Active Trunk Extensor Contributions to Dynamic Posteroanterior Lumbar Spinal Stiffness

Christopher J. Colloca, DC,[a] and Tony S. Keller, PhD[b]

Abstract

Background: Assessments of posteroanterior (PA) spinal stiffness using mobilization apparatuses have demonstrated an increase in PA spine stiffness during voluntary contraction of the lumbar extensor muscles; yet, little work has been done to this degree in symptomatic subjects.

Objective: To use a previously validated dynamic mechanical impedance procedure to quantify changes in PA dynamic spinal stiffness at rest and during lumbar isotonic extension tasks in patients with low back pain (LBP).

Methods: Thirteen patients with LBP underwent a dynamic spinal stiffness assessment in the prone-resting position and again during lumbar extensor efforts. Stiffness assessments were obtained using a handheld impulsive mechanical device equipped with an impedance head (load cell and accelerometer). PA manipulative thrusts ($\approx$150 N, <5 milliseconds) were delivered to skin overlying the L3 left and right transverse processes (TPs) and to the L3 spinous process (SP) in a predefined order (left TP, SP, right TP) while patients were at rest and again during prone-lying lumbar isotonic extension tasks. Dynamic spinal stiffness characteristics were determined from force and acceleration measurements using the apparent mass (peak force/peak acceleration, kg). Apparent mass measurements for the resting and active lumbar isotonic task trials of each patient were compared using a 2-tailed, paired *t* test.

Results: A significant increase in the PA dynamic spinal stiffness was noted for thrusts over the SP (apparent mass [17.0%], $P = .0004$) during isotonic trunk extension tasks compared with prone resting, but no statistically significant changes in apparent mass were noted for the same measures over the TPs.

Conclusions: These findings add support to the significance of the trunk musculature and spinal posture in providing increased spinal stability. (J Manipulative Physiol Ther 2004;27:229-237)

Key Indexing Terms: *Apparent Mass; Biomechanics; Electromyography; Low Back Pain; Lumbar Spine; Chiropractic; Manipulation; Muscle Coactivation; Stiffness; Stability*

Introduction

Maintenance of posture and performance of purposeful trunk motion are the result of coordinated load sharing between passive and active paraspinal tissues that act to balance the external loads.[1] Indeed, the spinal musculature plays a major role in spine stability.[2,3] Voluntary contraction of the erector spinae muscles acts to stiffen the intervertebral joints.[4] Physiologic deformation of the viscoelastic structures of the spine have also been shown to elicit active and reflexive muscular contraction of the multifidus and longissimus muscles, which, in turn, act to stiffen and stabilize the spine during movements.[5]

Disturbances in the musculoskeletal system that result in excessive load sharing, abnormal motion, and higher strains in the highly innervated lumbar spinal soft tissues have been suggested as possible causes of some low back disorders and chronic low back pain.[6,7] Clinically, increased levels of muscle coactivation may constitute an objective indicator of the dysfunction in the passive stabilizing system of the lumbar spine.[4] Biomechanical assessments that provide noninvasive estimates of spinal stiffness together with other objective tests and outcome measures may help clinicians to discriminate and treat patients with spinal disorders.[8]

[a] Private practice of chiropractic, Phoenix, Ariz; Department of Kinesiology, Arizona State University, Tempe, Ariz.

[b] Professor, Department of Mechanical Engineering, University of Vermont, Burlington, Vt.

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Submit requests for reprints to: Dr Christopher J. Colloca, 11011 S 48th Street, Suite 205, Phoenix, AZ 85044 (e-mail: *DrC100@aol.com*).

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Table 1. *Patient demographics*

Subject	Age	Sex	Height	Weight	VAS	Oswestry	Symptom frequency*	Back pain history†	Health perception‡
N = 13	(y)	(M/F)	(cm)	(kg)	(0–10)	(0–50)	(0–3)	(0–3)	(SF-36; 0–4)
4	37	M	175.26	80.74	1	9	1	1	2
5	54	M	182.88	86.18	1	2	1	1	1
6	23	M	180.34	84.37	3	10	2	1	1
8	67	M	184.15	85.28	1	8	2	3	1
9	44	M	172.72	81.65	1	1	1	1	1
10	38	M	181.61	109.77	5	12	3	3	3
13	40	F	142.24	59.88	5	16	3	3	2
14	38	F	171.45	74.39	5	11	3	3	1
15	69	M	170.18	78.02	5	12	3	3	1
16	56	F	165.56	57.15	2	8	1	3	2
17	15	F	172.72	49.90	6	19	3	2	0
20	28	F	167.64	67.13	5	14	3	3	2
22	48	M	187.96	79.83	1	3	1	3	1
Mean	42.85		173.21	76.48	3.15	9.62	–	–	–
SD	16.00		11.34	14.80	2.03	5.35	–	–	–

Mean ± SD.
N = 13.
VAS, Visual Analogue Scale, *SF ± 36*, 36-Item Short Form Health Survey; *LBP*, low back pain.
* Symptom Frequency. 0 = Currently asymptomatic; 1 = Occasional LBP; 2 = Intermittent LBP; 3 = Frequent LBP; 4 = Constant LBP.
† Back Pain History. 0 = No present LBP or pain in the past 6 months; 1 = Acute (< 4 weeks of symptoms); 2 = Sub acute (<12 weeks of symptoms); 3 = Chronic (<12 weeks of symptoms).
‡ Health Perception. 0 = Excellent; 1 = Very Good; 2 = Good; 3 = Fair; 4 = Poor.

Studies investigating posteroanterior (PA) spinal stiffness using mobilization assessment apparatuses have shown relationships between PA stiffness and a number of factors, including spinal level, body type, body position, and lumbar extensor muscle activity.[9-13] Results from these studies have shown an increased PA spine stiffness to voluntary contraction of the lumbar extensor muscles.[13,14] PA spinal stiffness, therefore, has been hypothesized to be an important parameter to discriminate between patients with low back pain and asymptomatic subjects.[8,15] To date, little objective evidence is available, however, discerning variations in PA spinal stiffness and its clinical significance. The objective of this study was to use a dynamic mechanical assessment procedure to quantify changes in PA spinal stiffness at rest and during prone-lying lumbar isotonic extension postures in patients with low back pain (LBP).

Methods

Subjects

Thirteen patients with LBP (8 males and 5 females, mean age of 42.9 years, range 15–69 years) were included in the study (Table 1). The patients were examined as part of a follow-up to an earlier study of 22 subjects in which they participated in a comprehensive physical examination and thoracolumbar muscle reflex and dynamic stiffness assessment protocol.[8,16] Thirteen subjects that were re-examined met the inclusion criteria for the current study. Patients were included in this study if they had present back pain but had not consulted a doctor for low back or leg pain treatment in the past 6 months. In this manner, patients who had been recently treated for low back pain were excluded to avoid bias from therapeutic influences on the trunk musculature.[17] Specifically, patients undergoing treatment for lower back pain may be receiving therapy which can affect the activity of their trunk muscles.[17,18] Patients were excluded if they were pregnant, had a previous history of lumbar surgery, or presented any contraindication to spinal manipulation therapy (SMT). Additionally, the patients had to be able to tolerate the task efforts of isotonic trunk extension. Therefore, those patients reporting unrelenting back or leg pain during lumbar extension at physical examination were excluded from the study. Following written and verbal explanation of the protocol for the follow-up study, patients signed a written informed consent form acknowledging their participation in the follow-up study. Back pain demographic data obtained from the patients participating in the study included visual analog score (VAS) (0–10, 10 worst); symptom frequency (0–4, 0 = none; 1 = occasional; 2 = intermittent; 3 = frequent; 4 = constant); back pain history (0–4, 0 = no present LBP or pain in the past 6 months; 1 = acute [<4 weeks of symptoms]; 2 = subacute [<12 weeks of symptoms]; 3 = chronic [> 12 weeks of symptoms]); perceived health status (0–4, taken from the short form 36 [SF-36] health survey questionnaire: 0 = excellent;

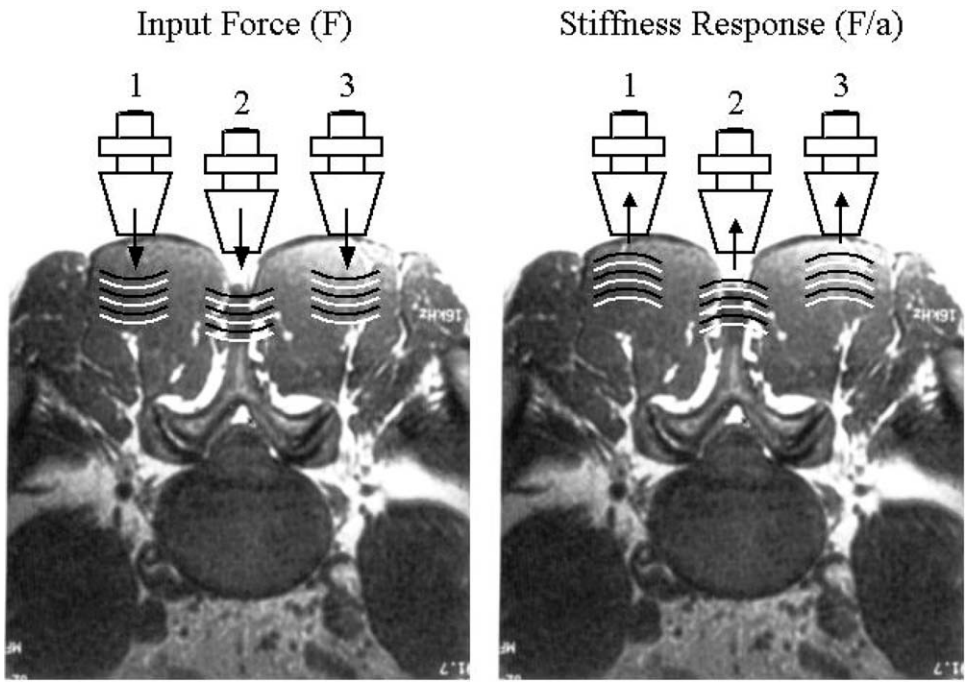

Fig 1. *Segmental contact points are shown for the dynamic stiffness assessment procedure. Stylus containing the impedance head was placed at (1) RTP, (2) SP, and (3) LTP of L3, where an input force (F) of approximately 150 N (≈ 5 milliseconds) was delivered to mechanically excite the structure. Using a mechanical impedance technique, apparent mass (kg) was calculated as input force/output acceleration (F/a) to derive the apparent mass, a measure of the dynamic PA stiffness of the spine for each of the trials.*

1 = very good; 2 = good; 3 = fair; 4 = poor); and the Oswestry Low Back Pain Disability Index (0–50, 50 worst). Back pain demographic data for the patients participating in the study are shown in Table 1.

Patient Assessment Procedure

Each subject was placed in the prone position by use of a motorized vertical/horizontal table (Softec/Tri-W-G, Valley City, ND) and asked to rest for a period of 2 minutes while the experimental protocol was read to them. Two pairs of pregelled, self-adhesive, silver/silver chloride bipolar electrodes (Easytrode 3SG3-N, MultiBioSensors, El Paso, Tex) were attached bilaterally over the erector spinae musculature at its aponeurotic origin overlying the multifidus at L5 and overlying the iliocostalis lumborum muscles at L3. The skin was lightly abraded prior to attachment of the electrodes. The surface electrodes had an active diameter of 1.0 cm and each electrode pair had an approximately 2.5-cm interelectrode distance. Electrodes and electrode leads were positioned bilaterally on the lateral aspect of the erector spinae muscle so that posterior-anterior thrusts could be delivered to both the spinous processes (SPs) and transverse processes (TPs) without contact with the electrodes or electrode leads. To verify proper function of the electromyograph (EMG) equipment, the prone-lying patients were asked to lift their chest and shoulders off the treatment table while surface electromyographic responses were monitored. During this time, adjustments in electromyographic signal amplification were made. Additionally, this initial trunk extension task also served as a tolerance test to observe the patient's ability to participate in the study. As part of the initial instructions given, patients were informed to abort the procedure immediately if the extension procedure caused them intolerable low back discomfort or peripheralization of their symptoms.

Using a previously described and validated analytical technique,[19,20] the PA force input and PA acceleration response of the spine were obtained using a modified handheld mechanical device (Activator Adjusting Instrument, Activator Methods International, Ltd, Phoenix, Ariz) equipped with a preload control frame and mechanical impedance head (load cell and accelerometer). This technology provides the ability to measure the input force and acceleration response characteristics of the spine at the segmental contact point.[20] This dynamic stiffness assessment method applied to the SPs is associated with an intrasubject variance of about 20% to 25%.[20] For repeated trials (n = 10) applied to spine surrogate,[19] the variance has been reported to be 9%. The 10-mm diameter contact surface of the instrument's indenter head consists of a stainless steel contact member encased by a neoprene tip.

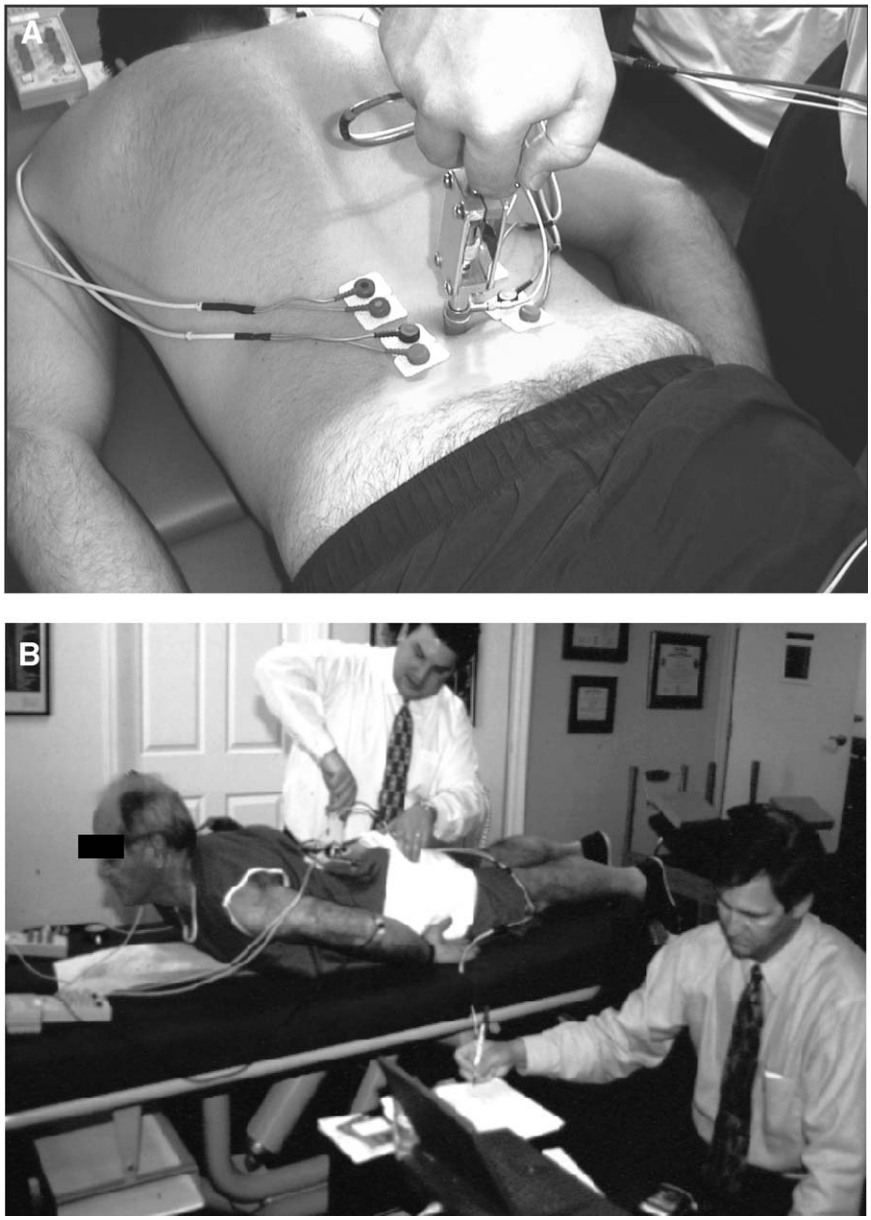

Fig 2. *Experimental setup.* ***A****, Dynamic PA spinal stiffness assessments were conducted on L3 SP and TPs using a handheld mechanical device equipped with an impedance head (load cell and accelerometer). Surface electromyographic recordings were made simultaneously from erector spinae musculature bilateral at L2 and L4 during the tests.* ***B****, Dynamic PA spinal stiffness assessment procedure being performed by clinician during an active lumbar isotonic extension task as the data is sampled by means of a portable computer.*

Further details of the device and its applications can be found elsewhere.[19]

For these measurements, high loading rate PA manipulative thrusts (150 N,<5 ms) were delivered over the L3 left and right TPs and to the L3 SP (Fig 1). Thrusts were applied to the segmental contact points while patients were lying in a prone, muscle-relaxed posture and then repeated while the patients performed an isotonic trunk extension task (Fig 2). Thrusts were always applied at the end of the expiration of breath. For the extension tasks, patients were instructed to lift their chest off the examination table for a count of 5 seconds. The dynamic PA spinal stiffness assessment was performed at approximately the 3-second time point of the extension task. Due to the symptomatic nature of the subjects participating in the study, patients were not restrained in any manner for the extension tasks so as not to exacerbate their condition. Patients were given a 2-minute rest period between each extension effort. Tests were then

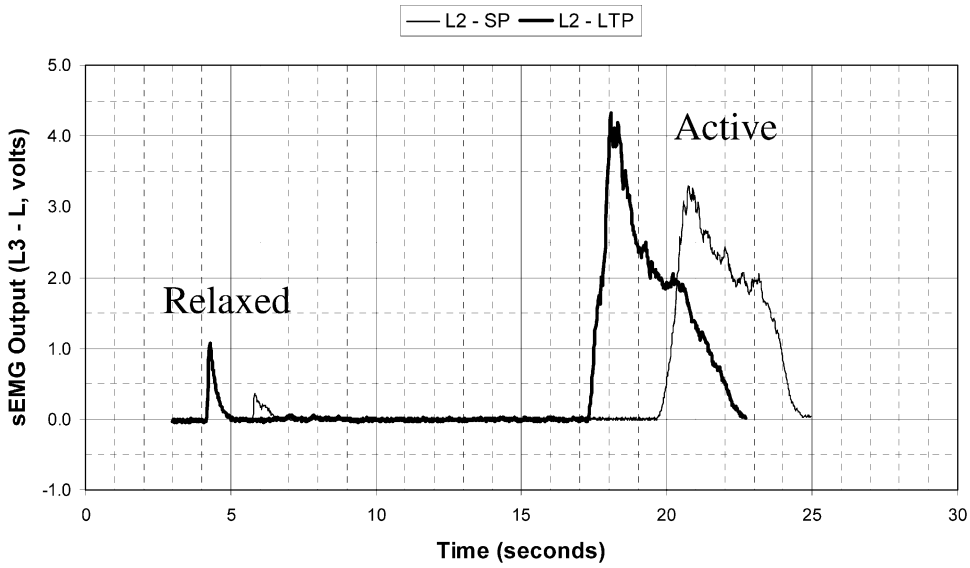

Fig 3. *Linear enveloped, erector spinae sEMG output (at L3–Left) recorded during AAI thrusts to the L2 LTP* (thick line) *and SP* (thin line) *of a 48-year-old male subject. Relaxed and Active refer to the relative muscle activity in the subject when lying prone.*

repeated for the right TP (RTP) and SP, respectively. A total of 6 thrusts were therefore performed on each subject (3 muscle relaxed and 3 muscle active, 1 each on the left TP [LTP], RTP, and SP).

Linear enveloped surface electromyographic (Noraxon Myotrace 10, Finland) and thrust force (PCB model 201A03, Depew, NY) signals were recorded using a Biopac MP100 (Biopac Systems, Inc, Santa Barbara, Calif) 16-bit data acquisition system and Acknowledge software (Biopac Systems, Inc). A linear envelope detector circuit consisting of a 0 offset full-wave rectifier and bandpass filter (16–500 Hz) followed by a low-pass filter (10 millisecond time constant) was used to electronically process the raw EMG signal. Linear enveloped surface electromyographic signals were sampled directly into the computer. Hereafter, the linear enveloped surface electromyographic signal will be referred to as sEMG. During the isotonic trunk extension trials, sEMG data were collected at 50 Hz over a 30-second time interval.

The apparent mass (peak force/peak acceleration, kg) was calculated for each of the thrusts. Apparent mass or apparent mass modulus is representative of the dynamic segment stiffness, since it characterizes the motion response (acceleration) to a known mechanical input (force). Apparent mass values recorded during the resting and active lumbar isotonic tasks trials were compared using a 2-tailed, paired observations *t* test. Surface electromyographic output was analyzed to confirm that the paraspinal muscles were active during the trunk extension tasks. To verify that the within-subject trunk extension tasks were performed at a consistent effort, peak sEMG values were obtained from the 3 isotonic trunk extension tasks for each subject and compared using a 2-tailed paired observations *t* test (POTT). The nominal type I error rate of .05 was used to establish significance.

Results

Table 1 summarizes the LBP demographics of the patients. Of the patients participating in the study, 4 reported having acute LBP, 2 reported subacute LBP, and 7 reported chronic LBP. Five patients described their back pain as occasional, 2 patients reported having intermittent back pain, and 6 patients had frequent LBP. Patients' self-perceived health status revealed 1 patient in excellent health, 7 patients with very good health, 4 patients noting good health, and 1 patient believing he was in fair health. The symptomatic nature of the patients ranged from visual analog scores of 1 to 6 and Oswestry low back disability indices ranging from 1 to 19.

Figure 3 shows a typical linear enveloped L3 sEMG output response obtained during the L3 segment stiffness assessment procedure. In this subject, a muscle reflex response to the PA thrust over both the TPs and SP is clearly evident during the resting portion of the test. In some subjects, a reflex response was also evident during the isotonic extension task portion of the test. In general, the isotonic trunk extension tasks performed by each subject produced relatively consistent peak sEMG output response. As a group, there were no significant left versus right side differences in sEMG output, nor was there any significant

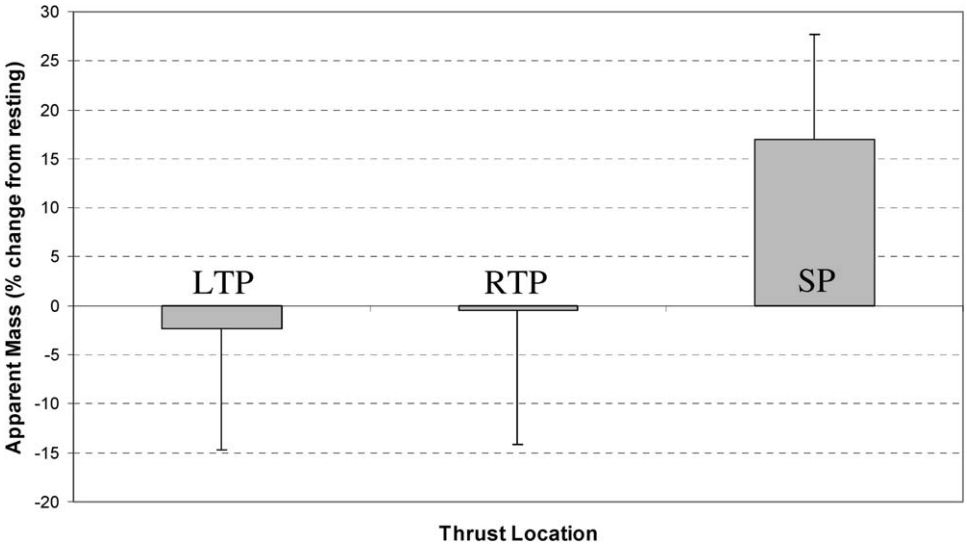

Fig 4. *Mean percent change in L2 apparent mass associated with the muscle active trunk isotonic extension activities in 13 patients.* Error bars *indicate the SD.*

differences in sEMG output during the performance of the 3 active trunk extension trials (LTP, RTP, SP).

For tests performed in the prone relaxed posture, the mean apparent mass obtained from the stiffness assessment over the LTP, RTP, and SP was 0.18 (SD 0.03) kg, 0.17 (SD 0.03) kg, and 0.14 (SD 0.02) kg, respectively. There were no significant differences in the apparent mass obtained for thrusts over the left side paraspinal muscles (LTP) compared with the right side paraspinal muscles (RTP) at L3 (muscle relaxed trials). The apparent mass measured over the L3 LTP was significantly ($P = .002$) greater than that measured over the L3 SP for the muscle relaxed trials.

Overall, there was no significant change in the apparent mass obtained during rest as opposed to tests performed during the active trunk extension tasks for thrusts over the active paraspinal muscles (LTP, RTP). However, all of the patients showed an increase in the apparent mass recorded over the L3 SP (range 1.3%–39.4%) during the trunk extension tasks in comparison with the apparent mass obtained during the resting assessments. Analysis of PA thrusts over the L3 SPs indicated that there was a significant increase in the apparent mass (17.0%, $P = .0004$) for the prone isotonic trunk extension tasks compared with tests conducted in the prone resting position. These results are summarized in Figure 4.

Discussion

In this study, dynamic stiffness assessments performed over the TPs remained unchanged during the isotonic trunk extension tasks. Hence, the mechanical impedance assessment procedure was unable to discriminate the relatively subtle differences in stiffness between relaxed and trunk extension posture. Dynamic PA stiffness assessments performed by directly contacting the SPs, however, resulted in a more marked and significant change in the apparent mass during voluntary contraction of the back extensor muscles in the active lumbar extension posture. Apparent mass or apparent mass modulus is the ratio of the force input and acceleration response of the spine. The apparent mass is a measure of the dynamic stiffness of the spine, since it is directly related to the mechanical impedance and apparent stiffness.[21,22] Changes in PA apparent mass observed in the current study are hypothesized to reflect the increased dynamic stiffness of the spinal segments caused by active contraction of the paraspinal muscles. It is likely that the indistinguishable results for stiffness assessments obtained over the muscles as opposed to the SPs may be due to the dampening effect of taking mechanical measurements directly over highly deformable muscle. Further research in this regard pertaining to PA spinal stiffness assessments are warranted.

Our findings of an increased apparent mass for tests conducted over the SPs during active contraction of paraspinal muscles corroborate the findings of previous studies examining changes in PA spinal force-deformation responses during mobilization assessments.[13,14] Lumbar extensor muscle activity has been found to result in an increase in lumbar PA spinal stiffness assessed at the SPs even at low levels of activity.[13] Lee et al[14] examined the responses of 11 normal asymptomatic subjects to the application of cyclical quasi-static (0.7 Hz) lumbar PA forces that simulated mobilization. In their study, subjects were examined in the prone resting

position during maximal voluntary isometric muscle contractions at the level of the L3 SP. Lee et al[14] found that spinal stiffness increased by 350% during maximum activation of the trunk extensor muscles as compared with resting prone measurements, indicating that muscle activity can significantly alter lumbar PA stiffness. In 1999, Shirley et al[13] expanded on the work of Lee et al[14] by reporting PA spinal stiffness during varying submaximal activity of the lumbar extensor muscles in 20 asymptomatic subjects. In their work, subjects were asked to perform a maximal isometric voluntary contraction (MVIC) with their pelvis fixed by exerting a force against a steel plate located over their T4 SP. They were then asked to perform contractions generating forces equivalent to 0%, 10%, 30%, 50%, and 100% of that obtained with an MVIC. PA stiffness was measured at the L4 SP during each of these trunk efforts. A linear increase in PA stiffness was observed during submaximal efforts where 10%, 30%, 50%, and 100% MVIC efforts increased mean PA stiffness by 12%, 41%, 75%, and 92%, respectively. The observed increase in the apparent mass associated with thrusts over the L3 SP during functional trunk extension tasks in the current study corresponds most closely with submaximal contractions generating forces equivalent to 10% to 20% of MVICs reported by Shirley et al.[13]

There are numerous reasons for the differences in our results as opposed to Lee et al[14] and Shirley et al.[13] First, the lower magnitude of the observed changes for trunk extension efforts as compared with resting reported in this study are generally lower than the previous work. This most likely reflects a number of factors, including both the change in posture from neutral to lumbar extension, as well as the specific nature of the voluntary muscle contractions performed. Noteworthy is the fact that in the current study subjects performed a functional prone-lying extension task in which they lifted their chest and thorax off the examination table. The thorax has been shown to increase spinal stiffness by a factor of 2.[23] Thus, compared with the PA stiffness assessments obtained in the relaxed posture where the thorax is in contact with the examination table, the PA stiffness assessments performed in the active lumbar extension posture (thorax lifted off of the examination table) showed a less remarkable change than would be predicted to occur when the thorax is in contact with the table. Second, by restraining the thorax by means of the patient exerting their extension force against a steel frame as in the Lee et al[14] and Shirley et al[13] studies, the subjects were able to generate much greater torque as opposed to the unrestrained subjects in our study. Additional research is needed to characterize the stabilizing role of the thorax on spinal stiffness measurements in the prone-lying subject. Last, in contrast to the research of Lee et al[14] and Shirley et al,[13] the subjects in the present study were symptomatic LBP patients. Thus, it was not deemed appropriate to assess MVICs in this patient population for fear of worsening their condition. Inasmuch, the lower stiffness magnitudes observed during the isotonic trunk extension maneuvers observed may be attributed to the symptomatic nature of the patients participating. These factors and others, including the differences in stiffness technique incorporated in each study, help to explain the differences among some of the work in this area.

The stiffness measurement procedure (apparent mass derived from load-acceleration measurements) reported in the current study cannot be directly compared with previous studies, since the majority of prior studies have reported on the load-deformation response during quasi-static loading (<1 Hz). Spinal stiffness increases substantially as the rate of loading and magnitude of loading increase.[11,24] The fact that we observed lower relative changes in spinal stiffness during muscle relaxed and muscle active tasks in comparison with Lee et al[14] most likely reflects the dynamic and impulsive nature of the force-time profile of our dynamic PA stiffness methodology. In general, impulsive forces (brief duration) are associated with a lower magnitude motion response in comparison with forces applied in a quasi-static manner.[25,26] Consequently, the change in stiffness observed will be smaller, consistent with the results reported herein.

The finding of increased PA stiffness during trunk extension efforts in this study and others is an expected finding, as around the neutral posture the spine exhibits the least stiffness.[7,27] The lumbar extensor muscles, specifically the erector spinae muscle group, when voluntarily contracted provide forces that act on L3 (and the other lumbar SPs) in the posterior and inferior direction.[28] The posterior vectored muscle forces act to increase the resistance to PA forces imparted to the spine. The multifidus muscle, also acting during lumbar extension, has been found to biomechanically increase the overall stiffness (stability) of the intervertebral joints.[1] Cholewicki et al[4] tested a biomechanical model to assess the coactivation of trunk flexor and extensor muscles with electromyography and determined that increased muscular forces were indeed necessary to provide spinal stability. Furthermore, some patients with low back pain have been reported to have involuntary hyperactivity of adjacent muscles at rest.[29]

As discussed by Lee et al,[14] in addition to the posterior shear force generated by the erector spinae muscles, longitudinal compressive forces coexist during extension. Such compression may further cause an increase in resistance to shear displacements or rotations. The compressive forces combined with extended position of the L3-4 functional spinal unit may further act to increase the spinal stiffness. Adams et al[30] reported that 2° of lumbar extension increased the maximum compressive stress within the posterior annulus by an average of 16% compared with the neutral posture among normal and degenerated lumbar disks. The activity of other muscle groups may have further served to increase the spinal stiffness. Abdominal muscles,

muscles of the thorax, hip extensors, and muscles of the pelvis, among others, acted in concert during the isotonic trunk extension task performed by our patients. Another possible contributor to the increased dynamic spinal stiffness during the isotonic extension task was the lumbar extension posture itself. Edmondston et al[31] recently reported a 12.4% increase in the PA stiffness obtained from the L3 and L5 SPs from the neutral to lumbar extended prone posture. Further investigations of active versus passive trunk postures are needed to specifically discriminate the muscular and postural contributions of dynamic spinal stiffness.

There are several shortcomings of this research. First, because we performed functional extension tasks rather than MVICs of the lumbar extensor muscles, there is inherently more variability in the level of the isotonic trunk extension muscle among the subjects. MVICs could not be performed in our LBP subject population, since maximal trunk extension activities may have caused increased pain. Although we characterized the sEMG output response of the subjects, such measures cannot typically be compared across subjects (unless normalized in some manner); thus, we were limited to comparisons of sEMG output only within the context of the 3 extension trials performed by each subject. Assessments of isometric trunk torque output during prone-lying extension tasks would provide a better means to directly compare the level of exertions produced by each subject and allow for cross-subject comparisons to be made. Such procedures would also help to constrain the movement of the chest and thorax. Moreover, because our sample size was relatively small, we were unable to examine the effects, if any, of patient symptomatology on apparent mass. In previous work with a larger patient population, we observed increased dynamic spinal stiffness in patients with increased symptom frequency, as well as increased neuromuscular reflex thresholds in patients with low back pain.[8,16] Being that the subjects in the current study had generally low levels of pain (average 3.5 VAS), our results may not be easily generalized to groups of back pain subjects with more severe symptoms. A larger patient population needs to be studied to determine how trunk muscle activation may affect the PA mechanical behavior of the lumbar spine in both asymptomatic and symptomatic subjects.

Conclusion

Lumbar spine isotonic trunk extension contributes to increased dynamic PA lumbar spine stiffness. These findings corroborate the findings of others and add support to the significance of the trunk musculature and spinal posture in providing spinal stability. Understanding the contributions of the trunk musculature in low back pain patients may serve to assist in the management of back pain patients. Further research directed toward understanding the influence of the trunk musculature on PA dynamic spine stiffness may serve clinically as an objective biomechanical outcome measure to evaluate between patients with musculoskeletal disorders.

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