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ORIGINAL ARTICLES

Stiffness and Neuromuscular Reflex Response of the Human Spine to Posteroanterior Manipulative Thrusts in Patients With Low Back Pain

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ABSTRACT

Background: Studies investigating posteroanterior (PA) forces in spinal stiffness assessment have shown relationships to spinal level, body type, and lumbar extensor muscle activity. Such measures may be important determinants in discriminating between patients who are asymptomatic and those who have low back pain. However, little objective evidence is available concerning variations in PA stiffness and their clinical significance. Moreover, although several studies have assessed only load input in relation to stiffness, a more complete assessment based on dynamic stiffness measurements (force/velocity) and concomitant neuromuscular response may offer more information concerning mechanical properties of the low back.

Objective: To determine the stiffness and neuromuscular characteristics of the symptomatic low back.

Study Design: This study is a prospective clinical study investigating the in vivo mechanical and muscular behavior of human lumbar spinal segments to high loading rate PA manipulative thrusts in research subjects with low back pain (LBP).

Methods: Twelve men and 10 women, aged 15 to 73 years (mean age of 42.8 ± 17.5 years) underwent physical examination and completed outcome assessment instruments, including Visual Analog Scale, Oswestry Low Back Disability Index, and SF-36 health status questionnaires. Clinical categorization was made on the basis of symptom frequency and LBP history. A hand-held spinal manipulation device, equipped with a preload control frame and impedance head, was used to deliver high-rate (<0.1 millisecond) PA manipulative thrusts (190 N) to several common spinal landmarks, including the ilium, sacral base, and L5, L4, L2, T12, and T8 spinous and transverse processes. Surface, linear-enveloped, electromyographic (sEMG) recordings were obtained from electrodes (8 leads) located over the L3 and L5 paraspinal musculature to monitor the bilateral neuromuscular activity of the erector spinae group during the PA thrusts. Maximal-effort isometric trunk extensions were performed by the research subjects before and immediately after the testing protocol to normalize sEMG data. The accelerance or stiffness index (peak acceleration/peak force, kg-1) and composite sEMG neuromuscular reflex response were calculated for each of the thrusts.

Results: Posteroanterior stiffness obtained at the sacroiliac joints, transverse processes, or spinous processes was not different for subjects grouped according to LBP chronicity. However, in those with frequent or constant LBP symptoms, there was a significantly increased spinous process (SP) stiffness index (7.0 kg-1) ($P < .05$) in comparison with SP stiffness index (6.5 kg-1) of subjects with only occasional or no LBP symptoms. Subjects with frequent or constant LBP symptoms also reported significantly greater scores on the visual analog scale ($P = .001$), Oswestry ($P = .001$), and perceived health status ($P = .03$) assessments. The average SP stiffness index was 6.6% greater ($P < .05$) and 19.1% greater ($P < .001$) than the average sacroiliac stiffness index and average transverse process stiffness index, respectively.

Conclusions: This study is the first to assess erector spinae neuromuscular reflex responses simultaneously during spinal stiffness examination. This study demonstrated increased spinal stiffness index and positive neuromuscular reflex responses in subjects with frequent or constant LBP as compared with those reporting intermittent or no LBP. (J Manipulative Physiol Ther 2001;24:489-500)

Key Indexing Terms: Biomechanics; Electromyography; Low Back Pain; Chiropractic; Manipulation; Reflex Responses; Trunk Muscle; Spine

INTRODUCTION

Physical examination of patients with low back pain (LBP) has included assessment of the motion of the human spine in an attempt to assess the functional status of underlying anatomy. Clinicians have used mobilization palpation procedures to manually apply posteroanterior (PA) forces over various spinal segments to assess the perceived tissue resistance and pain provocation. The clinician further uses the perceived results of these assessments to formulate clinical diagnoses and to identify which spinal level to treat and the supposed effectiveness of the intervention. However, because of the qualitative nature of such assessments, many studies have demonstrated that such clinical judgments are

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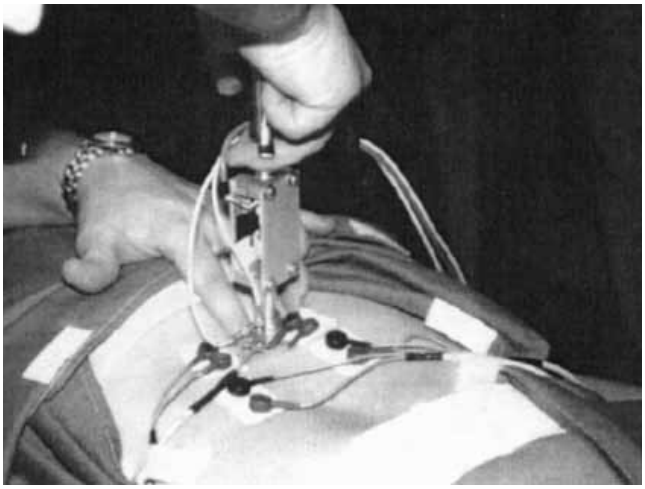

Fig 1. *Bilateral sEMG electrode placement and modified spinal manipulation device used to deliver PA manipulative thrusts to thoraco-lumbar spine and sacroiliac joints.*

unreliable or inaccurate.[1-4] For this reason, mechanical devices have been developed to more objectively quantify spine stiffness.[5-8]

A series of studies has investigated the reliability and validity of instruments in assessing spine stiffness with favorable results.[5-7,9-11] Spinal disorders may be characterized as exhibiting alterations in the mechanical behavior to loading, notably, changes in spinal stiffness.[12,13] Studies investigating PA forces in spinal stiffness assessment have shown relationships to spinal level, body type, and lumbar extensor muscle activity.[14-19] Such measures may be important in distinguishing patients with LBP and further provide significant information of the mechanical behavior of the human spine.[19,20] However, little objective evidence is available concerning variations in PA stiffness and their clinical significance.[16]

Although ligaments have been considered to provide primary restraint to most major joints, recently the musculature has been shown to play an important role in maintaining joint stability.[21,22] Solomonow et al[23] reported that mechanical deformation of ligamentous tissues of the human spine could reflexively elicit activity of the paraspinal muscles providing a net effect of stiffening of the motion segment. Because the spine is a complex dynamic structure whose viscoelastic makeup includes not only its discoligamentous elements but also stabilizing musculature, we aimed to study mechanical and neuromuscular reflex responses to PA manipulative thrusts. Specifically, the objective of this clinical study was to investigate the mechanical PA stiffness of the thoracic, lumbosacral, and pelvic regions and concomitant lumbar neuromuscular reflex responses to high loading rate, impulsive force PA thrusts in a group of research subjects with varying degrees of LBP.

METHODS

Subjects

Twelve men and 10 women, aged 15 to 73 years (mean age of 42.8 years, SD 17.5 years) were recruited from a group of volunteers who responded to a flyer circulated in the community advertising the experiment. Subjects were included if they had not consulted a physician or therapist for low back or leg pain in the past 6 months. Subjects were excluded if they were pregnant, had a previous history of lumbar spinal surgery, or presented any contraindication to spine stiffness testing (eg, malignancy, inflammatory or infective processes involving the spine, significant osteoporosis, or spinal disorders including spondylolisthesis, ankylosing spondylitis, spinal fusion, or neurologic deficit). Subjects were also excluded if they complained of significant symptoms unrelated to lumbar complaints. After written and verbal explanation of the protocol for the study, subjects signed a written informed consent form acknowledging their participation in the study.

Symptom Categorization

Subjects completed questionnaires consisting of a general health history, revised Oswestry Low Back Disability Index, and perceived health status questionnaire (SF-36). From these questionnaires, historical and demographic data were obtained to categorize low back symptomatology. Back pain history was recorded on a scale of 0 to 3, for which 0 = No LBP within the past 6 months, 1 = Acute (<4 weeks of symptoms), 2 = Subacute (<12 weeks of symptoms), and 3 = Chronic (>12 weeks of symptoms). Similarly, patients were characterized according to LBP symptom frequency within the past 6 months on a scale of 0 to 4, for which 0 = No symptoms, 1 = Occasional, 2 = Intermittent, 3 = Frequent, and 4 = Constant. The patients were also asked to provide a visual analog score (VAS), which represented their pain perception at the time of examination. The VAS score ranged from 0 to 10 with 0 representing "no pain" and 10 representing "the worst pain imaginable."

Procedure

After completion of the history, subjects were gowned and underwent physical examination consisting of orthopedic and neurologic examination, lumbar range-of-motion testing, and plain film radiographic examination of the lumbar spine to rule out neurologic deficit or spinal pathologic condition. The review of history and physical examination were performed by a licensed doctor of chiropractic (CJC) in accordance with standard clinical practice. Each subject was placed in the prone position by using a motorized vertical/horizontal table (Softec/Tri-W-G, Valley City, ND). The skin overlying the low back was lightly abraded before adhering pre-gelled silver/silver chloride bipolar electrodes (Isotrate 3SG3-N, Multi biosensors, El Paso, Tex) bilaterally over the L3 and L5 paraspinal musculature (Fig 1). The electrodes had an active diameter of 1.0 cm, and each electrode pair was spaced with an approximately 2.5-cm interelectrode distance. The electrodes were positioned such that posterior-anterior thrusts could be delivered to both the spinous processes and transverse processes without contact with the electrodes or leads. Surface, linear-enveloped, electromyographic (sEMG) signals were then recorded during the testing protocol.

After a brief testing session to verify proper function of the EMG equipment and adjusting of the gain settings, patients were asked to perform 3 consecutive prone-position isometric trunk extensions. Subjects were instructed to lift their chest and shoulders off of the treatment table as high and as hard as they could for a 3-second count and were then told to relax. The patients were informed to stop if they felt intolerable low back discomfort or peripheralization of their symptoms. Each isometric trunk extension task lasted approximately 3 to 5 seconds, and there was approximately a 5-second rest period between exertions. No trunk-force measurement devices or trunk-confinement apparatuses were used for these tests. A linear-envelope detector circuit consisting of a zero-offset full-wave rectifier and bandpass filter (16-500 Hz), followed by a low-pass filter (10 millisecond [ms] time constant), was used to electronically process the raw EMG signal.[24] The sEMG signals were sampled directly into the computer. During the isometric trunk-extension trials, sEMG data were collected at 50 Hz over a 30-second time interval. Average peak, isometric sEMG responses obtained from the 4 electrode pairs were used to normalize each channel of sEMG data.[25]

An Activator Adjusting Instrument (AAI) (Activator Methods, Inc, Phoenix, Ariz) equipped with a pre-load control frame, load cell, and accelerometer was then used to deliver a PA manipulative thrust to several common spinal landmarks, including the posterior superior iliac spine (PSIS) (left and right), sacral base (left and right), S1, and L5, L4, L2, T12, and T8 spinous and transverse processes (Fig 2).

The AAI is a spring-loaded instrument that uses the potential energy of its internal spring when compressed to cause an internal hammer to strike an anvil, propelling its stylus forward. This hand-held, manually activated chiropractic instrument produces an impulsive force-time history approximately 5 ms in duration, approximately 150 Newton in peak force amplitude, and approximately 6000 ms^{-2} in peak-to-peak acceleration amplitude.[11] The modification of the instrument by adding a preload control frame changed the force output to approximately 190 Newton (Fig 3). PA thrusts imparted to the spine were consistent with those delivered in routine clinical practice for which forces were directed perpendicular to the body surface curvature. Neuromuscular (sEMG) activity of the erector spinae muscles, load, and acceleration were recorded simultaneously during each PA thrust (Fig 3). A total of 20 PA thrusts were delivered. The accelerance, hereafter referred to as the stiffness index, was calculated from the force-time and acceleration-time histories for each of the thrusts as follows: positive peak acceleration divided by positive peak force (kg^{-1}).

Linear-enveloped sEMG (Noraxon Myotrace 10, Scottsdale, Ariz), thrust force (PCB model 201A03, Depew, NY) and acceleration (PCB model 305A04) signals were recorded with a Biopac MP100 (Biopac Systems, Inc, Santa Barbara, Calif) data acquisition system and Acknowledge software (Biopac Systems, Inc). For the PA mechanical thrust procedure the sEMG, thrust force, and acceleration responses

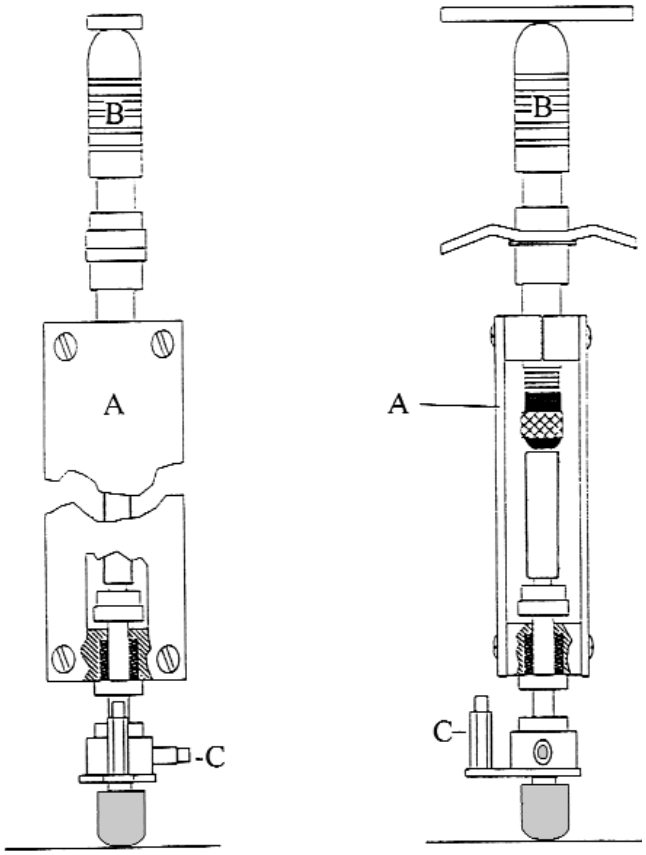

Fig 2. *Schematic illustration of modified Activator Adjusting Instrument (AAI) used to deliver PA manipulative thrusts. Aluminum frame attached to handle,* A*, facilitates preloading of internal spine without compressing spring actuator located in handle,* B*, of AAI. Input load and acceleration response of spine is measured with dynamic load cell and accelerometer attached to stylus,* C*. Modified instrument delivers approximately 190 N thrust over interval of less than 10 ms.*

were sampled at 10 kHz over a 273-ms interval (Fig 3). An external trigger was used to initiate data collection during each of the PA thrusts. The 20 PA thrusts and 4 EMG measurements resulted in a total of 80 sEMG measurements per subject. A composite index of sEMG activity was defined to simplify characterization of this data. Namely, a positive response was defined as an sEMG neuromuscular reflex response at least 5% of the average peak isometric extension sEMG response where isometric relative mean sEMG (Ext) = (Task – Rest)/(Ext – Rest).[26] Task and Rest correspond to the mean sEMG responses obtained during the 100-ms window (after thrust) and 10-ms window (baseline), respectively.

Statistical Analysis

Descriptive statistics were performed on all the parametric data. An analysis of variance (ANOVA) was used to determine within-group and across-group differences in PA stiffness index covarying for subject age. A 2-tailed *t* test was performed to assess grouped differences in functional status

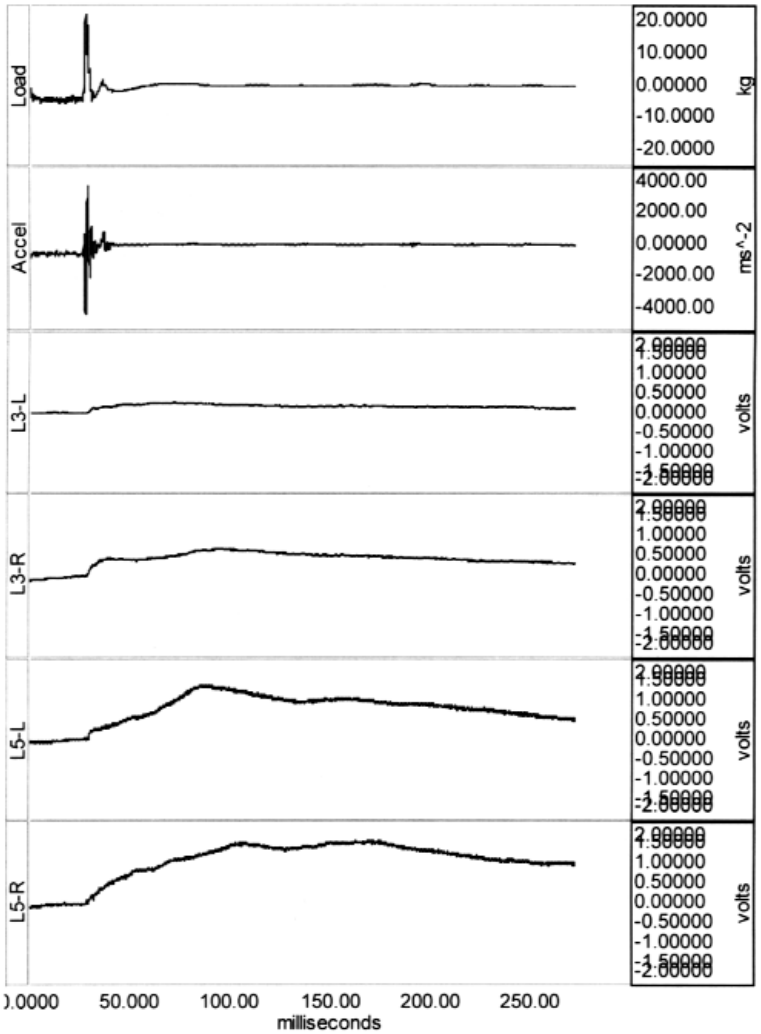

Fig 3. *Typical load (kg) and acceleration (ms-2) versus time (ms) curves obtained during application of PA manipulative thrusts to spine (Subject 017, thrust on L4 spinous process). Linear-enveloped sEMG response (volts) is shown for each of 4 bipolar surface electrodes reflecting neuromuscular reflex response.*

Table 1. *Patient demographics**

Parameter	All subjects (n = 22)	Men (n = 12)	Women (n = 10)
Age (y)	42.8 (17.5)	50.4 (15.1)	33.7 (16.3)
Weight (kg)	75.8 (18.0)	86.6 (15.9)	62.9 (10.2)
Height (cm)	173.5 (10.2)	179.3 (7.3)	166.6 (9.1)

*Mean and SD are indicated.

(VAS, Oswestry, SF-36). Statistical significance was set at a significance level of $P < .05$ to test the null hypotheses that no difference in stiffness index and neuromuscular reflex response exists between symptomatic and asymptomatic subjects.

RESULTS

Table 1 summarizes the demographics of the male and female patient population. In this study, men were significantly older than women (ANOVA, $P = .02$). Table 2 summarizes the functional status (Oswestry), symptomatology (VAS), perceived health perception (SF-36), and health history of the subjects. Approximately one-half of the subjects had a VAS score greater than 3. The mean Oswestry index was 9.7, which corresponds to a mean disability index of 19.4% for all subjects. All but 1 of the subjects had a perceived health status (SF-36) better than fair. In terms of symptomatology, 2 of the subjects were asymptomatic (no prior history of LBP), 6 had occasional LBP symptoms, 4 had intermittent symptoms, and 10 had chronic symptoms of LBP. More than half of the subjects reported that they had LBP for more than 4 weeks.

Examination of Figure 4 indicates that the PA stiffness index was higher for thrusts applied over the spinous processes (SPs) in comparison with thrusts applied over the transverse processes (TPs). Thrusts applied to the sacroiliac region (SI = PSIS and sacrum) produced PA stiffness index values between those of the SP and TP stiffness index values. Thoracic TP stiffness index was significantly greater (9.9%) than the lumbar TP stiffness index (ANOVA, $P < .05$). The

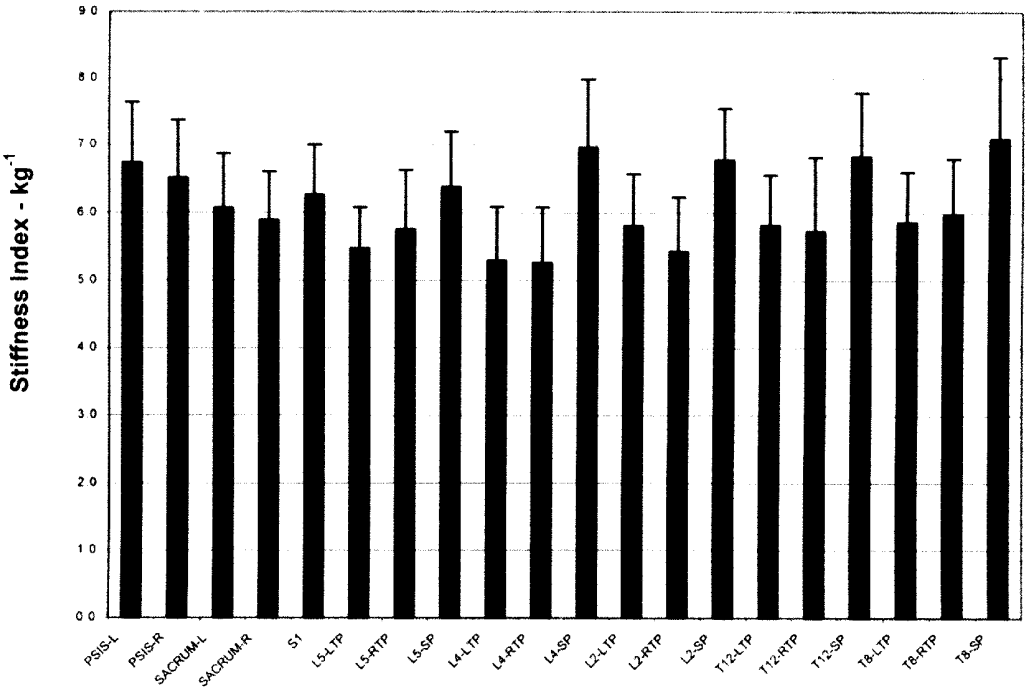

Fig 4. *Variation in PA stiffness index for thrusts applied to thoraco-lumbar spinous and transverse processes and sacroiliac region (PSIS + sacrum). Mean values and error bars (SD) are shown for each of the 20 levels examined. Differences in stiffness index were statistically significant.*

stiffness index of the thoracic SP was not significantly different than the lumbar SP stiffness index. Differences among SI, SP, and TP stiffness indices were statistically significant. The average SP stiffness index was 6.6% greater (ANOVA, $P < .05$) and 19.1% greater (ANOVA, $P < .001$) than the average SI stiffness index and average TP stiffness index, respectively. Subject mean SI, SP, and TP stiffness index values were used for the group comparisons that follow.

Thrusts over the SI, SP, and TP regions elicited one or more positive sEMG neuromuscular reflex responses in all subjects (mean composite positive sEMG response = 15, range 1-33). The majority of positive sEMG neuromuscular reflex responses occurred during PA thrusts applied to the lumbosacral spine. PA thrusts in the thoracic region elicited a positive lumbar sEMG neuromuscular reflex response in only 6 of the 22 subjects. Positive sEMG neuromuscular reflex responses were observed in response to thrusts that were applied over both the spinous processes and the transverse processes. Generally, sEMG neuromuscular reflex responses occurred between 2 to 4 ms after the initiation of the PA thrust and continued throughout the 273-ms measurement interval. In a few cases, the sEMG neuromuscular reflex response was initiated during the pre-load phase of the PA thrust application. The number and percentage of subjects eliciting various ranges of positive sEMG are summarized in Table 2.

Based on the health history findings, patients were subgrouped according to LBP history (None, Acute, or Subacute vs Chronic) and symptom frequency (None, Occasional, or Intermittent vs Frequent or Constant). Figures 5 and 6 summarize the subjective and biomechanical status of the subjects grouped in this manner. LBP chronicity (Fig 5*A*) and increased symptom frequency (Fig 6*A*) were associated with a significant (*t* test, $P < .001$) increase in Oswestry disability index scores and VAS measures of symptom

Table 2. *Summary of functional status (Oswestry), symptomatology (VAS), perceived health status (SF-36), LBP health history, LBP symptom frequency, and sEMG reflex response*

Parameter	Range, score, or index	Number of subjects	% of subjects
VAS			
(scale: 0-10, 10 = worst pain)	0-3	12	54.5
	4-7	10	45.5
	8-10	0	0
Oswestry	0-6	6	27.3
(scale: 0-50, 50 = worst score)	7-13	10	45.5
	14-20	5	22.7
	21-27	1	4.5
SF-36	0 (Excellent)	2	0.1
	1 (Very Good)	11	50.0
	2 (Good)	8	36.4
	3 (Fair)	1	4.5
	4 (Poor)	0	0
LBP history	0 (None)	6	27.3
	1 (Acute)	3	13.7
	2 (Sub-Acute)	1	4.5
	3 (Chronic)	12	54.5
LBP symptom frequency	0 (None)	2	9.1
	1 (Occasional)	6	27.3
	2 (Intermittent)	4	18.2
	3 (Frequent)	9	40.9
	4 (Constant)	1	4.5
Lumbar sEMG reflex response*	0-7	6	27.3
(scale: 0-80, 80=highest response)	8-15	8	36.4
	16-23	2	9.1
	24-31	4	18.2
	32-39	2	9.1

*Relative mean >5%.

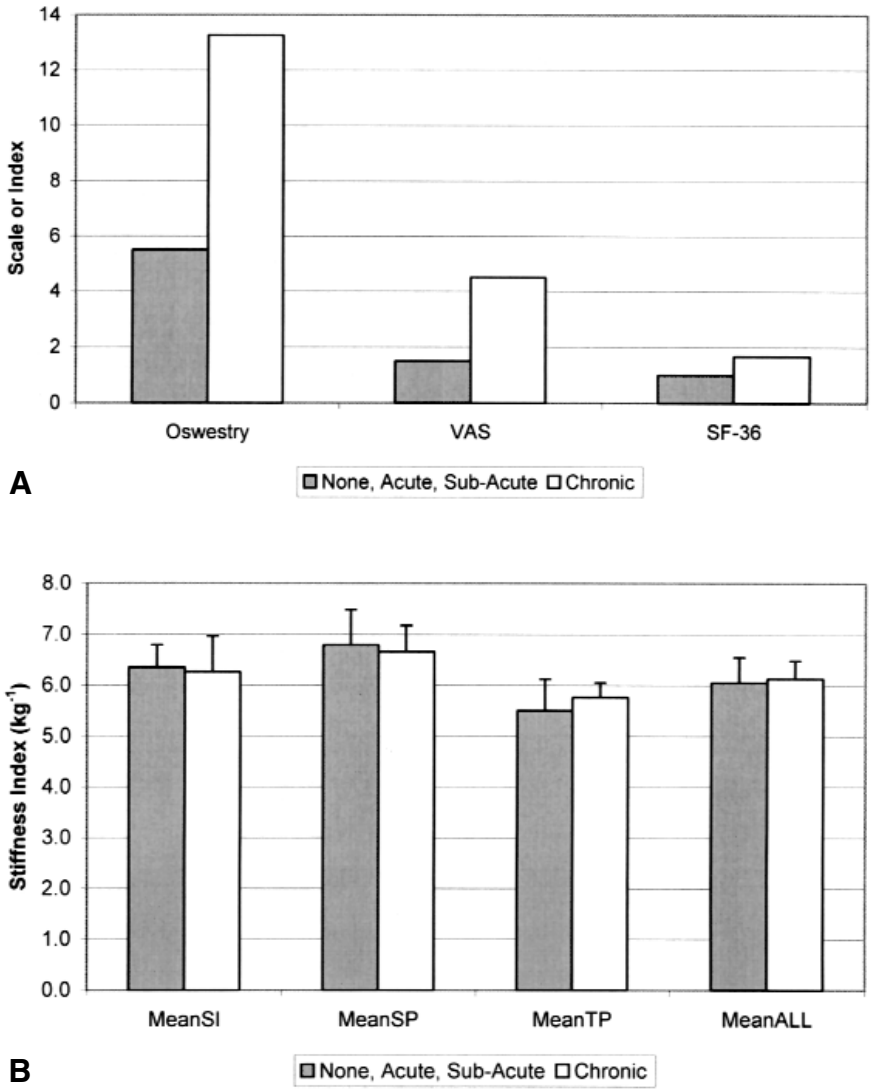

Fig 5. *Stiffness and neuromuscular reflex response. Subjective,* ***A****, and biomechanical,* ***B,*** *status of subjects grouped according to LBP chronicity. Error bars = 1 SD. Differences in stiffness index for sacroiliac (SI), spinous process (SP), and transverse process (TP) were not significant between chronic group and none, acute, subacute LBP group.*

intensity but were not associated with any significant differences in patient perception of disability (SF-36). PA stiffness index (SI, SP, TP) was not significantly different (ANOVA, $P > .05$) for subjects grouped according to LBP chronicity (Fig 5*B*). In subjects with frequent or constant LBP symptoms, however, there was a significantly increased (ANOVA, $P < .05$) SP stiffness index (7.0 kg^{-1}) in comparison with the SP stiffness index (6.5 kg^{-1}) of subjects with only occasional or no LBP symptoms (Fig 6*B*). Patients with frequent or constant LBP symptoms also reported significantly greater VAS (*t* test, $P = .001$), Oswestry (*t* test, $P = .001$), and SF-36 perceived health status (*t* test, $P = .03$) scores. A more positive sEMG neuromuscular lumbar reflex response was found in subjects with frequent to constant symptom frequency (mean 18/80 positive responses, range 8-33) in comparison with subjects with intermittent or no symptoms (12/80, range 1-27).

Patients were also grouped according to the number of positive sEMG neuromuscular reflex responses to the PA mechanical thrusts. Patients with 8 (10% of total) or more positive neuromuscular reflex responses to the PA thrusts were classified as "positive" neuromuscular responders (n = 16), whereas patients with fewer than 8 positive responses were classified as "negative" neuromuscular responders (n = 6). Subjective measures of patient status (Oswestry, VAS, SF-36) showed significant (*t* test, $P < .005$) group differences (Fig 7*A*) that were similar to the group differences observed for LBP chronicity and symptom frequency comparisons. A "positive" sEMG neuromuscular reflex response was associated with a significant increase (ANOVA, $P < .05$) in the TP stiffness index response to PA thrusts in comparison with "negative" neuromuscular responders (Fig 7*B*). Both null hypotheses that were tested were rejected.

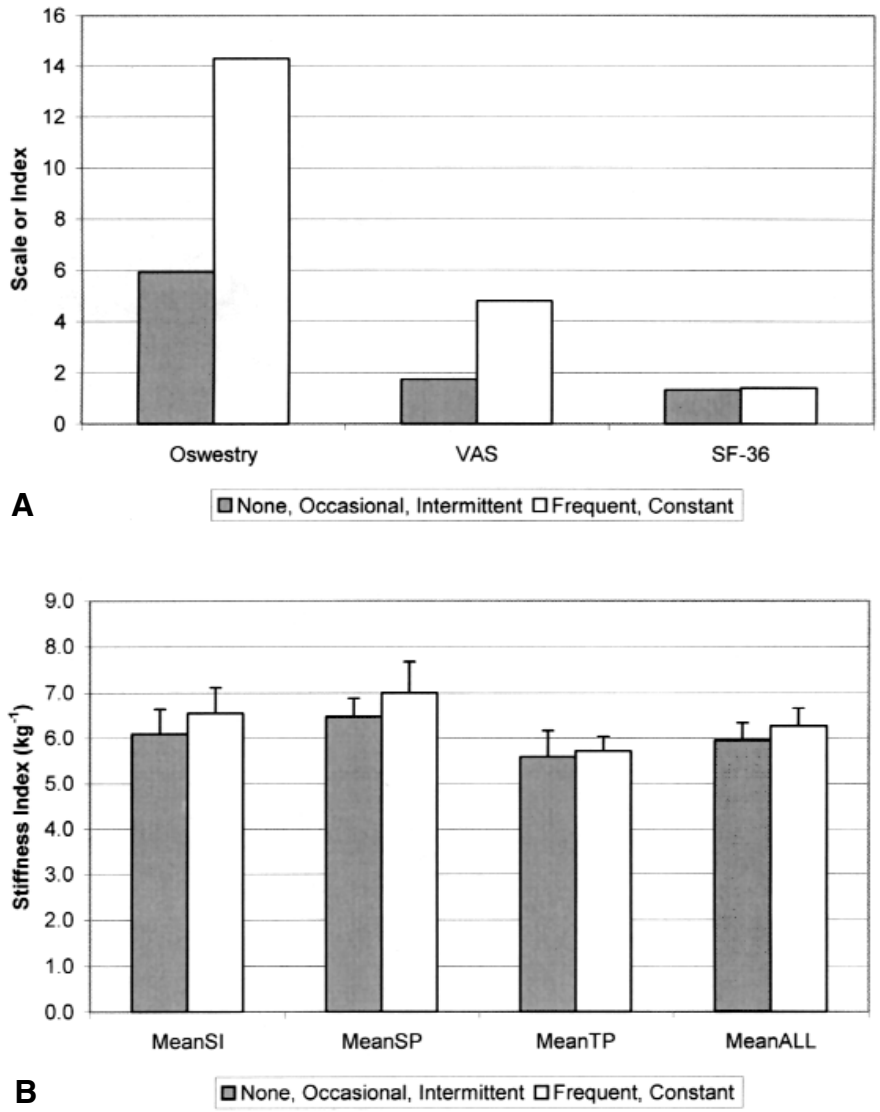

Fig 6. *Stiffness and neuromuscular reflex response. Subjective, **A**, and biomechanical, **B**, status of subjects grouped according to LBP symptom frequency. Error bars represent 1 SD. Differences in stiffness index for sacroiliac (SI), spinous process (SP), and transverse process (TP) were significant (SP stiffness only) between frequent and constant LBP group and none, occasional, and intermittent LBP group.*

DISCUSSION

Several important findings emerge from this study that provide additional support for clinical assessment strategies that use stiffness and neuromuscular measurements to probe and quantify the biomechanical characteristics of the spine. Noteworthy was the finding that "symptomatic" subjects or subjects presenting with frequent to constant LBP were characterized by having significantly increased Oswestry low back disability scores, VAS pain scores, and SP stiffness index in comparison with more "asymptomatic" subjects or subjects presenting with intermittent or no LBP. These results are similar to those reported by Latimer et al[20] who demonstrated that subjects with LBP showed increased PA stiffness index compared with times when they had little or no pain. Although there was no statistically significant relationship of spinal stiffness index to LBP history, the frequency of the subjects' complaints was found to be positively correlated to the spinal stiffness index. Thus, it may be that spinal stiffness is increased in subjects experiencing pain at the time of evaluation.

PA manipulative thrusts applied to the thoracic spine in some cases elicited positive neuromuscular reflex responses at sEMG leads located at the L3 and L5 spinal levels. Because the erector spinae musculature consists of several muscles surpassing multiple spinal levels,[27] and because sensory inputs are known to ascend or descend as much as 3 or 4 spinal levels by means of interneuronal connections

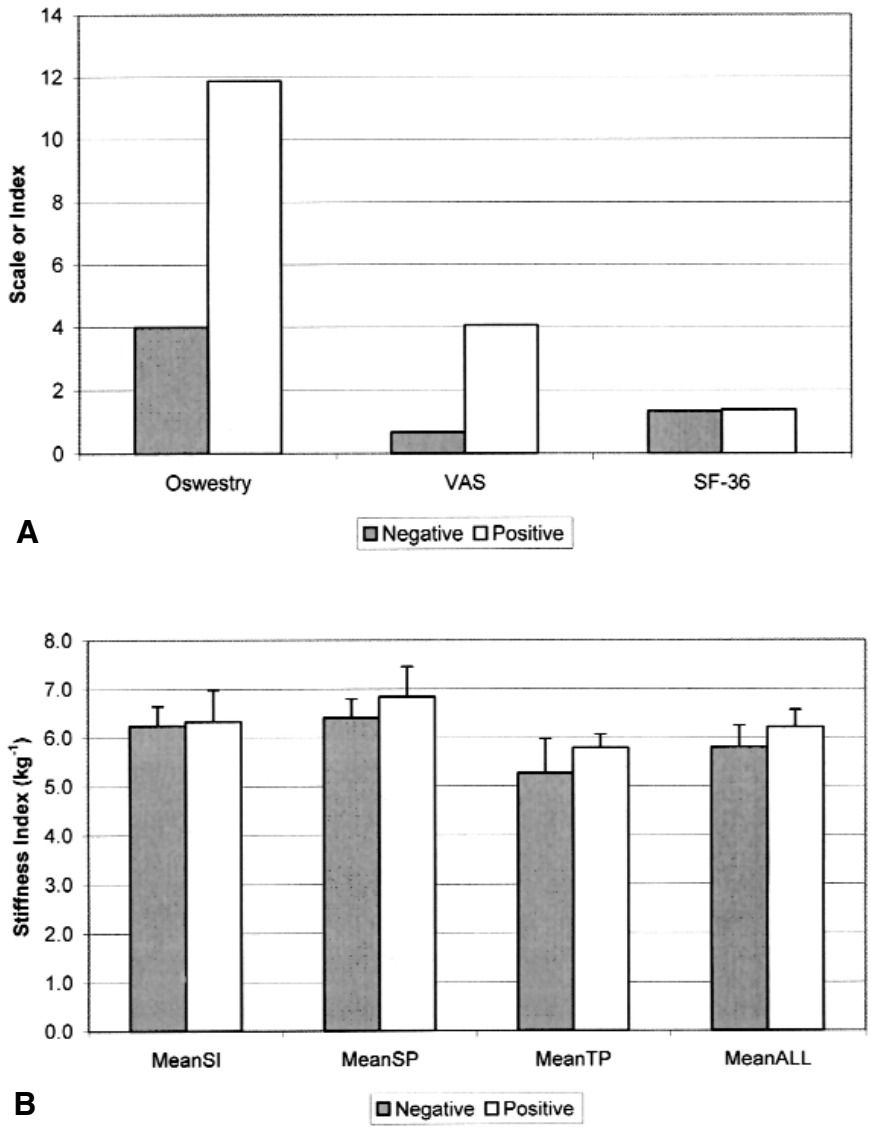

Fig 7. *Stiffness and neuromuscular reflex response. Subjective,* ***A****, and biomechanical,* ***B****, status of subjects grouped according to sEMG neuromuscular reflex response. Error bars represent 1 SD. Differences in stiffness index for sacroiliac (SI), spinous process (SP), and transverse process (TP) were significant (TP stiffness only) between "positive" sEMG reflex response group and "negative" sEMG reflex response group.*

with motor neurons,[28] it is not surprising that PA thrusts cause reflex responses quite distant from the point of application. AAI thrusts applied to the T12 spinous process have been found to cause significant rotations of the L3-L4 functional spinal units that could also be responsible for such observations.[29] Our finding that lumbar sEMG neuromuscular reflex responses were associated with all lumbar PA thrusts is consistent with the findings of Solomonow et al,[23] who found the strongest EMG reflex responses at the levels of electrical stimulation rather than at adjacent levels.

In this study, the stiffness index was calculated from the force-time and acceleration-time histories. The stiffness index is representative of the spine-segment motion response to the applied force input. In this case, the motion response to the applied input is based on the positive peak of the acceleration-time signal, which occurs approximately 1.2 ms after the positive peak force, and is therefore associated with the rebound motion response of the spine segment (Fig 3). To our knowledge, this is the first report assessing dynamic stiffness measures applied to the skin overlying the transverse processes and sacroiliac joints. In this regard, a statistically significant decrease in stiffness index exists in TPs in both the thoracic and lumbar spine when compared with SP stiffness index values. This is not surprising because there is more overlying musculature over TP bony landmarks as opposed to the SPs. Assessments made over the musculature (TPs) thus appear dampened when compared with contacts made over the SPs. The finding that thoracic TP stiffness index was significantly greater (9.9%) than the

lumbar TP stiffness index may be attributed to the fact that biomechanically, the thoracic spine is relatively stiffer than the lumbar spine because of the stability provided by additional spinal structures, including the costal articulations and interconnecting musculature.[17,30] Erector spinae muscles originating from thoracic vertebrae, therefore, have a more stable origin than muscles originating in lumbar vertebrae.

Thrusts applied to the sacroiliac region (PSIS and sacral base) produced PA stiffness index values between those of the SP and TP stiffness index values. Although the more stable articulations of the SI joints may be expected to be stiffer than the TPs, we found it curious that the SI joints were less stiff than the SPs. In this regard, soft-tissue volume overlying the SI joint contacts may be an important factor as has been reported in other studies.[14,15,31] However, to our knowledge there is no research that specifically documents the PA stiffness index of the SI joint. Considerations of body type or adiposity should be investigated in future work.

Biomechanical models have shown that intersegmental agonist and antagonist muscles biomechanically increase the overall stiffness (stability) of the intervertebral joints.[32] The load-bearing potential of the ligamentous spine is substantially increased by controlling its deformation modes through minimal exertion of selected muscles.[33] The paraspinal musculature has been found to play a large role in maintaining spine stability.[34,35] Similar conclusions have been realized by directly assessing muscular contributions to spine stiffness in a clinical setting. As reported by Lee et al,[19] PA stiffness is significantly greater during maximum activation of the lumbar extensor muscles. By assessing PA stiffness values during different percentages of the maximal voluntary contraction, Shirley et al[18] found that even small amounts of back muscle activity can increase lumbar PA stiffness.[18] Our results corroborate these findings.

We found that subjects with positive neuromuscular reflex responses to PA manipulative thrusts had more severe disability indices, higher pain scores, and increased TP stiffness index in comparison with subjects with negative neuromuscular reflex responses. Because neuromuscular reflex responses were associated with all lumbar thrusts, but less often in response to thoracic or sacroiliac thrusts, differentiation was achieved by grouping subjects into positive and negative neuromuscular responders. Muscular responses to PA forces (5%-10% of subjects maximal voluntary contraction) have been thought to be responsible for increases in lumbar PA stiffness observed by clinicians.[18] Subjects with positive neuromuscular reflex responses may exhibit heightened muscle activity so as to stabilize the spine in response to a perceived noxious stimulus or pain. Individuals who require sustained activity of their paraspinal muscles in occupational environments are subject to muscle fatigue and diminished ability of the muscles to stabilize the spine.[23] Subsequently, examination procedures geared toward understanding spinal stiffness and muscular activity may serve to identify those individuals at risk and monitor their response to therapeutic intervention.

In this study, positive sEMG neuromuscular reflex responses occurred between 2 and 4 ms after the initiation of the PA manipulative thrust and continued throughout the 273-ms measurement interval. These results are similar to those of Herzog et al,[36] who reported consistent neuromuscular reflex responses to spinal manipulative treatments (SMTs) applied to different regions of the spine and pelvis in 10 asymptomatic young men. Typically, the SMTs delivered in this manner last approximately 200 ms[37] and are of the force magnitude ranging from approximately 100 to 500 N depending on the region of the spine undergoing treatment.[38] Collectively, these authors reported that the reflex responses occurred within 50 to 100 ms after the onset of the treatment thrust, lasted for approximately 100 to 400 ms, and were said to be composed of a series of spatially and temporally nonsynchronized motor unit action potentials of multireceptor origin. More work is required to elucidate these findings.

Clear differences exist in the types of SMT delivered in the study by Herzog et al[36] and that of the current study. However, impulsive thrusts (as used in this study) delivered to the in vivo human lumbar spine have been shown to produce measurable intersegmental displacements (axial range = 0.25-1.62 mm; PA shear range = 0.1-0.51 mm) and rotations (0.13-0.9) of functional spinal units.[29] Similar intersegmental motions have been reported in response to manual-type SMTs of the same force magnitude,[39] albeit at a much larger (300 N) preload force[40] in comparison with preload forces (20 N) used with the AAI.[29] The time to peak force during manual SMT is nearly 2 orders of magnitude longer (200-250 ms) than that produced by the AAI. Additional research is required to elucidate the relationship(s) between time and frequency-dependent mechanical characteristics of SMTs and neuromuscular reflex responses. Such information may enable clinicians to maximize potential therapeutic benefits while minimizing the forces exerted and potential risk to the patient.

Differences exist in the recording technique used in our study as compared with that of others who have investigated neuromuscular reflex responses during SMT.[36,41] Our protocol used linear-enveloped electromyography, whereas those cited previously have used raw EMG. The electromyographic amplifier uses proprietary electronic hardware to condition (linear envelope) the raw electromyographic signals. As opposed to raw sEMG, linear-enveloped signals are sampled directly into the computer. Therefore, the band pass filter frequency cut-offs were 16 to 500 Hz, as opposed to the 1 kHz commonly used in raw EMG assessment of the lumbar musculature. Because the linear envelope sEMG signals were essentially quasistatic in terms of time variations, these signals were well characterized by a 50-Hz sampling frequency. It should be noted that for raw sEMG, we routinely use a sampling frequency that is twice the upper band pass filter cut-off frequency. In addition, the Noraxon Myotrace 10 signal conditioning system that we used utilizes an electronic feedback technique to cancel out very low frequency changes (DC to fractions of a Hz) in the

acquired physiologic signal. Signals in this very low frequency range arise because of the motion artifact phenomena. As such, the Noraxon signal is remarkably free of noise caused by skin or cable movement and offers a very stable baseline. In Noraxon's patented system, information carried by the overall signal is effectively split into an "EMG only" component and a low frequency "motion artifact" component. The motion artifact component is literally subtracted from the overall signal, allowing only the EMG signal to be presented. This artifact cancellation is far superior to the results achievable by use of conventional electronic filter techniques.

An important limitation to the technique used in this study lies in the fact that the modified AAI used for stiffness assessment is also a commonly used treatment device for spinal manipulation in the chiropractic profession. Therefore, each time the device is used for a stiffness test, the tissue is also potentially "treated." As a result, the testing procedure may cause physiologic and biomechanical changes in the area being tested. This may also be true for other types of stiffness tests that use low-frequency oscillatory assessments or static preload assessments. Recognizing this limitation, we are currently investigating an alternative methodology to minimize the potential for altering the tissue during the examination.

The neuromuscular reflexes observed in the current study of symptomatic patients with LBP, however, appear different than those reported in the work of others who used the AAI in asymptomatic subjects.[37] AAI thrusts delivered to the thoracic spine of an asymptomatic subject[37] and AAI-II thrusts delivered to different spinal regions in 10 asymptomatic subjects[41] have been associated with reflex responses in the shape of a single compound motor unit action potential and attributed to originate from the muscle spindles. This is in contrast to our findings. Because similar reflex responses were observed for contacts mainly over bone (SPs) and over muscle (TPs) in our study, it is unlikely that the reflex response simply originates from muscle spindles. The relatively long duration sEMG neuromuscular reflex responses observed in this study are similar to sEMG neuromuscular reflex responses that have been attributed to mechanoreceptors in the capsule of the spinal facet joints, pain and cutaneous receptors, and proprioceptors of skeletal muscles (muscle spindles and golgi tendon organs).[36] Unfortunately, separation of the reflex sEMG signal into its constituent components was not possible.

Immunohistochemical neuroanatomic and neurophysiologic investigation has demonstrated the existence of mechanosensitive and nociceptive afferent fibers within the discoligamentous tissues of the thoracic and lumbar spine, sacroiliac joints, and spinal musculature.[42-48] Spinal ligaments not only provide mechanical stability to spinal joints, but also act as active communicators of sensory information regarding the loading or noxious presence in spinal joints.[49] Through reflexogenic mechanisms, stimulation of discoligamentous structures results in reflex activity in the paraspinal musculature, thereby making a contribution toward maintaining spinal stability when subjected to various internal and external disturbances.[23,48,50-52] Research into probable causes of low back injury has revealed that desensitization of mechanoreceptive afferents in lumbar spinal tissues may occur from cyclic loading (repetitive activity) and is of primary importance relating to biomechanical failure.[53,54] Therefore the ability to assess the muscular and mechanical behavior of the spine in clinical practice reflects a clinical utility well suited for those evaluating patients with musculoskeletal disorders.

CONCLUSION

This study is the first to assess erector spinae reflex responses simultaneously during spinal stiffness examination. Because the supporting musculature significantly contributes to spine stability, knowledge of the physiologic and mechanical properties in a clinical assessment methodology may serve to better understand spinal function and LBP. The current study demonstrated an increased spinal stiffness index and positive neuromuscular reflex responses in subjects with frequent to constant LBP as compared with subjects reporting intermittent to no LBP. Such findings may reflect clinically relevant contributions of the muscles to increased spinal stiffness indices, which corroborates the research of others. Our findings are similar to those previously conducted with other methods. Noninvasive stiffness and sEMG measurements, when combined with conservative manipulative care of the back, may prove to be a particularly effective means to diagnostically probe and treat lower back disorders. Because this is the first report of dynamic spinal stiffness index while simultaneously monitoring neuromuscular responses, more work is necessary to better understand the relationships between the mechanical and physiologic characteristics of the human spine. Measurements of PA stiffness index and neuromuscular characteristics of symptomatic and asymptomatic patients with LBP are particularly important for clarification of the significance of these observations.

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