motion parameters examined in the present study were chosen to obtain a more complete representation of spinal motion biomechanics than achieved by sagittal
plane ROM alone. These motion parameters can be divided into time-independent and time-dependent parameters. The time-independent parameters examined in this study were sagittal ROM and two circumduction motion areas. Circumduction areas were calculated using all 2D or 3D data points measured during the circumduction motion and may therefore represent a more relevant measure than single-plane ROM when quantifying functional impairments. In a clinical setting, such circumduction measurements may be useful and practical because one simple test gives an impression of a patient’s overall functional ability by examining movement in several directions in the same maneuver. Besides the numerical calculation of the motion area, visual tools such as depicted in Fig. 1 may prove useful in the clinical setting. Such information, including the visual tools, might assist diagnosis and the evaluation of changes between successive treatment visits. Although the present 2D circumduction motion parameters encompass a complex motion scenario, the reliability seems to be better than for other parameters used in this study. Thus, with relevant protocol adjustments and/or technological improvements, it may be useful at an individual patient level in clinical settings.

Time-dependent parameters (phase-plot area, velocity, and the jerk index) are less static psychometric measures expressing dynamic spinal motion characteristics using higher order derivatives. We suggest that these variables provide important and relevant information for the evaluation of spinal function in LBP patients. To condense this information into single metric values containing as much kinematic data as possible, the phase-plot area was calculated using the combined sagittal angular position and angular velocity signals, respectively. Based on each individual’s calculated mean percentage change (Table 3), the phase-plot area and the 3D circumduction area showed good properties at assessing spinal motion changes over time.

Thus, the newly developed parameters (circumduction area and phase-plot area) appear to be sensitive motion parameters that could be useful in the clinical evaluation of individual LBP patients and in various research settings. To facilitate their use in the clinical setting, these parameters need to be studied more closely to determine their sensitivity to assist diagnosis or assess therapeutic patient outcomes.

The jerk index indicating the smoothness of motion (number of changes in acceleration from maximum extension to maximum flexion) remained unchanged with treatment when evaluated for the whole cohort. The hypothesis that LBP patients would move more smoothly after treatment was confirmed in the spinal manipulation group. The jerk index is limited in that it had relatively low reliability, that is, much noise relative to signal. However, this makes it even more surprising that a significant difference \( p = .0031 \) between treatment groups was found. This index can be calculated in different ways, and other formulas may provide more reliable outcomes, which should be explored in future studies.

**Study limitations/strengths**

This study examined a large number of participants, with a relatively stable LBP level at baseline and a high degree of chronicity (Table 1). In general, the objectivity of
all spinal motion measurements can be questioned, for example, a patient may exaggerate movements for a variety of purposes, either consciously or unconsciously. However, in the present study, patients with ongoing pending or current litigation were excluded, which probably reduces the influence by subjective factors such as the patient’s agenda.

In addition, the learning effect is a well-known phenomenon that may influence an outcome, that is, change the course of movements in the habituated state. To minimize this potential problem, all patients participated in two baseline assessments, and all analyses were done using data from the second baseline only.

Because these data were from a randomized comparative study, we believe that the present conclusions about different treatments are fairly robust. However, the absence of a strict no-treatment control group raises the possibility that the changes presently observed reflect the natural change in spinal motion characteristics over time.

Initially, 301 patients were recruited but because of technical problems (80 patients) and dropouts (22 patients), only 199 complete patient recordings were obtained at follow-up. Of the participants, 62 received SET (24 missing because of technical problems and 14 dropouts), 77 received SMT (19 missing because of technical problems and 4 dropouts), and 60 received HEA (37 missing because of technical problems and 4 dropouts). The individuals not available for analysis were slightly younger, but there was no difference in other baseline characteristics, such as BMI, gender, duration of pain, or depression score, back/leg pain intensity, and RMDQ score.

The complexity of spinal motion is enormous, and to use recordings as a quantitative outcome, data had to be condensed into a manageable number of parameters, which may have resulted in potentially important information being lost. In addition, we did not assess short-term spinal movement changes or immediate and short-term treatment effects. Finally, the study did address neither whether the observed changes in spinal motion outcomes were translated into improved patient-oriented outcomes nor if particular patterns of baseline motion characteristics are able to predict the range of adaptive improvement. These important aspects should be addressed in future studies.

Conclusions

This study provides evidence that spinal motion changes can occur in chronic LBP patients over a 12-week intervention period. Treatments in the form of exercise or spinal manipulation appear to elicit dissimilar adaptive changes in spinal motion ability.

References


