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ABSTRACT

Understanding the clinical characteristics of patients with low back pain (LBP) who display improved lumbar multifidus (LM) muscle function after spinal manipulative therapy (SMT) may provide insight into a potentially synergistic interaction between SMT and exercise. Therefore, the purpose of this study was to identify the baseline historical and physical examination factors associated with increased contracted LM muscle thickness one week after SMT. Eighty-one participants with LBP underwent a baseline physical examination and ultrasound imaging assessment of the LM muscle during submaximal contraction before and one week after SMT. The relationship between baseline examination variables and 1-week change in contracted LM thickness was assessed using correlation analysis and hierarchical multiple linear regression. Four variables best predicted the magnitude of increases in contracted LM muscle thickness after SMT. When combined, these variables suggest that patients with LBP, (1) that are fairly acute, (2) have at least a moderately good prognosis without focal and irritable symptoms, and (3) exhibit signs of spinal instability, may be the best candidates for a combined SMT and lumbar stabilization exercise (LSE) treatment approach.

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1. Introduction

Low back pain (LBP) is one of the most costly and prevalent medical conditions in the world (Dagenais et al., 2008; Walker, 2000). Despite many recent advances in imaging and surgical technology, identifying a specific pathoanatomical cause is not possible in the majority of LBP patients (Deyo and Weinstein, 2001; Deyo et al., 2009). This lack of a consistent relation between pathoanatomy and symptoms has instigated more recent attempts to classify LBP patients according to the intervention with which gives them the greatest benefit (Fritz et al., 2007a; Hebert et al., 2008). For example, clinical prediction rules have been developed to identify subgroups of patients likely to respond to spinal manipulation therapy (SMT) (Childs et al., 2004; Flynn et al., 2002) and lumbar stabilization exercise (LSE) (Hicks et al., 2005). While these clinical prediction rules appear to identify unique subgroups of patients who preferentially respond to SMT or LSE, they remain at various stages of validation (Haskins et al., 2012). Moreover, other evidence suggests that combining SMT and LSE results in superior clinical outcomes than either intervention alone (UK BEAM, 2004).

A growing body of evidence has reported an association between functional deficits of the lumbar multifidus (LM) muscle and LBP (Dickx et al., 2010; Hungerford et al., 2003; MacDonald et al., 2006; Wallwork et al., 2008). In previous work, we have found a relationship between the clinical factors identifying LSE responders and deficits in the LM muscle as measured by ultrasound imaging (Hebert et al., 2010). Most recently we have found changes in contracted LM thickness were associated with improved LBP-related disability one week after SMT (Koppenhaver et al., 2011). Together these findings lend support to the hypothesis that SMT may provide a facilitatory stimulus ("jump start") to the LM muscle, which may help initiate clinical recovery from LBP (Gill et al., 2007; Konitzer et al., 2011). Of interest, the changes that were observed in contracted LM thickness after SMT were not seen in all patients with LBP; rather the direction and extent of change was highly variable and dependent upon the individual (Koppenhaver et al., 2011).

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With these observations, understanding the range of clinical characteristics that describe patients with LBP who display improved LM function after SMT may provide further insight into a potentially synergistic interaction between SMT and LSE. Therefore, the purpose of this study was to identify the baseline historical and physical examination factors associated with increased LM muscle thickness during submaximal contraction after SMT.

2. Methods

2.1. Design overview

Data for this paper was collected originally from a prospective cohort study that examined the relation between improved disability and changes in resting and contracted abdominal and LM muscle thickness following SMT in LBP patients. The full details of the study have been published elsewhere (Koppenhaver et al., 2011) and showed that increased contracted LM thickness predicted improved LBP-related disability one week after SMT. While we also observed similar changes in other muscles (transverse abdominis and internal oblique), they were transient and unrelated to improvements in LBP related disability.

2.2. Subjects

Subjects were recruited from two geographic locations: (1) by responding to flyers posted around the University of Utah campus, and (2) from the Physical Therapy Department of Brooke Army Medical Center in San Antonio, Texas. The participant selection criteria are listed in Table 1.

2.3. Procedures

Subjects attended three sessions within one week. Session 1 included self-report questionnaires, baseline history and physical examination, SMT treatment, and pre- and post-SMT measures of LM muscle thickness on ultrasound images. Session 2 occurred 3–4 days after session 1 and included an additional SMT treatment. Session 3 occurred 1 week after Session 1 and included repeat subjective questionnaires and measurements of the LM muscle thickness on ultrasound images.

2.3.1. Baseline examination

Demographic information including age, sex, past medical history, smoking, height, and weight were collected by self-report. Additional information regarding history of participants' LBP was collected via interview and included duration and anatomical distribution of current symptoms, frequency of prior episodes, aggravating and relieving factors, and prior treatments.

Self-report questionnaires included: (1) an 11-point Numeric Pain Rating Scale (NPRS), to rate subjective pain intensity (Childs et al., 2005), (2) modified Oswestry Disability Questionnaire (ODI), a LBP-specific subjective measure of disability (Fritz and Irrgang, 2001), (3) Fear-Avoidance Beliefs Questionnaire (FABQ), a subjective questionnaire designed to measure a users beliefs about the relationship between physical activity, work, and their LBP (Waddell et al., 1993) and (4) treatment expectations. Similar to the procedures of Kalauokalani et al. (2001), we asked participants to respond on a 5-point Likert type scale about their beliefs that different treatments will improve their LBP as expectations of a treatment have been shown to affect outcomes for patients with LBP.

A standardized physical examination was performed on each participant including all tests and measures associated with the Treatment Based Classification System (Fritz et al., 2007a; Hebert et al., 2008) by an examiner blinded to measures of LM muscle thickness. Lumbosacral range of motion of flexion, extension, and side bending was measured using a standard inclinometer (Fritz and Piva, 2003) as was straight leg raise (Hicks et al., 2005) and hip internal range of motion (Flynn et al., 2002). Aberrant movements (e.g. painful arc, instability catch, difficult return from flexion, reversal of lumbopelvic rhythm) were noted during flexion (Hicks et al., 2003). A repeated motion exam was performed by having standing participants bend 10 times as far as possible into flexion and extension followed by sustained prone extension. Changes in symptoms were documented in terms of intensity (more or less pain) and location (centralize or peripheralize) (Fritz et al., 2007c). Segmental mobility was assessed by having the examiner apply manual pressure on each lumbar spinous process in a posterior to anterior (PA) direction. Intervertebral motion was judged to be normal, hypomobile, or hypermobile and pain as present or absent at each segment (L1 to L5) (Hicks et al., 2003). The prone instability test (PIT) was then performed and considered positive if patients reported less pain with PA pressure when they held their legs off the ground as opposed to resting with their feet touching the floor (Hicks et al., 2003). The active straight leg raise test (ASLR) was performed and considered positive when supine participants reported less difficulty in raising their leg when the examiner manually stabilized their pelvis (Mens et al., 2002).

2.3.2. Ultrasound examination

LM thickness was assessed at baseline and after one week with B-mode ultrasound imaging using a protocol with established reliability and validity (Hebert et al., 2009; Koppenhaver et al., 2009a,b) by an experienced examiner blinded to the findings of

Table 1
Study selection criteria.

Inclusion Criteria	Exclusion Criteria
Back pain located between the 12th rib and buttocks, that in the opinion of the screening examiner, was originating from the lumbar region	Neurogenic pain defined by either a positive ipsilateral or contralateral straight leg raise (reproduction of symptoms at $\leqslant 45°$) or reflex, sensation, or strength deficits in a pattern consistent with nerve root compression
Between the age of 18 and 60 years	Prior surgery to the lumbosacral spine
Meet either $\geqslant 4$ or $\leqslant 2$ out of 5 of the spinal manipulation clinical prediction rule criteria (Flynn et al., 2002): (1) symptoms fewer than 16 days (2) no symptoms distal to the knee (3) Fear avoidance behavior questionnaire work subscale score < 19 points (4) $\geqslant 1$ lumbar segment graded as hypomobile (5) $\geqslant 35°$ hip internal rotation range of motion on at least 1 side	Medical ‘red flags’ of a potentially serious condition including cauda equina syndrome, major or rapidly progressing neurological deficit, fracture, cancer, infection, or systemic disease
Ability to lie prone and supine for a minimum of 20 min	Prior spinal manipulation to the lumbosacral spine or trunk muscle stabilization exercises performed in the previous 4 weeks
Modified oswestry disability score at least 20%	Osteoporosis

the history and physical examination. Images on the LM muscle were obtained using a Sonosite Titan or Sonosite MicroMaxx (Sonosite Inc, Bothell, WA), with a 60-mm, 5-MHz curvilinear. The subject was placed prone with the abdomen supported as needed to ensure no more than 10° of lumbar lordosis. Ultrasonic images were taken of the LM during submaximal contraction which was achieved through a contralateral arm raise and a small hand weight previously shown to elicit approximately 30% of the maximal voluntary isometric contraction of the LM muscle (Fig. 1, Kiesel et al., 2007). Images were acquired three times each on the participant's more symptomatic side and averaged to reduce measurement error (Koppenhaver et al., 2009c).

Images were imported into a computer and measured offline using Image J software (Wayne Rasband, National Institutes of Health, USA). Thickness was measured as the distance between the posterior-most portion of the L4/L5 facet joint and the fascial plane between the muscle and subcutaneous tissue (Fig. 2). By using Image J's automatic measurement function, the examiner was additionally blinded to thickness values during measurement. Percent change over 1 week in contracted LM thickness was calculated as $[(\text{thickness}_{\text{1-week}} - \text{thickness}_{\text{baseline}})/\text{thickness}_{\text{baseline}}] * 100\%$.

2.3.3. Spinal manipulation treatment

Participants received lumbosacral SMT during Sessions 1 and 2 by a licensed physical therapist or chiropractor who were blinded

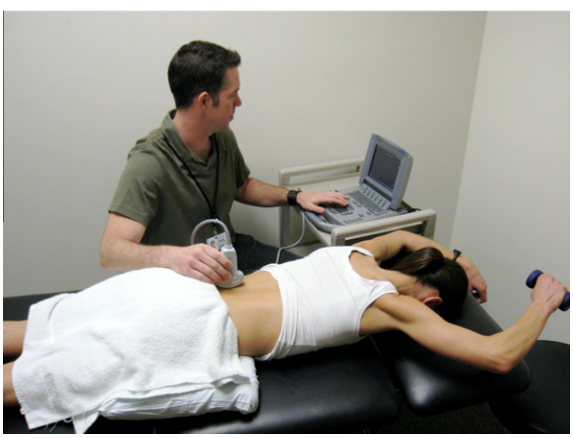

Fig. 1. Imaging of the lumbar multifidus (LM) muscle was performed during a contralateral arm raise using one of 3 possible hand weight selected based on the participants body weight.

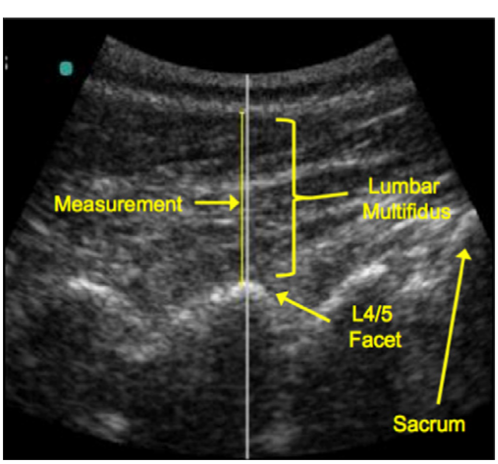

Fig. 2. Parasagital ultrasound image of the lumbar multifidus (LM) muscle. Measurements were taken between the posterior-most portion of the L4/L5 facet joint and the fascial plane between the muscle and subcutaneous tissue.

Fig. 3. Spinal manipulation technique. The participant was maximally side-bent away and then rotated toward the examiner. A high-velocity low-amplitude thrust was then given to the participant's anterior superior iliac spine (ASIS) in a posterior and inferior direction.

to both the findings of the baseline examination and the ultrasound image measurements. The technique involved maximally side-bending and rotating participants, and then providing an anterior to posterior high-velocity low-amplitude thrust to the participants' anterior superior iliac spine (Fig. 3) (Childs et al., 2004; Flynn et al., 2002). Each participant received SMT to both right and left sides, one or two times each. The examiner then recommended participants stay as active as possible and avoid specific trunk strengthening.

2.4. Statistical analysis

Potential predictor variables were chosen based upon their theoretical relationship to muscular responses following SMT. Initially, the bivariate relationships between these predictors and change in contracted LM thickness following SMT were assessed using correlation coefficients (point biserial correlations for dichotomous variables, spearman rho correlations for ordinal variables, and pearson product moment correlations for continuous variables). Continuous variables with skewed distributions were converted to ordinal variables based on rank. Alpha was liberally set at 0.15 for each comparison to minimize the potential for type 2 error.

The multivariate relationships between the baseline variables and change in contracted LM thickness were then evaluated using stepwise hierarchical multiple linear regression. Variables representing demographic and historical information that were significantly ($p < 0.15$) related to change in LM thickness were entered into the model in the first step. Statistically significant physical examination variables were entered into the second step. During each step, variables were entered and then removed using a backwards stepwise fashion with a significance value of less than 0.05 for model entry and greater than 0.10 for removal.

3. Results

Eighty-one individuals with LBP were enrolled. Three of the 81 participants did not complete the study, one for receiving an epidural steroid injection, one due to family illness, and one that was unable to be contacted. Additionally, investigators were unable to identify the LM muscle boundaries of five individuals leaving complete data on 73 participants. Overall participants experienced a mean (SD) improvement in ODI score of 26.3 (32.5)% and a mean (SD) increase of 1.1 (7.6)% in percent LM thickness. An increased LM thickness was observed in 39 (53.4%) of the participants and a decreased LM thickness was seen in 34 (46.6%) of the participants after one week. Individual changes in LM thickness for each participant are displayed in Fig. 4. As previously reported, an increase in contracted LM thickness one week pot-SMT was associated significantly with an improved ODI score. These changes explained only 7% of the variance in ODI changes over 1 week after accounting for sex, age and body mass index (Koppenhaver et al., 2011).

Descriptive statistics of all potential predictor variables, as well as the bivariate correlations of each with change in LM thickness, are listed in Tables 2 and 3. The distribution of the variable symp-

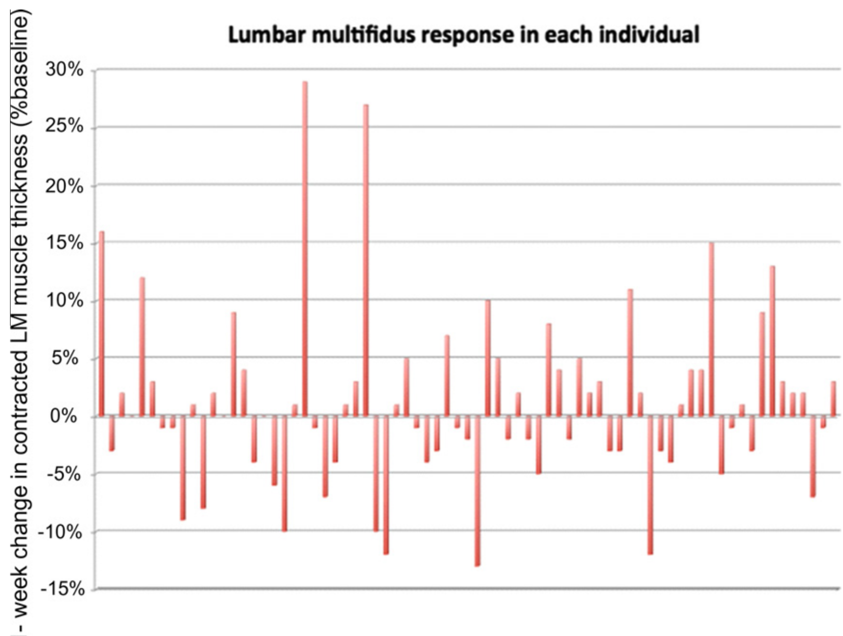

Fig. 4. One-week change in contracted lumbar multifidus (LM) thickness for each study participant. Bars represent change in LM thickness as a percentage of baseline.

Table 2
Demographic and Historical Information Variables (N = 73).

	Descriptive statistics	Correlation estimate	*p*-Value
Dichotomous variables	Frequency	Point biserial	
Sex	56.2% female	0.08	0.49
Symptom duration (acute vs. chronic)	72.6% chronic	−0.41	<0.01[a]
Smoking	8.2% yes	−0.10	0.39
Current or history of anxiety disorder and/or depression	27.4% yes	−0.10	0.41
Previous PT or chiropractic treatment	31.5% yes	−0.19	0.11[a]
Pain below buttocks	28.8% yes	−0.06	0.63
Pain below knee	21.9% yes	−0.06	0.61
Aggravated by bending	60.3% yes	0.00	0.99
Aggravated by sitting	82.2% yes	0.04	0.73
Aggravated by walking	21.9% yes	−0.02	0.86
Ordinal variables	Median/Mode	Spearman Rho	
Duration of symptoms (days)	154 (31, 709)[c]	−0.20	0.10[a]
Oswestry disability score (%)	30 (22, 37)[c]	−0.20	0.10[a]
Amount of missed work due to LBP	63.0% None[d]	−0.06	0.60
Believe SMT will help LBP	57.1% Somewhat agree[d]	0.08	0.50
Number of prior episodes of LBP	60.3% $\geqslant$ 10[d]	−0.11	0.35
Continuous variables	Mean (SD)	Pearson's	
Age (years)	33.7 (12.3)	−0.10	0.40
BMI (kg/m^2)	25.3 (5.2)	−0.15	0.22
FABQ- PA (0–42)	15.3 (4.3)	0.15	0.20
FABQ- work (0–24)	16.2 (9.4)	−0.11	0.37
Numeric pain rating scale for back (0–10)[b]	5.0 (1.7)	0.03	0.78
Numeric pain rating scale for leg (0–10)[b]	1.4 (2.2)	−0.17	0.15

PT: physical therapy; LBP: low back pain; SMT: spinal manipulative therapy; BMI: body mass index; kg/m: kilograms/meters; FABQ-PA: fear avoidance behavior questionnaire physical activity subscale.
[a] Statistically significant at the 0.15 level.
[b] Reports the average of the worst, best and current scores for pain over the last 24 h.
[c] Median (interquartile range).
[d] Most common response (Mode).

tom duration (number of days) appeared non-normal and was converted into both dichotomous and ordinal scales. Six weeks (45 days) was used as the threshold to dichotomize symptom duration (acute ⩽ 6 weeks, chronic > 6 weeks) based on previous literature (Fritz et al., 2007b, 2008XXX; van Tulder et al., 2006; Wand et al., 2004). Four demographic and history variables (Table 2) and seven physical examination variables (Table 3) were found to be correlated to one-week change in LM thickness ($r_{pbis} = -0.41$ to 0.18, $p < 0.15$). Symptom duration when dichotomized ($r_{pbis} = -0.41$, $p < 0.01$) and the presence of pain with PA pressure on L5 ($r_{pbis} = -0.37$, $p < 0.01$), demonstrated the strongest correlations with change in LM thickness. Specifically, larger increases in LM thickness changes were observed in acute participants and those that had no pain with PA pressure at L5.

Results of the hierarchical linear regression analysis are presented in Table 4. Four of the 14 variables uniquely contributed to the multivariate model ($p < 0.10$). The strongest contributors to the model were LBP acuity and lack of pain response to posterior-to-anterior pressure on L5. Having a positive ASLR test, and symptoms that centralize, rather than peripheralize with repeated lumbar extension were also associated with larger increases in LM thickness. The four variables together resulted in an adjusted R^2 of 0.27, representing 27% of the variance of change in LM thickness after adjusting for the number of variables in the model.

4. Discussion

Previous work has identified the clinical characteristics of patients with LBP who are likely to experience success with SMT (Childs et al., 2004; Flynn et al., 2002) and LSE (Hicks et al., 2005). Other evidence, however, suggests that the best clinical outcome may occur when using the combination of SMT and LSE to treat patients with LBP (UK BEAM, 2004). The purpose of this study was to identify the baseline historical and physical examination factors associated with increased contracted LM muscle thickness after SMT in an effort to better understand a potentially synergistic interaction between SMT and LSE. The current analysis identified four variables comprising the most parsimonious set of predictors for LM thickness changes after SMT. Having acute rather than chronic LBP, no pain with PA pressure to L5, a positive ASLR test, and symptoms that centralize rather than peripheralize with repeated lumbar extension were associated with larger increases in contracted LM thickness. Knowing these variables may help us determine what type of patient with LBP might be expected to benefit from a combination of SMT and LSE as well as lend support to the hypothesis that SMT may "jump start" the LM muscle in these individuals (Gill et al., 2007; Konitzer et al., 2011).

Having acute rather than chronic LBP was the variable most strongly associated with increased LM thickness one week after

Table 3
Physical examination variables.

Physical examination variables	Central tendency & variance	Correlation estimate	p-value
Dichotomous variables	Percent	Point biserial	
Pain with PA L4	73.6% yes	−0.18	0.12[a]
Pain with PA L5	72.2% yes	−0.37	<0.01[a]
Aberrant Movements	35.6% yes	0.16	0.19
Prone instability test	55.4% positive	−0.17	0.18
Active straight leg raise test	50.7% positive	0.18	0.12[a]
Ordinal Variables	Mode	Spearman Rho	
Mobility with PA L4[b]	50.7% hypo	−0.02	0.85
Mobility with PA L5[b]	54.2% hypo	−0.04	0.73
Pain Intensity with repeated flexion ROM[c]	55.5% increased	−0.23	0.05[a]
Pain Location with repeated flexion ROM[d]	88.6% no effect	−0.22	0.07[a]
Pain intensity with repeated extension ROM[c]	65.7% increased	−0.10	0.40
Pain location with repeated extension ROM[d]	85.7% no effect	−0.32	0.01[a]
Continuous variables	Mean (SD)	Pearson's	
Number SMT criteria met (out of 5)	2.8 (1.3)	0.15	0.20
Number LSE criteria met (out of 4)	1.8 (1.1)	0.09	0.46
Flexion ROM (deg)	90.7 (27.5)	−0.08	0.52
Extension ROM	29.5 (9.7)	−0.07	0.56
Asymmetry in SB ROM (deg)	4.8 (4.0)	−0.06	0.63
Average SLR ROM	75.6 (16.3)	−0.23	0.05[a]
Average Hip IR ROM	35.3 (8.3)	0.00	0.99

PA: posterior-to-anterior; ROM: range of motion; deg: degrees; SMT: spinal manipulative therapy; LSE: lumbar stabilization exercise; SB: side bending; SLR: straight leg raise; IR: internal rotation.
[a] Statistically significant at the 0.15 level.
[b] Coded as 1 = hypomobile, 2 = normal, 3 = hypermobile.
[c] Coded as 1 = decreased pain, 2 = no effect, 3 = increased pain.
[d] Coded as 1 = centralize, 2 = no effect, 3 = peripheralize.

Table 4
Hierarchical linear regression analysis predicting 1-week change in lumbar multifidus (LM) muscle thickness after spinal manipulation.

Variables retained in final model	Standardized β coefficient	Significance of β coefficient	Adjusted R^2	Significance of model fit
Acute low back pain	0.29	0.02		
No pain with PA pressure to L5	0.29	0.01		
Positive ASLR test	0.20	0.09		
Centralize rather than peripheralize with repeated extension	0.20	0.07		
Full model			0.27	<0.001

PA: posterior-to-anterior, ASLR: active straight leg raise.

SMT, both by itself and as part of the multivariate model. Symptom acuity has previously been found to be strongly prognostic for recovery of LBP both in general (Hancock et al., 2009) and specifically in patients that have been treated with SMT (Childs et al., 2004; Flynn et al., 2002; Fritz et al., 2005). The reason that patients with acute LBP have larger thickness changes than those with chronic LBP may be that chronic LBP often includes psychosocial components (Keeley et al., 2008), structural changes (atrophy and fatty infiltrate) (Yoshihara et al., 2001; Zhao et al., 2000) and/or central pain mechanisms (including neural adaptations and pain sensitization) that are likely less affected by SMT (Sharma et al., 2011; Young et al., 2003). In comparison, acute LBP largely concerns local and/or peripheral mechanisms, including neuromotor inhibition (Dickx et al., 2010; Kiesel et al., 2008), that can be altered by SMT (Bialosky et al., 2009).

The centralization phenomenon, like symptom acuity, has been shown to be strongly prognostic for recovery of LBP (Werneke et al., 2009) and occurs most commonly with repeated lumbar extension (Aina et al., 2004). The fact that we observed larger changes in LM thickness in participants who centralized with repeated lumbar extension may be due to an increased ability to contract the LM muscle due to their higher rate of clinical recovery. Because we did not include a control group, we cannot know whether these two prognostic factors (symptom acuity and centralization) predicted a larger LM response to SMT or merely quicker recovery regardless of treatment.

The ASLR test was initially advocated for use with pelvic girdle pain after pregnancy (Mens et al., 1999, 2002). More recently it has been used as a test of general lumbar spine instability in patients with LBP and has been demonstrated to vary with both lumbar spine stability (Liebenson et al., 2009) and transverse abdominis muscle activity (Teyhen et al., 2009). The fact that participants who had a positive ASLR test demonstrated larger LM thickness changes after SMT may possibly be explained by the presence of lumbopevic motorcontrol deficits at baseline that were to some extent reversed by SMT.

Finally, the reason for an association between no pain with PA pressure at L5 with larger changes in LM thickness in the multivariate model is more difficult to ascertain. This finding is somewhat counterintuitive as pain with PA pressure at L5 would seem to indicate the presence of local L5 area irritation and/or dysfunction that would be indicative of treatment with regional SMT. Alternatively, it is possible that pain with PA pressure on L5 signified more severe irritation and/or pathology in the region. Evidence suggests that patients with nerve root/sciatic pain have a worse prognosis than patients with non-specific LBP (Bronfort et al., 2004), especially with SMT (Axen et al., 2005; Malmqvist et al., 2008). And while our screening process likely excluded individuals with more severe nerve root pathology, it is possible that pain with PA pressure on L5 identified participants with a higher degree of local pathology, like nerve root inflammation, that demonstrated less physiologic change to SMT.

Only one of the identified variables (symptom acuity) approximated a variable previously found to be predictive of clinical success with SMT (Childs et al., 2004; Flynn et al., 2002) or LSE (Hicks et al., 2005). This may be because the subgroup of patients that experiences the largest change in LM thickness after SMT is somewhat distinct from the subgroups of patients expected to experience clinical success after SMT or LSE alone. Alternatively, this could be due to the common overlap between treatment-based classifications, especially the SMT and LSE categories (Stanton et al., 2011). In the current study we purposefully avoided dichotomizing most of our variables, as we believe it would be premature to develop another clinical prediction rule or distinct subgroup of patients. Instead our focus was to describe the general type of LBP patient that might exhibit a meaningful increase in contracted LM thickness after SMT, and therefore, be an especially good candidate for SMT followed by LSE. Our results suggest that patients with LBP, (1) that are fairly acute, (2) have at least a moderately good prognosis without focal and irritable symptoms, and (3) exhibit signs of spinal instability, may be the best candidates for such a combined treatment approach.

Limitations of this study have been discussed elsewhere (Koppenhaver et al., 2011) including concerns for using ultrasound rather than electromyography to measure muscle function and using flyers to recruit participants rather than recruiting those seeking healthcare. Perhaps more important to the current study was and the fact that patients were only observed for one week and were not treated with LSE. Therefore any conjecture about the interaction between SMT and LSE is purely speculation that needs to be investigated in future research. Additionally the lack of the inclusion of a control group has been criticized in clinical prediction studies as it makes it impossible to ascertain whether the identified factors predicted a larger LM response to SMT or merely a larger LM response in general (Haskins et al., 2012).

Because we did not include a control group, we cannot know whether these two prognostic factors (symptom acuity and centralization) predicted a larger LM response to SMT or merely quicker recovery regardless of treatment.

Future studies should explore the interaction between SMT and LSE by measuring changes in LM muscle function during such interventions across longer time frames. It should additionally be noted that there might have been important predictors of LM thickness change that were not included in this study. Although the historical and physical examination used in this study was comprehensive and approximated a routine LBP examination, the analysis performed was retrospective in nature and did not include some potentially important predictors such as pain level during the contralateral arm raise procedure or manual assessment of LM contraction. Lastly, many statistical comparisons were performed in the current study using a liberal alpha level. As a result, it is possible that some of our findings may be spurious and attributable to Type I error. Our approach, however, is consistent with the exploratory nature of the study, as we were interested in identifying potentially important relationships that could be considered in future research regarding muscular changes associated with SMT.

5. Conclusions

Four baseline historical and physical examination variables best predicted the magnitude of increases in contracted LM thickness one week after SMT. When combined, these variables suggest that patients with LBP, (1) that are fairly acute, (2) have at least a moderately good prognosis without focal and irritable symptoms, and (3) exhibit signs of spinal instability, may be the best candidates for a combined SMT and LSE treatment approach. Such findings provide insight into the potentially synergistic interaction between SMT and LSE and may provide guidance for future studies regarding such a combined treatment approach.

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the Surgeon General, the Department of the Army, Department of the Air Force, Department of Defense, or the U.S. Government.

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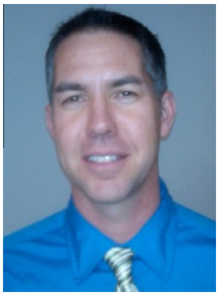

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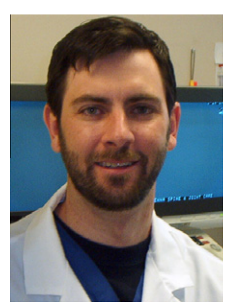

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