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ORIGINAL ARTICLES

Mechanical Force Spinal Manipulation Increases Trunk Muscle Strength Assessed by Electromyography: A Comparative Clinical Trial

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ABSTRACT

Objective: The objective of this study was to determine whether mechanical force, manually-assisted (MFMA) spinal manipulative therapy (SMT) affects paraspinal muscle strength as assessed through use of surface electromyography (sEMG).

Design: Prospective clinical trial comparing sEMG output in 1 active treatment group and 2 control groups.

Setting: Outpatient chiropractic clinic, Phoenix, AZ.

Subjects: Forty subjects with low back pain (LBP) participated in the study. Twenty patients with LBP (9 females and 11 males with a mean age of 35 years and 51 years, respectively) and 20 age- and sex-matched sham-SMT/control LBP subjects (10 females and 10 males with a mean age of 40 years and 52 years, respectively) were assessed.

Methods: Twenty consecutive patients with LBP (SMT treatment group) performed maximum voluntary contraction (MVC) isometric trunk extensions while lying prone on a treatment table. Surface, linear-enveloped sEMG was recorded from the erector spinae musculature at L3 and L5 during a trunk extension procedure. Patients were then assessed through use of the Activator Methods Chiropractic Technique protocol, during which time they were treated through use of MFMA SMT. The MFMA SMT treatment was followed by a dynamic stiffness and algometry assessment, after which a second or post-MVC isometric trunk extension and sEMG assessment were performed. Another 20 consecutive subjects with LBP were assigned to one of two other groups, a sham-SMT group and a control group. The sham-SMT group underwent the same experimental protocol with the exception that the subjects received a sham-MFMA SMT and dynamic stiffness assessment. The control group subjects received no SMT treatment, stiffness assessment, or algometry assessment intervention. Within-group analysis of MVC sEMG output (pre-SMT vs post-SMT sEMG output) and across-group analysis of MVC sEMG output ratio (post-SMT sEMG/pre-SMT sEMG output) during MVC was performed through use of a paired observations *t* test (POTT) and a robust analysis of variance (RANOVA), respectively.

Main Outcome Measures: Surface, linear-enveloped EMG recordings during isometric MVC trunk extension were used as the primary outcome measure.

Results: Nineteen of the 20 patients in the SMT treatment group showed a positive increase in sEMG output during MVC (range, –9.7% to 66.8%) after the active MFMA SMT treatment and stiffness assessment. The SMT treatment group showed a significant (POTT, $P < .001$) increase in erector spinae muscle sEMG output (21% increase in comparison with pre-SMT levels) during MVC isometric trunk extension trials. There were no significant changes in pre-SMT vs post-SMT MVC sEMG output for the sham-SMT (5.8% increase) and control (3.9% increase) groups. Moreover, the sEMG output ratio of the SMT treatment group was significantly greater (robust analysis of variance, $P = .05$) than either that of the sham-SMT group or that of the control group.

Conclusions: The results of this preliminary clinical trial demonstrated that MFMA SMT results in a significant increase in sEMG erector spinae isometric MVC muscle output. These findings indicate that altered muscle function may be a potential short-term therapeutic effect of MFMA SMT, and they form a basis for a randomized, controlled clinical trial to further investigate acute and long-term changes in low back function. (J Manipulative Physiol Ther 2000;23:585-95)

Key Indexing Terms: Biomechanics; Electromyography; Chiropractic Manipulation; Low Back Pain; Spine.

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INTRODUCTION

A number of different outcome measures have been used to investigate the effectiveness of spinal manipulative therapy (SMT). Among these are subjective measures of patient's self-reported level of pain, disability, and functional status.[1-4] Objective measures used to assess outcome in patients receiving treatment for low back pain (LBP) include orthopedic examination tests,[5] range of motion assessment,[6,7] radiographic measures,[8,9] spinal stiffness,[10] and trunk muscle strength.[11]

Increasing support for the role of muscles in stabilizing the spine have drawn attention in recent years.[12-17] The erector spinae musculature acts posterior to the intervertebral

Table 1. *Summary of patient demographics, health status (VAS, Oswestry), and pain tolerance (lumbar algometry)*

	SMT treatment group		Sham-SMT group		Control group	
Parameter	Males (n = 11)	Females (n = 9)	Males (n = 5)	Females (n = 5)	Males (n = 5)	Females (n = 5)
Age (y)	51.0 (15.7)	34.6 (17.1)	52.4 (16.1)	41.8 (13.4)	51.6 (14.0)	38.6 (12.7)
Height (cm)	179.9 (7.4)	166.1 (9.4)	178.3 (2.1)	168.9 (6.4)	181.4 (5.9)	161.8 (7.6)
Weight (kg)	87.1 (16.6)	62.5 (10.7)	87.3 (12.9)	63.8 (11.5)	98.7 (16.1)	61.9 (17.1)
VAS (0-10)	2.9 (2.5)	4.1 (1.6)	2.6 (1.1)	2.8 (1.6)	2.6 (1.1)	3.4 (2.7)
Oswestry (0-50)	9.0 (5.4)	12.8 (5.7)	6.6 (7.5)	7.4 (7.2)	9.0 (5.7)	8.8 (4.5)
Algometry (kg/cm^{-2})	6.6 (0.7)	5.2 (1.1)	6.8 (0.4)	5.6 (1.1)	6.3 (0.8)	6.1 (1.0)

SDs are shown in parentheses.
VAS, Visual analog scale.

joint centers to compensate for the net moment caused by external load and body weight.[14] The maintenance of posture and performance of purposeful trunk motion are the results of coordinated load-sharing between the passive discoligamentous tissues and active contractile muscular tissues to balance external loads. A disorder in the musculoskeletal system or loss of control in the neuromuscular system may result in excessive load-sharing of the passive system that can cause abnormal motion and increased deformation of the highly innervated structures of the spine.[18] Abnormal motion and increased strain are often accompanied by increased pain and discomfort.[14,19-22] Individuals with LBP have been found to use a different motor control strategy in comparison with asymptomatic healthy individuals, and this may be a result of pain or damage to muscular, ligamentous, or nervous (mechanosensitive) tissues.[23-27] The role of rehabilitation programs in improving objective outcomes, including increases in trunk muscle strength, mobility, and functional capacity as well as improved motor control system function, are important goals of patient care.[28]

Measurement of muscle action and forces may be documented by electromyographic studies.[29] Because muscle output has been found to be closely correlated with muscle strength,[30-32] the potential ability of rehabilitation programs and the role of SMT in affecting the neuromuscular system are of interest to researchers and clinicians.[33-35] To date, few studies have been done to investigate the effect of SMT on trunk muscle output.

In a recent prospective clinical study, we investigated the mechanical and muscular behavior of human lumbar spinal segments to high-loading-rate posterior-to-anterior (PA) manipulative thrusts *in vivo*.[36] As part of our experimental protocol, prone-lying patients were asked to perform isometric maximum voluntary contraction (MVC) trunk extension efforts while surface, linear-enveloped electromyographic electrodes monitored erector spinae muscular activity from leads placed bilaterally at L3 and L5. These maximums being used to normalize surface electromyography (sEMG) data,[37] reflex responses occurring during mechanical force, manually-assisted (MFMA) SMTs were calculated to establish relative muscle activity, expressed as a percentage of the maximum muscle activity.[38] An unexpected outcome of this work was the finding that there was a consistent and significant increase in the post-SMT isometric MVC sEMG output in comparison with the pre-SMT output. This finding prompted us to undertake a clinical trial on a second group of 20 age- and sex-matched subjects. Our null hypothesis was that there would be no significant change in isometric MVC sEMG output for subjects undergoing sham-SMT treatment or a control protocol.

METHODS

Forty subjects with LBP participated in this study, and each was assigned to one of 3 groups: SMT treatment (n = 20), sham-SMT treatment (n = 10), and control protocol (n = 10). Patients were included in the study if they had not consulted a physician or therapist for low back or leg pain in the past 6 months or previously undergone SMT. Patients were excluded if they were pregnant, had a previous history of lumbar spinal surgery, or presented any contraindication to SMT (eg, malignancy, inflammatory or infective processes involving the spine, significant osteoporosis, or spinal disorders, including spondylolisthesis, ankylosing spondylitis, spinal fusion, previous spine surgery, or neurologic deficit). Patients were also excluded if they complained of significant symptoms unrelated to lumbar complaints. Patients with combined low back and referred or radicular buttock, thigh, or leg pain were included in the study.

Subjects were informed that a study was being undertaken to investigate biomechanical and neuromuscular responses to chiropractic treatment, and a brief explanation of the examination and treatment was provided by means of a handout. After receiving written and verbal explanations of the protocol for the study, each subject signed a written informed consent form acknowledging his or her participation in the study.

The SMT treatment group initially consisted of 22 consecutive patients with LBP who participated in a comprehensive clinical and biomechanical study of MFMA SMT. Two of the original 22 patients had no history of LBP and were excluded from the present study. The sham-SMT and control groups consisted of 20 consecutive LBP subjects examined approximately 18 months after the SMT treatment group; each of these groups consisted of equal numbers of male and female subjects. Subjects were assigned to the sham-SMT and control groups in such a way that age and sex were uniformly stratified with respect to the active SMT treatment group. All subjects were given the same verbal

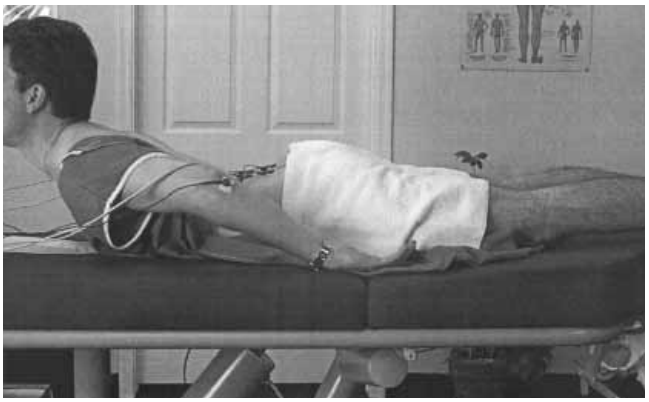

Fig 1. *Photograph shows patient performing MVC isometric extension task.*

directives in terms of the objectives of the study, and no indication was made of patient grouping or the comparative nature of the study. The complete testing procedure involved 4 assessment protocols: (1) MVC and sEMG assessment, (2) AMCT assessment and adjustment, (3) stiffness assessment, and (4) algometry assessment. Each of these procedures is detailed below. However, results obtained from procedures 2-4 will be presented elsewhere.

Procedure. Each subject completed a history and health status questionnaire (visual analog score, LBP history, LBP symptom frequency, and Oswestry Low Back Disability Index). Demographic and health status data for the treatment, control, and sham-SMT group subjects are summarized in Table 1. Each subject was gowned and underwent a physical examination consisting of orthopedic and neurologic examinations, lumbar range of motion, and plain film radiographic examination of the lumbar spine. The review of history and physical and radiographic examinations was used to rule out neurologic deficit or spinal pathology and was performed by a licensed doctor of chiropractic in accordance with standard clinical practice. On the basis of these findings, patient symptoms and physical status were used for inclusion criteria in the study.

Each subject was then placed in the prone position by use of a motorized vertical/horizontal table (Softec/Tri-W-G, Valley City, ND). Pre-gelled, silver/silver chloride bipolar electrodes (Easytrode 3SG3-N, MultiBioSensors, El Paso, TX) were located bilaterally over the L5 and L3 paraspinal musculature. After skin preparation, electrode leads were spaced approximately 2.5 cm apart. Electrodes were positioned on the lateral aspect of the erector spinae muscle so that PA manipulative thrusts could be delivered to both the spinous processes and the transverse processes without contact with the electrodes. The subject was asked to lie quietly until further instructed while the MVC isometric trunk extension procedure was explained. The subject was informed that he or she was to begin the MVC after hearing the words, "Ready? Begin," at which time he or she was to lift the chest and shoulders off of the table as high and as hard as possible for a count of three. After each MVC, the subject rested for a count of five. The subject was asked to

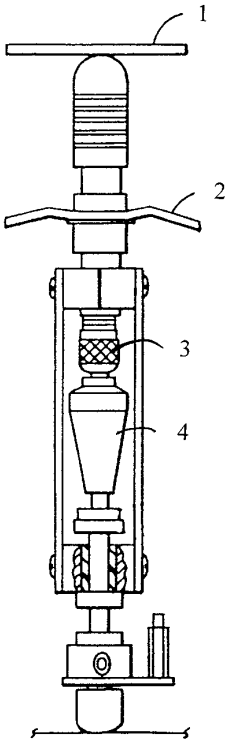

Fig 2. *Schematic of AAI equipped with preload control frame and impedance head (load cell and accelerometer). To deliver a thrust with instrument, first* (1) *and second* (2) *handles are squeezed together for a predetermined distance; this imparts potential energy on internal spring and triggers release of spring, propelling thrust element* (4) *rapidly outward. Device is equipped with internally threaded expansion control knob* (3) *that allows for adjustment of amount of potential energy imposed on spring. When set to zero position (off), no potential energy is imposed on spring and no excursion of thrust element occurs, although an audible click is heard from internal engagement of instrument's trigger. Thus, zero position can be used in research setting as sham procedure.*

practice 1 or 2 times before data collection; gain settings were adjusted to ensure the proper settings and working order of the electromyographic equipment and electrodes. The subjects were further informed that, if the extension procedure caused them intolerable low back discomfort or peripheralization of their symptoms, they were to abort the procedure immediately. No trunk restrainment apparatuses were used to obtain the MVCs, as such efforts exerted by the patient may have likely exacerbated the LBP symtoms.

Subjects in all 3 groups were asked to perform 3 consecutive MVC isometric trunk extensions, approximately 3 to 5 seconds in duration and with a 3- to 5-second rest between exertions (Fig 1). Isometric MVC sEMG signals were recorded during this procedure. Two 2-channel Myotrace 10 electromyographic amplifiers (Noraxon, Inc, Helsinki, Finland) were used to condition and linear-envelope the raw electromyographic signals. The linear-enveloped sEMG signals were recorded through use of a Biopac MP100 16-bit data acquisition system (Biopac Systems, Inc, Santa Barbara, CA) and Acknowledge software (Biopac Systems, Inc).

Table 2. *Summary of assessment sequences used for SMT treatment group, sham-SMT group, and control group*

SMT treatment group	Sham-SMT group	Control group
MVC & sEMG assessment	MVC & sEMG assessment	MVC & sEMG assessment
AMCT assessment protocol & adjustment (set at maximum force expansion position)	AMCT assessment protocol & sham adjustment (set at minimum force expansion position)	AMCT assessment protocol
Stiffness assessment through use of activator instrument set at maximum expansion position (20 thrusts)	Stiffness assessment through use of activator instrument set at minimum expansion (Sham) position (20 thrusts)	20-min rest period
Algometry assessment	Algometry assessment	Algometry assessment
MVC & sEMG assessment	MVC & sEMG assessment	MVC & sEMG assessment

Linear-enveloped sEMG data were collected at 50 Hz during the MVC extension tasks. The SMT treatment, shamSMT treatment, and control interventions are described in the following sections.

SMT treatment group intervention. Twenty LBP patients in the SMT treatment group were assessed through use of the Activator Methods Chiropractic Technique (AMCT) assessment protocol.[39] Chiropractic adjustment of the indicated thoracolumbar spine, sacrum, and pelvis was performed through use of MFMA SMT. The AMCT protocol consists of a visual leg length inequality assessment while the prone-lying patient performs various maneuvers with the trunk and extremities. These isolation tests are designed to locate areas of the spine thought to be exhibiting dysfunction.[39] Chiropractic adjustment through use of MFMA SMT was delivered with the Activator II Adjusting Instrument (AAI II; Activator Methods International, Ltd, Phoenix, AZ) set in the maximum expansion position, as it is used in routine clinical chiropractic practice. The AAI II delivers a very short duration (<5 ms) force-time impulse with a peak force magnitude of approximately 150 N.[40] Segmental contact is made with an 80-durometer rubber tip, 15 mm in diameter, that permits localized thrusts to be applied to the spine. Forces were directed perpendicular to the body surface curvature with a preload of approximately 25 N. The MFMA SMT thrusts used to treat the affected segment identified by the AMCT assessment are consistent with SMT thrusts delivered in routine clinical practice.

After the AMCT chiropractic assessment and treatment protocol, a biomechanical evaluation of dynamic spinal stiffness was performed. An AAI equipped with a preload control frame and impedance head (load cell and accelerometer; Fig 2) was used to deliver high-rate (<5 ms) PA manipulative thrusts (190 N) to several common spinal landmarks. Specifically, dynamic PA stiffness assessment was performed on the left and right posterior superior iliac spine, left and right sacral base (2 cm lateral to the first sacral tubercle), S1 and L5, L4, L2, T12, and T8 transverse (left and right) and spinous processes. A total of 20 PA manipulative thrusts were delivered during the course of the PA stiffness evaluation, which lasted for approximately 20 minutes. Algometry recordings were also obtained at each of the segmental contact areas. An algometry instrument with a precision of 0.1 kg/cm^2 was used to apply pressure to each of the segmental contact points until the patient indicated that he or she first felt significant pain. Pressures up to 7 kg/cm^2 were applied, and a value of 7 kg/cm^2 was recorded if no pain was produced at this level. The algometry measurements provide semiquantitative measures of segmental pain tolerance.[41-44] Algometry measurements are reported for the lumbar levels examined.

MVC isometric trunk extension tests were repeated immediately after the stiffness and algometry assessment procedures. The MVC isometric trunk strength assessment, AMCT assessment, dynamic stiffness assessment, and algometry assessment procedures required approximately 30 minutes to complete. Table 2 summarizes the assessment sequence used for the SMT treatment group.

Sham-SMT Group Intervention. Each of the 10 sham-SMT group subjects received a protocol identical to that described above, with the following exception: a sham-SMT thrust was delivered during the AMCT protocol, and sham-dynamic stiffness tests were performed (Table 2). The sham procedure was accomplished by setting the expansion control knob on the AAI II to the zero (off) position. The expansion control knob is used to adjust the spring compression and thus the amount of excursion of the instruments' stylus (Fig 2). The most common AAI II setting used clinically is the maximum setting, at which the expansion control knob is open to its fullest extent. In the zero position, no excursion of the stylus occurs, although the same clicking sound that the instrument produces during normal use is heard after manual activation of the mechanical trigger. During each of the sham-SMT procedures, a static preload of approximately 25 N was applied to the segmental contact point with the AAI instrument set at the lowest force setting. An investigation of the force-time history associated with the sham-SMT setting was conducted in a separate trial of 6 thrusts on the S1 spinous process of a volunteer subject. This setting was found to produce a mean peak force of 19.5 N (SD 3.04). In comparison with the maximum setting of the AAI II equipped with a preload frame, the sham-SMT setting produced an approximately 5-fold lower peak force and a 10-fold lower peak impulse (Fig 3). Sham-SMT patients performed isometric MVC trunk extension tasks before and immediately after the clinical interventions.

Control Group Intervention. Intervention for the 10 control group subjects consisted of performance of the AMCT protocol, including leg length inequality assessment and isolation testing procedures only (Table 2). When a putative dysfunctional area of the spine was detected, no SMT intervention was given. Thus, the control group received no SMT treatment, sham-SMT treatment, or dynamic stiffness assess-

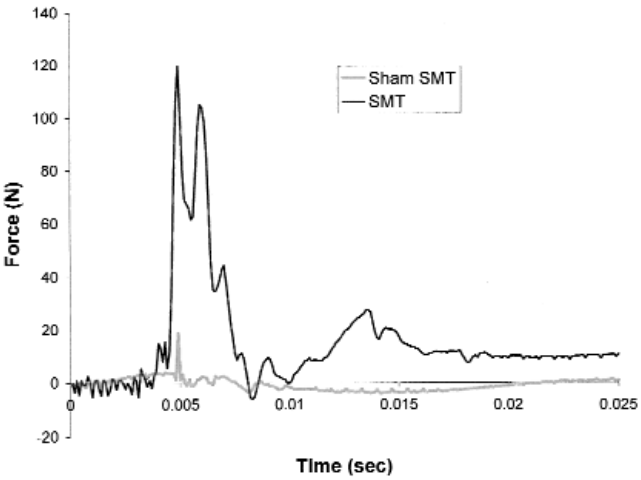

Fig 3. *Comparison of force profiles of MFMA SMT delivered with AAI II in maximum excursion setting and with expansion control knob closed to act as a sham. In separate trial of 6 thrusts delivered to S1, mean peak force of sham-SMT was found to be 19.5 N (SD 3.04). In comparison with maximum setting of AAI II, sham-SMT setting had an approximately 5-fold lower peak force and a 10-fold lower peak impulse.*

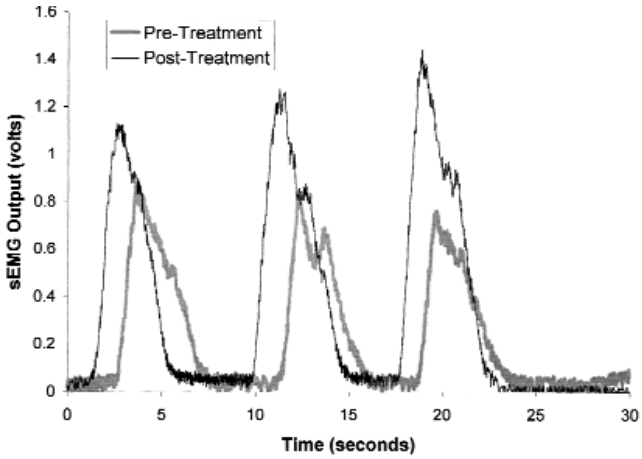

Fig 4. *Comparison of lumbar sEMG output obtained before AMCT assessment protocol* (Pre-Treatment) *with lumbar sEMG output obtained after AMCT leg check/adjustment and biomechanical tests* (Post-Treatment). *Results shown are for a patient in SMT treatment group (subject 22; L3-R sEMG lead).*

ment. After the AMCT assessment protocol, the subject was asked to lie quiet for approximately 20 minutes, which was the length of time required for performance of the stiffness and algometry assessments in the other 2 groups. Control subjects performed the isometric MVC trunk extension tasks before and immediately after the control interventions. Algometry assessments were taken after the post–trunk extension protocol in this group. Sham-SMT and control group participants received normal chiropractic treatment after the experimental protocol.

Data and Statistical Analyses. Baseline and peak sEMG values from each of the 3 consecutive MVC isometric extension tasks were recorded, and the baseline-peak sEMG intensity level was determined for each electrode. We will hereafter refer to the baseline-peak sEMG intensity as *sEMG output*.

Descriptive statistics were determined for all variables grouped according to sex and SMT treatment protocol. Within-group (pretreatment vs posttreatment sEMG output) comparisons were performed through use of a paired observations *t* test (POTT), which was used to determine whether MVC sEMG output was different for the pretreatment versus posttreatment isometric strength data. Across-group analysis of the patient demographics and MVC sEMG output ratio (post-SMT sEMG/pre-SMT sEMG output) was performed through use of a robust analysis of variance (RANOVA). The RANOVA consisted of a Kruskal-Wallis 1-way analysis of variance by ranks followed by Scheffé's test. The Kruskal-Wallis was performed to test for independence among the 3 group means. After the Kruskal-Wallis test, we performed a post hoc analysis through use of Scheffé's test to determine whether the group means were significantly different at the $P = .05$ significance level. Scheffé's test is the most stringent post hoc test with least probability of a type I or α error. Because the SMT treatment group was larger than the SMT sham and control groups, Hartley's test ($Fmax = \sum_{max}^2 / \sum_{min}^2$ was also performed to test the "equality of variance" (SD) or normality assumption implicit in an analysis of variance. The largest sample size (that of the SMT treatment group) was used to determine the percentage points of *Fmax* (3.65 for $\alpha = 0.05$), which was then compared with the *Fmax* calculated for the main outcome parameter (MVC sEMG output).

RESULTS

There were no significant differences (RANOVA) with respect to age, height, and weight among the subjects in the SMT, sham-SMT, and control groups. Nor were there any significant differences with respect to any of the health status parameters and lumbar pain tolerance (assessed by algometry) for the SMT, sham-SMT, and control groups. When these data were examined according to sex, patient demographics, health status parameters, and pain tolerance were very similar (Table 1). Female subjects in the sham-SMT and control groups were slightly older than their counterparts in the SMT treatment group, but this difference was not statistically significant (RANOVA). The mean ages of subjects with LBP in the SMT, sham-SMT, and control groups were 43.6, 47.1, and 45.1 years, respectively.

Fig 4 illustrates a typical pretreatment and posttreatment MVC sEMG output signal recorded for one of the patients in the SMT treatment group. In general, the L3 and L5 erector spinae sEMG output of the 3 MVC trials was very consistent (<14% variation) for all of the LBP patients examined. The percent coefficient of variation ($100 \times$ SD/mean) in sEMG output for the 3 repeat extension trials ranged from 7.9% (control group, L5-L, pretreatment) to 14.0% (SMT treatment group, L3-R, pretreatment) across all subjects (Table 3). There were no significant differences between the 3 MVC extension tasks in the pretreatment sEMG measurements (RANOVA) or in the

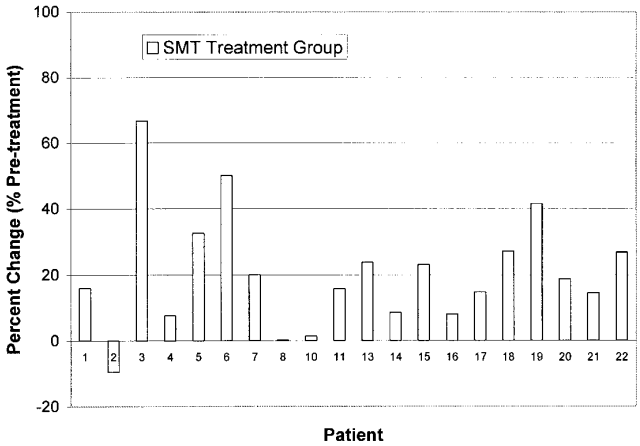

Fig 5. *Changes in individual lumbar MVC sEMG output responses to SMT (expressed as percentages of pre-SMT values). Nineteen of 20 patients showed a positive increase in lumbar MVC sEMG output after treatment (mean increase = 20.5%). Group changes were significantly different (POTT,* P < *.001) from pretreatment values.*

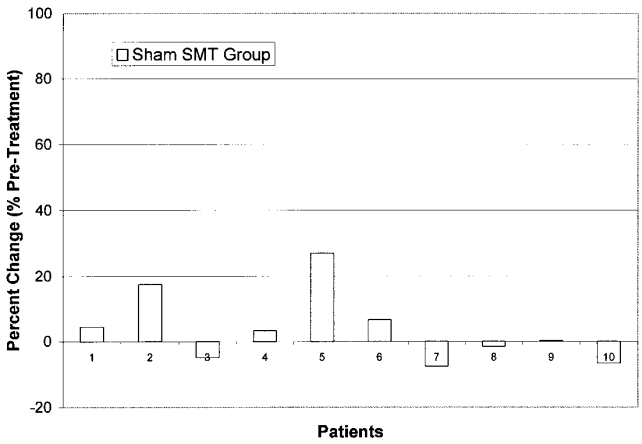

Fig 6. *Changes in individual lumbar MVC sEMG output responses to sham-SMT (expressed as a percentage of pre-SMT values). Six of 10 patients showed a positive increase in lumbar MVC sEMG output after treatment (mean increase, 3.9%). Group changes were not significantly different (POTT,* P = *.24) from pretreatment values.*

Table 3. *Mean percent coefficient of variation (COV = 100 × SD/mean) in sEMG output obtained for 3 MVC extension trials performed by each patient*

	L3-L		L3-R		L5-L		L5-R		All leads	
Group	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SMT	10.1	9.4	14.0	9.5	11.3	10.8	11.0	10.0	11.6	9.9
Sham-SMT	8.5	8.0	8.1	9.6	11.4	8.8	8.8	10.3	9.2	9.2
Control	11.3	8.6	10.8	10.4	7.9	10.3	13.8	8.0	11.0	10.2

Pre, Variation in sEMG output during pretreatment MVC extension tasks; *Post,* variation in sEMG output during posttreatment MVC extension tasks.

posttreatment measurements (RANOVA) for any of the muscle leads. Nor was there any consistent change in sEMG output patterns (increase, decrease, or neutral) for the repeat extension tasks. Hereafter, the individual erector spinae muscle MVC extension sEMG outputs (L3-L, L3-R, L5-L, L5-R) will be considered collectively as *lumbar sEMG output*.

Subject-specific changes in lumbar sEMG output after SMT, sham-SMT, and control group interventions are illustrated in Figs 5-8. Nineteen of the 20 patients in the SMT treatment group showed a positive increase in lumbar sEMG output after treatment. Fourteen (70%) of the 20 SMT treatment group patients had a posttreatment lumbar sEMG output at least 10% greater than the pretreatment lumbar sEMG output (range, –9.7% to 66.8%). Six of the 10 patients in the sham-SMT treatment group showed a positive increase in lumbar sEMG output after treatment. However, the posttreatment change in lumbar sEMG output was greater than 10% in only 2 (20%) of the sham-SMT treatment patients (range, –7.6% to 27.0%). Six of the 10 subjects in the control-treatment group also showed a positive increase in lumbar sEMG output after treatment, but only 2 subjects had a greater than 10% posttreatment improvement in lumbar sEMG output (range, 17.4% to 76.9%).

Fig 8 compares the changes in lumbar sEMG output obtained after treatment for each of the 3 treatment groups. When all extension trials and all 4 lumbar sEMG electrodes were analyzed collectively, the SMT treatment group showed a significant (POTT, $P < .001$) within-group increase in lumbar sEMG output after treatment (20.5% mean increase in comparison with pretreatment levels). There were no significant within-group changes in pretreatment versus posttreatment lumbar sEMG output for the sham-SMT (5.8% mean increase) and control (3.9% mean increase) groups. Across-group comparisons of the MVC lumbar sEMG output ratios of the 3 treatment groups also indicated that there was a statistically significant difference (RANOVA) among treatment groups. On the basis of the sEMG SDs obtained for the SMT treatment group (SD 24.56), sham-SMT group (SD 20.3), and control group (SD 36.7), Hartley's test indicated that the lumbar sEMG population variances were homogeneous ($Fmax = 3.27 < 3.65$).

DISCUSSION

SMT is a commonly used conservative treatment in the care of patients with LBP.[4] Our aim was to determine whether MFMA SMT affects paraspinal muscle strength as assessed through use of sEMG. The role of muscle strength as an etiologic or predisposing factor of low back disorders is controversial.[28] Some studies[45,46] have found little association between muscle strength and the development of low back symptoms, whereas others[47-49] have found that the trunk muscles in patients with chronic LBP are significantly

weaker than those of healthy individuals. A muscle deficiency model of chronic LBP was proposed by Cassisi et al.[50] Those investigators found that patients with chronic LBP exhibited lower peak torque and lower maximum surface-integrated electromyography bilaterally during isometric extension. Triano and Schultz[11] found that both myoelectric signal levels and trunk strength ratios of patients with LBP were inversely related to the patients' disability scores. Because paraspinal muscle function is thought to be essential for providing intrinsic support to the spinal column, suboptimal or impaired muscle control and function could permit abnormal motion segment movement or predispose a person to pain.[51]

Electromyographic signal analysis, a commonly used technique for quantifying muscle function during lifting tasks, has been used by many researchers.[52] Although the relationship between myoelectric output and muscle force production is not perfectly linear, EMG analysis is considered to be a semiquantitative measure of the force developed by a muscle.[53-56] The linear envelope method used in our study is one of the least complex and most often used methods of assessing myoelectric responses.[57] A linear envelope consists of a zero offset full-wave rectifier followed by a low-pass filter to average the variation that occurs in the input sEMG signal. The linear-enveloped sEMG signal therefore represents the mathematical average or mean of the rectified input signal; alternatively, it can be thought of as a moving average of EMG activity. Numerous studies have demonstrated sEMG to be a repeatable, stable, and reliable measure of muscle output during various tasks, including isometric MVCs.[58-61] In this study, a series of 3 isometric MVC extension trials were performed to assess erector spinae muscle output. Repeat isometric MVC trials are often used to examine changes in median frequency associated with fatigue.[61,62] Such trials generally involve protocols with a short rest period between efforts (typically, 2 seconds) combined with long duration for the MVC (typically, 5-15 seconds) over a relatively long period of time (typically, more than 60 seconds). Our MVC protocol was relatively brief in duration and included sufficient time for rest between each trial so that little, if any, muscle fatigue occurred.

We found a significant increase in lumbar muscle sEMG output after SMT and stiffness assessment, whereas no significant pre-versus-post differences in lumbar sEMG output were observed in the 2 control groups. Previous studies investigating the efficacy of SMT in the treatment of patients with LBP have assessed subjective measures of self-reported pain and disability.[1,4] Pope et al[63] conducted a prospective randomized 3-week trial of SMT, transcutaneous muscle stimulation, massage, and corset in the treatment of subacute LBP. Patients were evaluated once a week through use of questionnaires (including visual analog scale), range of motion, maximum voluntary extension effort, straight leg raising and Biering-Sorensen fatigue testing. After 3 weeks, the manipulation group scored the greatest improvements in flexion and pain. The massage group had the best extension effort and fatigue response, whereas the muscle stimulation group showed the best extension. None of the groups were significantly different with respect to changes in physical outcome measures (range of motion, fatigue, strength, and pain). Other researchers have noted a decrease in quadriceps muscle inhibition and increased knee extensor torque and muscle activation after sacroiliac joint manipulation.[64] The generally favorable objective findings reported by Pope et al[63] and Suter et al[64] are consistent with the findings of the present study.

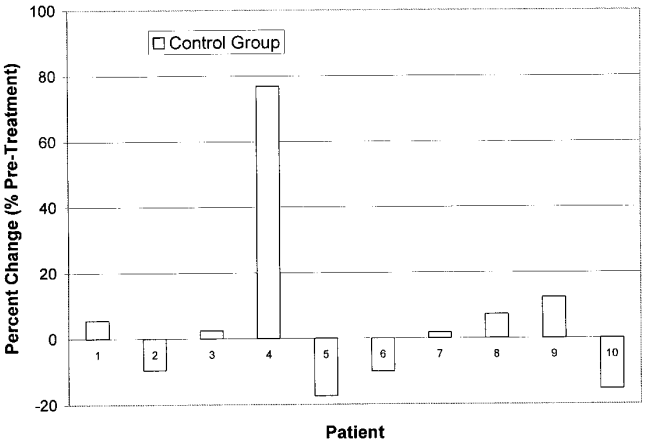

Fig 7. *Changes in individual lumbar MVC sEMG output responses to control intervention (expressed as percentages of pre-SMT values). Six of 10 patients showed a positive increase in lumbar MVC sEMG output after intervention (mean increase, 5.8%). Group changes were not significantly different (POTT,* P = *.54) from pretreatment values.*

In this study, a prone-position, repeated MVC extension task was used to determine trunk muscle output. MVC trunk extension tasks performed in the prone-lying position have been found to produce the greatest challenge to the erector spinae musculature.[27,65,66] The prone posture has also been a commonly used method of quantifying erector spinae strength by means of electromyography.[67] Protocols that require subjects to perform 3 isometric MVCs to establish a reference level of maximum isometric trunk extension are often advocated as a normalization procedure and are considered to provide more accurate comparisons between subjects and muscle groups.[65] Quantification of MVC isometric trunk extension, however, includes inherent problems in standardizing a dynamic event such as trunk strength. Potential confounding factors include subject motivation, subject effort, joint angle, velocity of movement, and pain provocation in performance of the effort.[52] Another potential confounding factor is the length of time that the subject lies prone during the testing procedure. In this study, each LBP subject spent approximately 30 minutes lying prone during the MVC, AMCT, PA stiffness, and algometry protocols. Of course there was some variation in the precise amount of time that the subjects in the 3 treatment groups remained in the prone position, because each underwent an AMCT protocol specific to his or her leg check findings. In general, however, our data file records indicated that the 30-

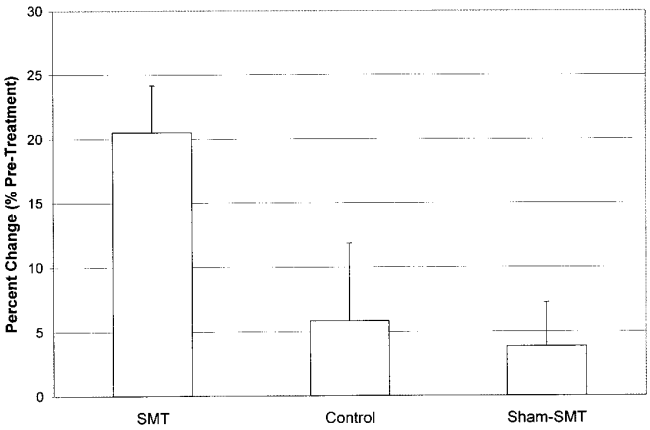

Fig 8. *Bar graph shows summary of changes in lumbar MVC sEMG output for SMT, sham-SMT, and control groups. Bars represent mean values; error bars show SEMs. Mean and SEM are based on analysis of a total of 80 SMT measurements (20 subjects × 4 sEMG leads), 40 sham-SMT measurements (10 subjects × 4 sEMG leads), and 40 control measurements (10 subjects × 4 leads). There was a significant within-group increase (POTT,* P < *.001) in lumbar MVC sEMG output for SMT group only. Changes in posttreatment versus pretreatment lumbar sEMG output ratio for SMT group were also significantly greater (RANOVA,* P = *.05) than for sham-SMT and control groups.*

minute time interval was fairly consistent across all subjects. In the case of the control group, which did not receive any stiffness or algometry assessments, the rest period was precisely established from the SMT treatment group data file records, which provided us with a precise timeline for the stiffness assessment protocol. Thus, the time spent in the prone position was not a significant variable for any of the groups examined in this study.

Our study design involved assigning 20 subjects with LBP to the sham-SMT and control groups in such a way that age and sex were uniformly stratified with respect to the SMT treatment group. All subjects, however, were given the same verbal directives in terms of the objectives of the study, and no indication was made of patient grouping or the controlled nature of the study to those participating. Subject demographics, health status parameters, and pain tolerance were similar among the 3 groups. Our study design also included a sham-SMT procedure, and the peak forces and peak impulses delivered to the patients during the sham-SMT thrust were substantially less than the peak forces and impulse delivered to the SMT treatment group. Study designs based on a sham-SMT effectively control for any influence associated with the doctor-patient interaction.[68-70] Although the sham-SMT and control trials were performed 18 months after the initial SMT tests, the procedures were performed through use of an identical protocol, in the same clinical setting, and by the same practitioner who uses AMCT exclusively (C.J.C.). Thus, there were no changes in practice patterns associated with the sham-SMT and control subject trials. Moreover, the nature of the sham-SMT (zero force setting) and control (no intervention) trials preclude any confounding effects related to practice patterns. The positive outcomes observed in the treatment group provide additional insight toward understanding the underlying physiologic mechanisms that may be associated with SMT.

From the standpoint of sEMG output, our study appears to be the first to show an acute change in lumbar paraspinal muscle function after SMT. Specifically, our results indicate that an MFMA adjustment in combination with a PA stiffness assessment was associated with a greater than 20% increase in MVC lumbar sEMG amplitude after treatment. We also hypothesized that MVC lumbar sEMG output would not change after sham-SMT and sham-stiffness interventions or no intervention (control). This hypothesis was substantiated by the results obtained from the tests conducted on a group of age- and sex-matched subjects with LBP. These findings suggest that the MVC lumbar sEMG output increases observed in the SMT treatment group resulted directly from the SMT and stiffness assessment interventions. Moreover, we found that the pretreatment/posttreatment MVC lumbar sEMG changes noted for the SMT treatment group were significantly greater than corresponding changes in the sham-SMT and control groups, although a larger group size comparison is necessary to substantiate this finding.

It is important to point out that the positive changes in MVC lumbar sEMG output cannot be directly attributed to the SMT treatment alone, inasmuch as the posttreatment MVC test did not immediately follow the MFMA adjustment. The current study was motivated by preliminary findings obtained from an initial group of 20 subjects with LBP who underwent, in addition to MFMA adjustment, a comprehensive dynamic stiffness assessment protocol through use of a specially designed instrument.[40] Future studies should include more specific treatment modalities to further investigate the effects of SMT-specific interventions on trunk muscle strength.

Currently, numerous basic science research studies are focusing on investigating the mechanical and physiologic basis for SMT. Neurophysiologic models theorize that SMT may stimulate or modulate the somatosensory system and may subsequently evoke neuromuscular reflexes.[33,34] MFMA SMT has been found to elicit significant neuromuscular reflexes in patients with LBP.[36,38] Such mechanical and neurophysiologic studies indicate that joint manipulation may have both direct and indirect clinical benefits. Beneficial effects of SMT have been thought to be associated with mechanosensitive afferent stimulation and presynaptic inhibition of nociceptive afferent transmission in the modulation of pain,[71,72] inhibition of hypertonic muscles,[33,73] and improved functional ability.[2,74] Mechanosensitive and nociceptive afferents have been identified in the lumbar intervertebral discs,[18,75,76] zygapophyseal joints,[22,77,78] spinal ligaments,[79-81] and the paraspinal musculature [82,83] in both animal and human studies. In addition, joint stimulation has been found to be intimately related to reflexogenic muscular reactions.[12,13,84-86] According to myo-

genic models that relate abnormal EMG patterns to the experience of pain, lumbar paravertebral muscle activity has been considered to play an important role in chronic LBP.[87,88] The acute improvements in lumbar sEMG output after MFMA SMT and stiffness assessment suggest that a potential beneficial effect derived from SMT may be acute improvement in muscle functional status. A larger-scale, randomized controlled clinical trial needs to be conducted to further investigate the clinical relevance of these findings.

CONCLUSION

Considering its inherent limitations, the results of this preliminary study suggest that MFMA or percussive-type SMT applied to the lumbar spine may produce an increase in erector spinae muscle surface electromyography output as measured during maximum voluntary contraction extension tasks. These findings may be related to the ability of mechanical forces to stimulate the somatosensory system, inhibit nociception, improve functional ability of trunk muscles, and/or improve dorsolumbar range of motion. These findings indicate that altered muscle function may be a potential short-term therapeutic effect of these types of clinical interventions.

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