

PAUL F. BEATTIE, PT, PhD, OCS, FAPTA¹ • CATHY F. ARNOT, DPT, OCS² • JONATHAN W. DONLEY, DPT, ATC³
 HARMONY NODA, DPT⁴ • LANE BAILEY, DPT⁴

The Immediate Reduction in Low Back Pain Intensity Following Lumbar Joint Mobilization and Prone Press-ups Is Associated With Increased Diffusion of Water in the L5-S1 Intervertebral Disc

Despite advances in diagnosis, classification, and intervention, many patients presenting with nonspecific low back pain (LBP) fail to have recovery from symptoms and activity limitation.²⁶ Systematic reviews of the best available research suggest that interventions commonly used by physical therapists, such as various applications of exercise, manual therapy, and patient education, may be effective for some but not all subsets of people with LBP.^{14,32,38} Determining those subsets of patients who respond favorably to intervention has been the focus of many observational studies and randomized clinical trials.^{13,15,20,30,32,33} Data from these, and other studies have led to the development of clinical prediction rules and treatment-based classification systems that have, in turn, greatly refined



- **STUDY DESIGN:** Single-group, prospective, repeated-measures design.
- **OBJECTIVES:** To determine differences in the changes of diffusion of water in the L5-S1 intervertebral disc between subjects with nonspecific low back pain (LBP) who reported an immediate reduction in pain intensity of 2 or greater on an 11-point (0-10) numeric rating scale after a 10-minute session of lumbar joint mobilization, followed by prone press-up exercises, compared to those who did not report an immediate reduction in pain intensity of 2 or greater on the pain scale.
- **BACKGROUND:** Combining lumbar joint mobilization and prone press-up exercises is a common intervention for patients with LBP; however, there is conflicting evidence regarding the effectiveness and efficacy of this approach. Increased knowledge of the physiologic effects of the combined use of these treatments, and the relationship to pain reports, can lead to refinement of their clinical application.
- **METHODS:** Twenty adults, aged 22 to 54, participated in this study. All subjects reported LBP of at least 2 on an 11-point (0-10) verbally administered numeric rating scale at the time of enrollment in the study and were classified as being candidates for the combination of joint mobilization and prone press-ups. Subjects underwent T2- and diffusion-weighted lumbar magnetic resonance imaging scans before and immediately after receiving

a 10-minute session of lumbar pressures in a posterior-to-anterior direction and prone press-up exercises. Subjects who reported a decrease in current pain intensity of 2 or greater immediately following treatment were classified as immediate responders, while the remainder were classified as not-immediate responders. The apparent diffusion coefficient, representing the diffusion of water in the nucleus pulposus, was calculated from the midsagittal diffusion-weighted images.

- **RESULTS:** Following treatment, immediate responders ($n = 10$) had a mean increase in the apparent diffusion coefficient in the middle portion of the L5-S1 intervertebral disc of 4.2% compared to a mean decrease of 1.6% for the not-immediate responders ($P < .005$).
- **CONCLUSION:** In a group of subjects with LBP, who were classified as being candidates for extension-based treatment, the report of an immediate reduction in pain intensity of 2/10 or greater after a treatment of posterior-to-anterior-directed pressures, followed by prone press-up exercises, was associated with an increase in diffusion of water in the nuclear region of the L5-S1 intervertebral disc. Subjects who did not report a pain reduction of at least 2/10 did not have a change in diffusion. *J Orthop Sports Phys Ther* 2010;40(5):256-264. doi:10.2519/jospt.2010.3284
- **KEY WORDS:** low back pain, magnetic resonance imaging, manual therapy

¹Clinical Associate Professor, Program in Physical Therapy, Department of Exercise Science, School of Public Health and the Department of Developmental Biology and Anatomy, School of Medicine, University of South Carolina, Columbia, SC. ²Clinical Assistant Professor, Program in Physical Therapy, Department of Exercise Science, University of South Carolina, Columbia, SC. ³Assistant Professor of Clinical Internal Medicine, Palmetto Health Systems, Department of Internal Medicine, Richland-Palmetto Health, Columbia, SC. ⁴Doctoral Students, Program in Physical Therapy, Department of Exercise Science, University of South Carolina, Columbia, SC. The protocol for this study was approved by the institutional review board at the University of South Carolina. Address correspondence to Dr Paul Beattie, Department of Exercise Science, School of Public Health and the Department of Developmental Biology and Anatomy, School of Medicine, University of South Carolina, Columbia, SC 29208. E-mail: pbeattie@mailbox.sc.edu

clinical decision making relative to treatment selection.^{5,25,33} One concern, however, is that patients who meet the criteria for a clinical prediction rule or for assignment to a treatment-based classification do not always have a favorable outcome from treatment.^{5,32} Thus, a common question faced by clinicians and researchers is, “Why do some patients with nonspecific LBP who are quite similar relative to examination findings have different responses to the same treatment?”

One potential reason for variation in outcome following treatment may be linked to differences in the physiological responses of lumbar tissues to the stimuli generated by intervention.^{1,2,6,12,21,23,24,43-45} Historically, technologic limitations have made measuring these physiologic responses difficult; thus, little is known regarding this phenomenon. Recently however, an innovative application of lumbar magnetic resonance imaging (MRI) known as diffusion-weighted imaging has allowed investigators to track an important physiologic event within the lumbar spine: the diffusion of water within spinal tissues.^{7,10,36} Diffusion of water is linked to the metabolic environment of tissues and is believed to be associated with variations in loading tolerance within the lumbar intervertebral disc (IVD)^{6,23,24,34,44}; therefore, the measurement of changes in diffusion resulting from intervention may help to identify important variations in physiological responses and their potential relationship to symptoms.^{1-4,6,12,46,47,49} It has been suggested that an increase in diffusion within the nuclear portion of the lumbar IVD may have a favorable effect upon LBP; however, this has not yet been demonstrated.^{6,44,45}

Diffusion-weighted imaging provides an estimate of diffusion of water within specific tissues slices by the calculation of the apparent diffusion coefficient (ADC).^{3,10,36} In previous work,¹⁰ we found that measures of the ADC obtained from the nuclear region in the lumbar IVDs have excellent reliability. In a follow-up study, we observed that the ADC of the L5-S1 IVD was significantly increased

following a 10-minute application of posterior-to-anterior-directed (PA) manual pressures applied to the lumbar spine of people who had a prior history of LBP.⁷ This finding was not present in the same individuals after they had been prone for 10 minutes during a separate session. Based upon this finding, we concluded that PA pressures may generate a stimulus that results in a rapid, measurable increase in diffusion of water within the nuclear region of the IVD. The clinical meaningfulness of this finding was, however, unclear, and, because many of the study subjects were not symptomatic at the time of testing, we were unable to make judgments regarding the relationship of this finding to pain.

In the current study, we expand upon our previous work using a new data set to address differences between those subjects who, although assigned to the same treatment-based classification, had different responses to the same treatment. We chose to investigate an extension-based treatment for subjects who we operationally classified as being a candidate for extension-based treatment. The treatment consisted of PA pressures applied to the spinous processes of the lumbar vertebrae, as described by Maitland,⁴⁰ followed by the prone press-up exercise as described by McKenzie.⁴² We selected this approach because we believed that it is commonly used in clinical settings and would provide both actively and passively generated stimuli that may influence diffusion within the IVD at the lumbosacral joint; however, the conflicting evidence regarding the efficacy and effectiveness of these 2 interventions to reduce pain intensity^{11,20,30,31,37,39,41,50,51} suggested that we observe a variation in the immediate change in pain intensity following this intervention. Identifying physiologic differences in response to these treatments between those subjects who report an immediate reduction in symptoms and those who do not, may help explain 1 reason for inconsistent findings in the literature. This information will be of great value in the continual refinement of treatment-based classification systems.

The purpose of the current study was to determine differences in the changes of diffusion of water in the L5-S1 IVD between those subjects with nonspecific LBP who reported an immediate reduction in pain intensity of 2 or greater on an 11-point (0-10) numeric rating scale after a 10-minute session of lumbar joint mobilization followed by prone press-up exercises, compared to those who did not report an immediate reduction in pain intensity of 2 or greater on the pain scale.

METHODS

Subjects

Inclusion and Exclusion Criteria Study participants were eligible for enrollment if they were aged 20 to 60 years and reported a LBP intensity of at least 2/10 on the verbally administered numeric rating scale at the time of testing.^{19,22,35} In addition, subjects had to have clinical signs and symptoms that suggested that they might be candidates for extension-based treatment consisting of PA pressures followed by prone press-ups. For the purpose of this study, we operationally defined a candidate for extension-based treatment as a subject whose current symptoms of LBP were provoked, or increased, and/or peripheralized (ie, pain was reported to move from the midline laterally, or to the buttocks, and/or lower extremity) with lumbar forward bending^{27,42,54} and prolonged sitting to a greater degree than with lumbar backward bending, or walking. We believed that this finding would be an indication to evaluate prone press-ups as a component of treatment.⁴² In addition, limited anterior displacement of the L5 vertebra was subjectively interpreted as hypomobile during manual assessment.^{27,28} We believed that this finding would indicate the use of PA pressures as a component of treatment.⁴⁰ Lumbar range of motion was assessed visually but was not quantified or used to classify subjects. Potential subjects were excluded if they had any contraindications for undergoing MRI⁸ or lumbar joint mobilization,⁴⁰ had signs of nerve root compression, a visual

evidence of a lateral shift of the spine,⁴² might have been pregnant, or had a history of inflammatory joint disease, osteoporosis, discitis, or neoplastic disorders of the spine. Additional exclusion criteria included a history of invasive procedure to the lumbar spine, or evidence of any of the following abnormalities visible on T2-weighted imaging: lumbar disc extrusion,⁹ severe nerve compression,⁹ spondylolisthesis of greater than 4 mm, and/or sacralization of a lumbar vertebra.

Recruitment Potential subjects were recruited by word of mouth from the local community. To maximize the likelihood that interested potential subjects would be appropriate for this study, they were initially contacted by a member of the study team and underwent a prescreen to determine the presence of inclusion and exclusion criteria. Eligible potential subjects were then scheduled for an appointment at the McCausland Brain Imaging Center, where all data were collected.

Intake Measures and Patient Classification

At the time of the appointment, potential subjects initially underwent standard safety screening for MRI and provided written informed consent, as approved by the institutional review board at the University of South Carolina. Potential subjects completed a medical screening form, a pain drawing, the Roland-Morris Back Pain Disability Questionnaire,⁵³ and questions regarding the effects of sitting, walking, standing, and forward and backward bending on their current symptoms. At this time, potential subjects provided a verbal estimate of pretreatment current pain intensity using the 11-point numeric rating scale.^{19,22,35} The anchor points described to each potential subject were, “How would you rate your current pain intensity if 0 equals no pain and 10 is the worst imaginable pain?” Those potential subjects who were still eligible underwent a physical examination performed by one of the authors (P.B.) in a room adjacent to the scanner. This examination began with visual assessment of standing posture to

TABLE 1	IMAGING PARAMETERS
T2-weighted images	
Slice thickness	4 mm
FoV read	280 mm
FoV phase	98.4%
TR	3200 ms
TE	79 ms
Flip angle	120°
Fat and water suppression	Not used
Base resolution	512 dpi
Bandwidth	257 Hz/pixel
Diffusion-weighted images	
b-factor	400 s/mm ²
Voxel size	2.3 × 2.3 × 2.3 mm
TE	76 ms
TR	6000 ms
EPI echo spacing	0.73 ms
Bandwidth	1628 Hz/pixel
Averages (n) acquired to compute the ADC	10
<i>Abbreviations: ADC, apparent diffusion coefficient; EPI, echo planar imaging; FoV, field of view; TE, echo time; TR, repetition time.</i>	

exclude those subjects who presented with a lateral shift. This was followed by 5 repetitions of active lumbar flexion and 5 repetitions of lumbar extension. Subjects who reported peripheralization of symptoms during lumbar extension or reported greater pain during lumbar extension than during lumbar flexion were excluded.⁴² Subjects were then positioned supine, where active range of motion of hip flexion, hip internal and external rotation, and passive straight leg raising were determined by visual assessment. Passive overpressure was applied at the end of each of these motions. Subjects who reported distal lower extremity pain during passive straight leg raising at less than 45° were excluded.⁵² Following this, subjects were positioned prone, and 2 passive PA pressures were applied to the spinous process of the L5 vertebra to the end of the available range of motion, as perceived by the examiner.⁴⁰ The examiner classified the mobility of the motion segment as normal, hypermobile, or hypomobile.^{28,29} Potential subjects classified as normal or hypermobile, or those who

reported a peripheralization of symptoms during this maneuver were excluded. The remaining subjects were classified as candidates for extension-based treatment, and were enrolled in the study.

Imaging Procedure

Subjects were imaged supine with the hips and knees maintained at 30° of flexion by a bolster positioned behind the knees. Spin echo techniques, using multi-element spine coils, were used to obtain T2-weighted sagittal views. These images were used to assist in ruling out contraindications for treatment and to classify the L5-S1 IVD, based upon the presence or absence of degeneration. Following this procedure, subjects underwent a diffusion-weighted MRI scan using a single-shot, dual spin echo, echo planar imaging acquisition with multi-element spine coils and abdominal coils. Images were obtained using a Siemens Trio 3.0 Tesla MRI scanner at the McCausland Brain Imaging Center, Richland-Palmetto Hospital, Columbia, SC. The imaging parameters are listed in **TABLE 1**.

Extension-Based Intervention

Upon completion of the pretreatment scan, one of the authors (C.A.) entered the scan room, removed the subject from the scanner, and assisted the subject to roll into the prone position. This author, who is a fellow in the American Academy of Orthopedic Manual Physical Therapists, was blinded to all subject information. She began the intervention by performing graded oscillating PA pressures to the spinous processes of each lumbar vertebra, starting with L5 and progressing rostrally to L1. Each pressure was performed using the I-to-IV grading scale described by Maitland,⁴⁰ at the highest grade below the threshold for pain reporting. Two sets of oscillating pressures of 30 seconds each were performed at each level. Immediately after the manual therapy intervention, the patient was instructed to perform 3 sets of 10 prone press-ups, using the procedure described by McKenzie.⁴² Upon completion of the intervention, the subject was returned to the supine position, and re-entered the MRI for the repeat scans. Upon completion of the repeat scans, the subject provided a posttreatment estimate of current pain intensity using the 11-point numeric rating scale (FIGURE 1).

Evaluation of Images

Classification of T2-Weighted Signal A modification of the rating scale developed by Pfirrmann et al⁴⁸ that identifies the presence and degree of IVD degeneration based upon the intensity (brightness) and homogeneity of the T2-signal in the nuclear region was used for this study as follows: normal, nucleus is homogenous and bright white, with a clear distinction between annulus and nucleus; degenerative, nucleus is inhomogenous and appears gray or black (FIGURES 2A and 3A).⁷ Each of the T2-weighted, midsagittal images obtained during the initial scanning of all subjects were evaluated independently by 2 of the authors (P.B. and J.D.) to classify the L5-S1 IVD as normal or degenerative. Consensus between the 2 examiners was used to address any

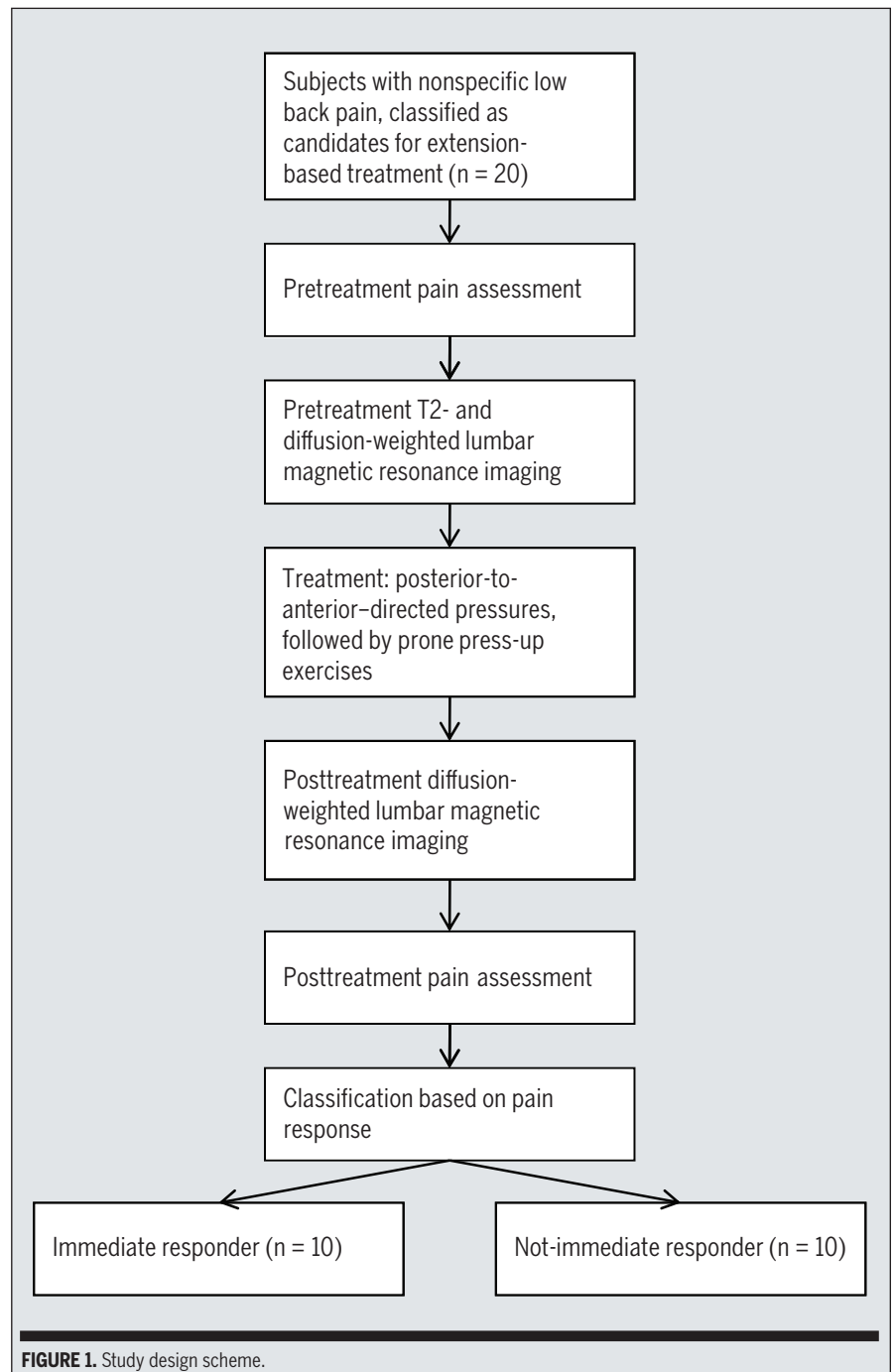


FIGURE 1. Study design scheme.

disagreements in classification.

Determination of ADC Values Maps of the mean ADC were calculated online by the MRI scanner (FIGURES 2B-C and 3B-C). After the images were obtained, the coded files were saved and transferred to a remote workstation for analysis. The midsagittal ADC maps were used to ob-

tain measures of the ADC from the central, nuclear region of L5-S1 for all scans. We chose to concentrate on the L5-S1 segment based upon our previous study, which suggested that this segment demonstrated significant increases in diffusion following joint mobilization, and the fact that previous research suggests that

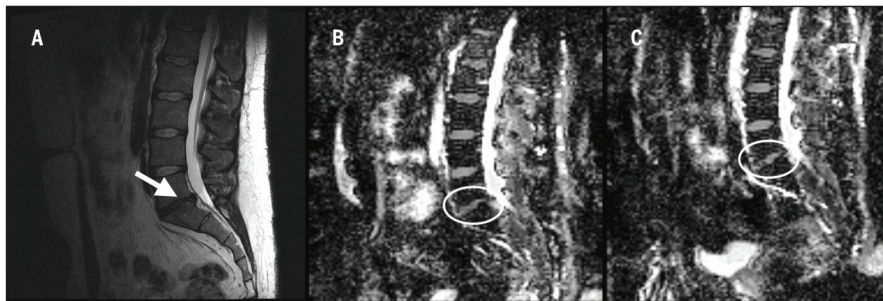


FIGURE 2. Midsagittal images obtained from a 26-year-old male with acute lumbosacral pain who was an immediate responder to extension-based intervention. (A) Preintervention T2-weighted image. Note the reduced T2-signal intensity in the nuclear region of the L5-S1 intervertebral disc (arrow). (B) Preintervention apparent diffusion coefficient (ADC) map of diffusion-weighted images revealed an ADC of $1.14 \times 10^{-3} \text{ mm}^2/\text{s}$. (C) Postintervention ADC map of diffusion-weighted images revealed an ADC of $1.79 \times 10^{-3} \text{ mm}^2/\text{s}$.

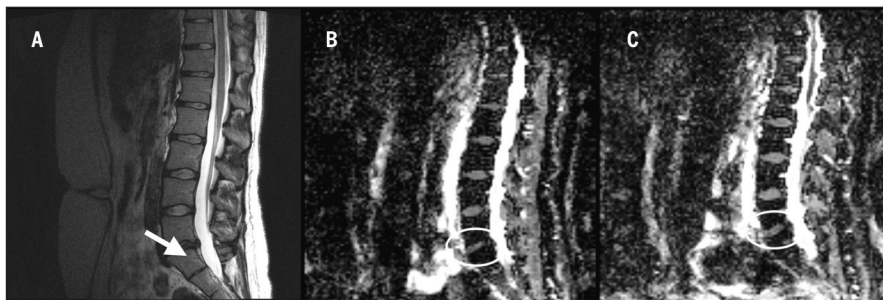


FIGURE 3. Midsagittal images obtained from a 24-year-old female with acute lumbosacral pain who was not an immediate responder to extension-based intervention. (A) Preintervention T2-weighted image. Note the reduced T2-signal intensity in the nuclear region of the L5-S1 intervertebral disc that is similar to that seen in **FIGURE 2A** above (arrow). (B) Preintervention apparent diffusion coefficient (ADC) map of diffusion-weighted images revealed an ADC of $1.62 \times 10^{-3} \text{ mm}^2/\text{s}$ in the nuclear region of the L5-S1 intervertebral disc. (C) Postintervention ADC map of diffusion-weighted images revealed an ADC of $1.41 \times 10^{-3} \text{ mm}^2/\text{s}$.

this segment is often a pain generator in individuals with LBP.^{2,9,7,16,18}

The ADC values were calculated using standard software available on the workstation that assessed signal intensity within the pixels selected by examiners using a circular region of interest. Care was taken to restrict the region of interest to the exact center of the L5-S1 IVD and to avoid partial volume effect (ie, the heterogeneity of tissue that could occur by including the vertebral bodies or endplates in the region of interest). Measures obtained using this technique have been shown to be reliable, with intraclass correlation coefficients (ICCs) ranging from 0.95 to 0.99 and the standard error of measure (SEM) ranging from 0.006 to $0.026 \times 10^{-3} \text{ mm}^2/\text{s}$ (0.1%-5.5%).¹⁰

To reduce measurement bias and to confirm reliability, 2 different authors (H.N. and L.B.) obtained all measures

of ADC, while blinded to all subject information (subject code, date, test condition, and T2-findings). Blinding was accomplished by a third party who, after authors H.N. and L.B. left the room, randomly selected each image to be evaluated and placed a file card over all patient identifiers. Following this, authors H.N. and L.B. separately entered the room, obtained measures of the ADC, and recorded them on separate data sheets. The entire process was repeated 1 week later.

Classification of Immediate and Not-Immediate Responders

Subjects whose posttreatment pain intensity, using the 11-point numeric rating scale, had a reduction of greater than or equal to 2/10 when subtracted from the pretreatment pain intensity were classified as immediate responders. All others were classified as not-immediate

responders. The change score of greater than or equal to 2/10 was chosen because previous research has suggested that this represents a likely minimal detectable change in this scale.^{19,22}

Data Analysis

Reliability of Measures of the ADC The intrarater and interrater reliability of measures of the ADC obtained by examiners H.N. and L.B. was calculated in 2 ways. Absolute agreement between each set of paired measures was assessed using the average measures obtained from a 2-way mixed-effect ICC. The likely magnitude of error was then determined using the SEM, calculated as $SD \times \sqrt{1-ICC}$.¹⁰ Point estimates and 95% confidence intervals were calculated for each of these statistics.

Characteristics of Immediate Compared to Not-Immediate Responders To provide a broader description of our sample, continuous and categorical variables representing subject characteristics prior to treatment were assessed. We used 2 approaches to determine the presence of any differences in these measures between subjects classified as immediate responders compared to those classified as not-immediate responders. An independent *t* test was used to assess between-group mean differences for continuous variables (age, body mass index [BMI], Roland Morris score, and pretreatment measures of pain intensity), and a Pearson chi-square test was used to determine between-group differences in frequencies for categorical variables (duration of current symptoms, history of prior back problems, presence or absence of disc degeneration visible on T2-weighted images, and anatomic locations of symptoms).

ADC Values of Immediate Compared to Not-Immediate Responders Pretreatment and posttreatment ADC values of the nuclear region in the L5-S1 IVD for subjects in both groups were summarized and tested for assumptions of normality using the Shapiro-Wilk test. To determine the presence of significant

differences in the ADC values between immediate and not-immediate responders that occurred over time, we used a general linear model, repeated-measures, 2-by-2 (time by response group) analysis of variance (ANOVA), with preintervention and postintervention ADC as the within-subjects factor and group assignment (immediate responder or not-immediate responder) as the between-subjects factor. This statistical approach was chosen to allow us to examine the main effect of treatment, as well as the presence or absence of a significant interaction between group assignment and the preintervention to postintervention change in ADC. The α value was arbitrarily set at .05/2 (.025). To provide an estimate of the strength of the differences in the within- and between-group comparisons in ADC values, we calculated effect sizes using Cohen d .¹⁷ All analyses were performed with SPSS Version 17.0 (SPSS, Inc, Chicago, IL).

RESULTS

Subject Characteristics

A TOTAL OF 23 SUBJECTS WERE scheduled for appointment following prescreening and evaluated for potential enrollment in this study between October 2008 and May 2009. Of these, 3 potential subjects were asymptomatic at the time of testing and were not enrolled. The remaining 20 subjects were classified as candidates for extension-based treatment and were enrolled in this study. Of those enrolled in the study, a total of 12 subjects were female and 8 were male. Their mean (SD) age was 30.4 (9.7) years. All subjects were working full-time at the time of the study or were full-time students.

Reliability of Measures of ADC

Assessment of intrarater reliability of measures of ADC yielded ICCs of 0.98 (95% CI: 0.96-0.99) for examiner H.N. and 0.98 (95% CI: 0.95-0.99) for examiner L.B. The ICC between examiners was 0.99 (95% CI: 0.98-1.00), with the SEM of 0.005×10^{-3}

TABLE 2		PATIENT CHARACTERISTICS FOR THE IMMEDIATE AND NOT-IMMEDIATE RESPONDER GROUPS*	
Subject Characteristic	Immediate Responder	Not-Immediate Responder	
Age (y)	33.1 (12.3)	27.8 (5.7)	
Body mass index	25.1 (6.2)	21.9 (4.2)	
Roland-Morris score (0-24)	4.2 (2.7)	3.2 (2.3)	
Pretreatment pain (0-10)	3.8 (1.5)	3.5 (1.2)	
Average pain on typical day (0-10)	3.4 (1.8)	3.6 (1.3)	
Highest pain on a typical day (0-10)	7.0 (1.3)	6.9 (1.5)	
Lowest pain on a typical day (0-10)	1.7 (1.8)	1.5 (1.4)	

* There were no significant differences in the mean values between the 2 responder groups. Data are expressed as mean (SD).

TABLE 3		FREQUENCY COUNTS OF PATIENT CHARACTERISTICS FOR THE IMMEDIATE AND NOT-IMMEDIATE RESPONDER GROUPS	
Subject Characteristic	Description	Immediate Responders	Not-Immediate Responders
Duration of current episode	2 mo or less	6*	0
	More than 2 mo, less than 6 mo	0	1
	6 mo or longer	4	9*
Lifetime history	No back problems before current episode	4	5
	Previous back problems before current episode	6	5
Anatomic location of symptoms	Low back only	5	6
	Low back as well as buttock and/or thigh	5	4
Decreased T2 signal at L5-S1 intervertebral disc	Yes	6	5
	No	4	5

* Significant difference $P < .05$.

mm²/s (95% CI: $0.00-0.01 \times 10^{-3}$ mm²/s) representing a mean error of approximately 1.4% for interrater reliability.

Comparison of Sample Characteristics Between Immediate and Not-Immediate Responders

Ten subjects (5 males and 5 females) had a reduction in pain intensity of greater than or equal to 2/10 immediately following treatment and were classified as immediate responders. The remaining 10 subjects, 3 of whom were male and 7 of whom were female, were classified as the not-immediate responders. There were no significant between-group differences in age, BMI, Roland-Morris scores, or pretreatment pain reports (TABLE 2). Six

of those subjects classified as immediate responders reported that the duration of their current episode of symptoms was less than 2 months, while 9 out of 10 of those subjects classified as not-immediate responders reported that the duration of their current episode of symptoms was greater than 6 months ($\chi^2 = 8.92$, $df = 2$, $P = .012$). There were no other pretreatment differences in self-report measures, nor were there differences in the frequency of reduced T2-signal intensities between these groups (TABLE 3).

Comparison of ADC Values Between Immediate and Not-Immediate Responders

A significant interaction between response group and time was present

TABLE 4

THE APPARENT DIFFUSION COEFFICIENT (ADC) FOR THE IMMEDIATE AND NOT-IMMEDIATE RESPONDER GROUPS BEFORE AND AFTER TREATMENT*

Subject Classification	Total Sample (n = 20)	Immediate Responder (n = 10)	Not-Immediate Responder (n = 10)
Mean (SD) pretreatment ADC	1.89 (0.19)	1.91 (0.20)	1.86 (0.18)
Mean (SD) posttreatment ADC	1.91 (0.21)	1.99 (0.15)	1.83 (0.23)
Mean (SD) change in ADC	0.03 (0.09)	0.08 (0.08)	-0.03 (0.07)
Percent change in mean ADC	1.60%	4.20%	-1.60%
95% confidence interval of change in mean ADC	-0.02-0.07	0.03-0.14	-0.08-0.07

*ADC is expressed in units of $\times 10^{-3} \text{ mm}^2/\text{s}$.

($F = 10.05$, $df = 18$, $P = .005$), suggesting that the immediate responder group had a greater change in ADC than did the not-immediate responder group. Prior to treatment, the mean ADC of the immediate responder group was $1.91 \times 10^{-3} \text{ mm}^2/\text{s}$, while that of the not-immediate responder group was $1.86 \times 10^{-3} \text{ mm}^2/\text{s}$. Following treatment, the mean ADC for the immediate responder group was $1.99 \times 10^{-3} \text{ mm}^2/\text{s}$, while that of the not-immediate responder group was $1.83 \times 10^{-3} \text{ mm}^2/\text{s}$. This represented a 4.2% increase in the mean ADC for the immediate responders and a decrease of 1.6% for the not-immediate responders (TABLE 4). The posttreatment effect size difference in ADC between these groups was 0.36.

DISCUSSION

IN OUR SAMPLE, SUBJECTS WHO WERE classified as candidates for extension-based treatment and who reported a reduction of pain intensity immediately following a treatment of manually applied PA pressures followed by prone press-up exercises had a small (4.2%) but significant mean increase in the diffusion of water within the central, nuclear area of the lumbar L5-S1 IVD. Those subjects who were classified as candidates for extension-based treatment but did not report a reduction in pain intensity of greater than or equal to 2/10 following treatment had no change in the ADC. These results, although preliminary, suggest the potential for a linkage between changes in diffusion

of water within the L5-S1 IVD and patient reports of changes in pain immediately following the application of an extension-based treatment approach that combines manual therapy and exercise. This may illustrate 1 physiologic mechanism by which analgesia results in some patients immediately following lumbar PA pressures followed by prone press-up exercises.

The reasons for the observed differences in diffusion between the 2 responder groups is unknown. One potential reason may relate to variations in changes in intersegmental range of motion following treatment. Powers et al,⁵⁰ using a sample similar to ours, examined the effects of PA pressures compared to prone press-up exercises on intersegmental motion by calculating a series of intervertebral angles from T2-weighted images of prone subjects before and after treatment. The authors reported an association between increased total lumbar extension and reduced pain scores immediately following intervention. Thus, it is possible that immediate responders in our study may have had greater improvements in segmental or total range of motion of the lumbar spine compared to the nonresponder group; however, we did not obtain these measures. Another potential reason for between-group differences in diffusion and pain reduction may be that those subjects who did not report pain during PA pressures were more likely to receive a higher magnitude of pressures (grade III and grade IV), while those subjects who reported pain were more likely to receive

grade I and grade II pressures.¹¹

Because of the preliminary nature of our findings, it is difficult to determine their immediate clinical relevance. Describing the physiologic effects of lumbar manual therapy has great importance relative to refining the current applications of these techniques and to the development of future approaches to manual therapy. This will require a multistage series of investigations that assess biomechanical, morphologic, and electrophysiologic changes that result from various applications of manual therapy. Future work related to the present study will assess longitudinal changes in diffusion and relate them to T2 signals, pain response, intersegmental motion, and psychobehavioral variables.

Several limitations to the current study should be acknowledged. The intent was to provide preliminary evidence to guide further, larger clinical trials. It is important to note that we only assessed the immediate change in reported pain intensity. We are unable to make any judgments from our data regarding the association between our intervention and longer-term changes in reported pain intensity. Our small sample was one of convenience and represented individuals with relatively low pain intensities and degrees of activity limitation. It is not known if our findings would be reproduced in larger, more heterogeneous samples of subjects with LBP. Thus our findings lack external validity relative to the overall population of people receiving care for LBP. An additional limitation of our study is that our measures of the ADC represent only the center, midsagittal portion of the L5-S1 disc; further study that assesses the entire disc using a 3-D representation is needed.

CONCLUSIONS

IN A GROUP OF SUBJECTS WITH LBP, who were classified as being candidates for extension-based treatment, the report of an immediate reduction in pain intensity of 2/10 or greater following

a treatment of PA pressures followed by prone press-up exercises was associated with an increase in diffusion of water in the nuclear region of the L5-S1 IVD. Subjects who did not report a pain reduction of 2/10 or greater did not have a change in diffusion. ●

KEY POINTS

FINDINGS: Patients with nonspecific LBP who were classified as candidates for extension-based treatment to the lumbar spine received a treatment of lumbar PA pressures followed by prone press-up exercises. The patients who reported a decrease in their pain of 2/10 or greater had evidence of an increase in diffusion of the nuclear region of the L5-S1 intervertebral disc, while those who did not report a decrease in pain of 2/10 greater had no change in diffusion at the L5-S1 level.

IMPLICATION: These findings suggest a relationship between changes in diffusion within the IVD at L5-S1 and changes in pain intensity for patients with nonspecific LBP. This may explain one mechanism by which manual therapy treatment could have an immediate effect on pain reports.

CAUTION: These findings are preliminary and may not be applicable to other groups of patients with nonspecific LBP.

ACKNOWLEDGEMENTS: *The authors would like to thank Claire Coyne, Courtney Kelso, Katie Hutchinson, Karen Bonney, Scott Gams, Brandon Vaughn, and Kimmy Gillespie for their kind assistance on this project.*

REFERENCES

- Adams MA, McNally DS, Dolan P. 'Stress' distributions inside intervertebral discs. The effects of age and degeneration. *J Bone Joint Surg Br.* 1996;78:965-972.
- Adams MA, Roughley PJ. What is intervertebral disc degeneration, and what causes it? *Spine.* 2006;31:2151-2161.
- Antoniou J, Demers CN, Beaudoin G, et al. Apparent diffusion coefficient of intervertebral discs related to matrix composition and integrity. *Magn Reson Imaging.* 2004;22:963-972.

- <http://dx.doi.org/10.1016/j.mri.2004.02.011>
- Aoki Y, Ohtori S, Takahashi K, et al. Innervation of the lumbar intervertebral disc by nerve growth factor-dependent neurons related to inflammatory pain. *Spine (Phila Pa 1976).* 2004;29:1077-1081.
 - Beattie P, Nelson R. Clinical prediction rules: what are they and what do they tell us? *Aust J Physiother.* 2006;52:157-163.
 - Beattie PF. Current understanding of lumbar intervertebral disc degeneration: a review with emphasis upon etiology, pathophysiology, and lumbar magnetic resonance imaging findings. *J Orthop Sports Phys Ther.* 2008;38:329-340. <http://dx.doi.org/10.2519/jospt.2008.2768>
 - Beattie PF, Donley JW, Arnot CF, Miller R. The change in the diffusion of water in normal and degenerative lumbar intervertebral discs following joint mobilization compared to prone lying. *J Orthop Sports Phys Ther.* 2009;39:4-11. <http://dx.doi.org/10.2519/jospt.2009.2994>
 - Beattie PF, Meyers SP. Magnetic resonance imaging in low back pain: general principles and clinical issues. *Phys Ther.* 1998;78:738-753.
 - Beattie PF, Meyers SP, Stratford P, Millard RW, Hollenberg GM. Associations between patient report of symptoms and anatomic impairment visible on lumbar magnetic resonance imaging. *Spine (Phila Pa 1976).* 2000;25:819-828.
 - Beattie PF, Morgan PS, Peters D. Diffusion-weighted magnetic resonance imaging of normal and degenerative lumbar intervertebral discs: a new method to potentially quantify the physiologic effect of physical therapy intervention. *J Orthop Sports Phys Ther.* 2008;38:42-49. <http://dx.doi.org/10.2519/jospt.2008.2631>
 - Benec GJ, Kulig K, Landel RF, Powers CM. The relationship between lumbar segmental motion and pain response produced by a posterior-to-anterior force in persons with nonspecific low back pain. *J Orthop Sports Phys Ther.* 2005;35:203-209. <http://dx.doi.org/10.2519/jospt.2005.1479>
 - Brisby H. Pathology and possible mechanisms of nervous system response to disc degeneration. *J Bone Joint Surg Am.* 2006;88 Suppl 2:68-71. <http://dx.doi.org/10.2106/JBJS.E.01282>
 - Bronfort G, Haas M, Evans R, Kawchuk G, Dagenais S. Evidence-informed management of chronic low back pain with spinal manipulation and mobilization. *Spine J.* 2008;8:213-225. <http://dx.doi.org/10.1016/j.spinee.2007.10.023>
 - Bronfort G, Haas M, Evans RL, Bouter LM. Efficacy of spinal manipulation and mobilization for low back pain and neck pain: a systematic review and best evidence synthesis. *Spine J.* 2004;4:335-356. <http://dx.doi.org/10.1016/j.spinee.2003.06.002>
 - Browder DA, Childs JD, Cleland JA, Fritz JM. Effectiveness of an extension-oriented treatment approach in a subgroup of subjects with low back pain: a randomized clinical trial. *Phys Ther.* 2007;87:1608-1618; discussion 1577-1609. <http://dx.doi.org/10.2522/ptj.20060297>
 - Brown MF, Hukkanen MV, McCarthy ID, et al. Sensory and sympathetic innervation of the vertebral endplate in patients with degenerative disc disease. *J Bone Joint Surg Br.* 1997;79:147-153.
 - Carlson K, Schmidt F. Impact of experimental design on effect size: findings from the research literature on training. *J Appl Psychol.* 1999;84:851-862.
 - Cavanaugh JM. Neural mechanisms of lumbar pain. *Spine (Phila Pa 1976).* 1995;20:1804-1809.
 - Childs JD, Piva SR, Fritz JM. Responsiveness of the numeric pain rating scale in patients with low back pain. *Spine (Phila Pa 1976).* 2005;30:1331-1334.
 - Chiradejanant A, Maher CG, Latimer J, Steptovitch N. Efficacy of "therapist-selected" versus "randomly selected" mobilisation techniques for the treatment of low back pain: a randomised controlled trial. *Aust J Physiother.* 2003;49:233-241.
 - Costi JJ, Stokes IA, Gardner-Morse MG, Iatridis JC. Frequency-dependent behavior of the intervertebral disc in response to each of six degree of freedom dynamic loading: solid phase and fluid phase contributions. *Spine (Phila Pa 1976).* 2008;33:1731-1738. <http://dx.doi.org/10.1097/BRS.0b013e31817bb116>
 - Farrar JT, Young JP, Jr., LaMoreaux L, Werth JL, Poole RM. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain.* 2001;94:149-158.
 - Ferguson SJ, Ito K, Nolte LP. Fluid flow and convective transport of solutes within the intervertebral disc. *J Biomech.* 2004;37:213-221.
 - Ferrara L, Triano JJ, Sohn MJ, Song E, Lee DD. A biomechanical assessment of disc pressures in the lumbosacral spine in response to external unloading forces. *Spine J.* 2005;5:548-553. <http://dx.doi.org/10.1016/j.spinee.2005.03.012>
 - Flynn T, Fritz J, Whitman J, et al. A clinical prediction rule for classifying patients with low back pain who demonstrate short-term improvement with spinal manipulation. *Spine (Phila Pa 1976).* 2002;27:2835-2843. <http://dx.doi.org/10.1097/01.BRS.0000035681.33747.8D>
 - Freburger JK, Holmes GM, Agans RP, et al. The rising prevalence of chronic low back pain. *Arch Intern Med.* 2009;169:251-258. <http://dx.doi.org/10.1001/archinternmed.2008.543>
 - Fritz JM, Cleland JA, Childs JD. Subgrouping patients with low back pain: evolution of a classification approach to physical therapy. *J Orthop Sports Phys Ther.* 2007;37:290-302. <http://dx.doi.org/10.2519/jospt.2007.2498>
 - Fritz JM, Piva SR, Childs JD. Accuracy of the clinical examination to predict radiographic instability of the lumbar spine. *Eur Spine J.* 2005;14:743-750. <http://dx.doi.org/10.1007/s00586-004-0803-4>
 - Fritz JM, Whitman JM, Childs JD. Lumbar spine segmental mobility assessment: an examination of validity for determining intervention strategies in patients with low back pain. *Arch Phys Med Rehabil.* 2005;86:1745-1752. <http://dx.doi.org/10.1016/j.apmr.2005.03.012>

[RESEARCH REPORT]

- org/10.1016/j.apmr.2005.03.028
30. Goodsell M, Lee M, Latimer J. Short-term effects of lumbar posteroanterior mobilization in individuals with low-back pain. *J Manipulative Physiol Ther.* 2000;23:332-342.
 31. Hahne AJ, Keating JL, Wilson SC. Do within-session changes in pain intensity and range of motion predict between-session changes in patients with low back pain? *Aust J Physiother.* 2004;50:17-23.
 32. Hancock M, Herbert RD, Maher CG. A guide to interpretation of studies investigating subgroups of responders to physical therapy interventions. *Phys Ther.* 2009;89:698-704. <http://dx.doi.org/10.2522/ptj.20080351>
 33. Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. *Arch Phys Med Rehabil.* 2005;86:1753-1762.
 34. Horner HA, Urban JP. 2001 Volvo Award Winner in Basic Science Studies: Effect of nutrient supply on the viability of cells from the nucleus pulposus of the intervertebral disc. *Spine (Phila Pa 1976).* 2001;26:2543-2549.
 35. Jensen MP, Karoly P, Braver S. The measurement of clinical pain intensity: a comparison of six methods. *Pain.* 1986;27:117-126.
 36. Kealey SM, Aho T, DeLong D, Barboriak DP, Provenzale JM, Eastwood JD. Assessment of apparent diffusion coefficient in normal and degenerated intervertebral lumbar disks: initial experience. *Radiology.* 2005;235:569-574. <http://dx.doi.org/10.1148/radiol.2352040437>
 37. Long A, Donelson R, Fung T. Does it matter which exercise? A randomized control trial of exercise for low back pain. *Spine.* 2004;29:2593-2602.
 38. Macedo LG, Maher CG, Latimer J, McAuley JH. Motor control exercise for persistent, nonspecific low back pain: a systematic review. *Phys Ther.* 2009;89:9-25. <http://dx.doi.org/10.2522/ptj.20080103>
 39. Machado LA, de Souza MS, Ferreira PH, Ferreira ML. The McKenzie method for low back pain: a systematic review of the literature with a meta-analysis approach. *Spine (Phila Pa 1976).* 2006;31:E254-262. <http://dx.doi.org/10.1097/01.brs.0000214884.18502.93>
 40. Maitland GD. *Maitland's Vertebral Manipulation.* 7th ed. London, UK: Butterworth-Heinemann; 2005.
 41. McCollam RL, Benson C. Effects of postero-anterior mobilization on lumbar extension and flexion. *J Man Manip Ther.* 1993;1:134-141.
 42. McKenzie RA. *The Lumbar Spine: Mechanical Diagnosis and Therapy.* Christchurch, New Zealand: Spinal Publications; 1981.
 43. Natarajan RN, Williams JR, Andersson GB. Modeling changes in intervertebral disc mechanics with degeneration. *J Bone Joint Surg Am.* 2006;88 Suppl 2:36-40. <http://dx.doi.org/10.2106/JBJS.F.00002>
 44. Nguyen-minh C, Riley L, 3rd, Ho KC, Xu R, An H, Haughton VM. Effect of degeneration of the intervertebral disk on the process of diffusion. *AJNR Am J Neuroradiol.* 1997;18:435-442.
 45. Niosi CA, Oxland TR. Degenerative mechanics of the lumbar spine. *Spine J.* 2004;4:202S-208S. <http://dx.doi.org/10.1016/j.spinee.2004.07.013>
 46. Osti OL, Vernon-Roberts B, Moore R, Fraser RD. Annular tears and disc degeneration in the lumbar spine. A post-mortem study of 135 discs. *J Bone Joint Surg Br.* 1992;74:678-682.
 47. Peng B, Hao J, Hou S, et al. Possible pathogenesis of painful intervertebral disc degeneration. *Spine (Phila Pa 1976).* 2006;31:560-566. <http://dx.doi.org/10.1097/01.brs.0000201324.45537.46>
 48. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N. Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine (Phila Pa 1976).* 2001;26:1873-1878.
 49. Podichetty VK. The aging spine: the role of inflammatory mediators in intervertebral disc degeneration. *Cell Mol Biol (Noisy-le-grand).* 2007;53:4-18.
 50. Powers CM, Beneck GJ, Kulig K, Landel RF, Fredericson M. Effects of a single session of posterior-to-anterior spinal mobilization and press-up exercise on pain response and lumbar spine extension in people with nonspecific low back pain. *Phys Ther.* 2008;88:485-493. <http://dx.doi.org/10.2522/ptj.20070069>
 51. Rasmussen J, Laetgaard J, Lindecrona AL, Qvistgaard E, Bliddal H. Manipulation does not add to the effect of extension exercises in chronic low-back pain (LBP). A randomized, controlled, double blind study. *Joint Bone Spine.* 2008;75:708-713. <http://dx.doi.org/10.1016/j.jbspin.2007.12.011>
 52. Rebain R, Baxter GD, McDonough S. A systematic review of the passive straight leg raising test as a diagnostic aid for low back pain (1989 to 2000). *Spine (Phila Pa 1976).* 2002;27:E388-395.
 53. Roland M, Morris R. A study of the natural history of back pain. Part I: development of a reliable and sensitive measure of disability in low-back pain. *Spine (Phila Pa 1976).* 1983;8:141-144.
 54. Werneke MW. Letters to the Editor-in-Chief. *J Orthop Sports Phys Ther.* 2009;39:827-828. <http://dx.doi.org/10.2519/jospt.2009.0204>



MORE INFORMATION

WWW.JOSPT.ORG

DOWNLOAD PowerPoint Slides of JOSPT Figures & Tables

JOSPT offers **PowerPoint slides of figures and tables** to accompany selected articles on the *Journal's* website (www.jospt.org). These slides can be downloaded and saved and include the article title, authors, and full citation. With each article where this feature is available, click **“View Slides”** and then right click on the link and select **“Save Target As”**.