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Spectral Electromyographic Assessment of Back Muscles in Patients With Low Back Pain Undergoing Rehabilitation

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Study Design. A surface electromyographic procedure for evaluating back muscle impairment was studied in patients undergoing rehabilitation for low back pain.

Objectives. The results were analyzed to determine whether the electromyographic procedure was able to: 1) distinguish muscle impairment between patients with low back pain and normal subjects, and 2) monitor changes in muscle function after low back pain rehabilitation.

Methods. Patients with chronic low back pain (n = 85) were tested to measure the median frequency of the electromyographic signals from six lumbar electrode sites during sustained trunk extensions. A subset (n = 28) of these patients was re-tested after low back pain rehabilitation. A discriminant function for classifying subjects into "low back pain" and "normal" groups was formulated using the electromyographic data from a subset of the patients with low back pain (n = 28) and a normative sample (n = 42). Results for this "learning" sample were compared with results using the same function on the remaining "holdout" sample of patients (n = 57) and an additional normative sample (n = 6). Differences in electromyographic parameters before and after rehabilitation also were analyzed.

Results. The discriminant function classified subjects into low back pain and normal groups, with 86% and 89% correct classification for the "learning" and "holdout" samples, respectively. These classification results were independent of trunk extensor strength. Changes in median frequency after the rehabilitation program were consistent with improvements in back muscle fatigability.

Conclusion. These findings demonstrate how electromyographic spectral measurements may be used to identify and monitor back muscle impairment in patients undergoing rehabilitation for low back pain. [Key words: electromyogram, low back pain, median frequency, muscle fatigue, paraspinal muscle] **Spine 1995;20:38–48**

Back muscle assessment is a critical part of the evaluation process for identifying physical impairment in patients with low back pain (LBP) syndromes. Muscle impairment is a common finding associated with LBP and typically is described in terms of strength, fatigue, or muscle activity.[1,26–28,37,43,45,52] The nature of these impairments in patients with LBP are still unknown and have been speculatively associated with deconditioning,[1,8,9,23,33,37] abnormal fiber type composition,[1,8,23,30,49] spasm,[22] or "protective" inhibition[1,18,19,34] of muscle. Despite the belief among clinicians that back muscle function is relevant to rehabilitation outcome, effective diagnostic and treatment management procedures based upon the measurement of muscle impairment remain elusive. Most of the techniques in use are subjective or rely upon the use of instruments that measure mechanical parameters that are cognitively perceived and therefore subject to voluntary regulation.[46]

Physical tests of muscle strength and endurance may be influenced directly by the patient's motivation and willingness to risk discomfort as well as by socioeconomic factors and secondary gain.[31,56] Indices of muscle performance that are based on spectral parameters of the surface electromyographic (EMG) signal may provide a more objective measure of muscle performance than purely mechanical indices.[1,5,6,17,31,36,39,41,49] Spectral parameters of the EMG signal are influenced by metabolic fatigue processes that are not cognitively perceived or voluntarily regulated by the subject when performing a sustained contraction, particularly when numerous muscle groups are being monitored.[4,10,13,14,32,47]

The earliest applications of the EMG spectral technique to back muscles were limited by the use of only a few EMG electrodes, the failure to properly isolate the trunk extensor muscles, and the reliance upon cumbersome methods of spectral analysis.[36,42,44,54] Many of these initial limitations recently have been resolved.[2,5,6,7,29,31,36,48–50,55] The current approach is based on the concept that by simultaneously monitoring the median frequency from multiple electrode sites, it is possible to evaluate the relative contributions of individual paraspinal muscle groups during a sustained extension of the

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trunk.[49] This concept was reviewed in detail in a recent position paper.[15] Based upon the accepted notion that muscle dysfunction may follow injury, pain, or disuse, it is reasonable to expect that some muscles would compensate for these deficits, resulting in a relative alteration in their EMG activity during induced localized muscle fatigue.

In a previous study,[49] we found that muscle impairment in patients with LBP disorders could be distinguished from normal muscle functioning in subjects without LBP with a 90% accuracy based solely on median frequency parameters. Similar studies of collegiate rowers with and without LBP also revealed relatively high levels of correct classification based on median frequency parameters.[50] In yet another study, we found the discriminating ability of median frequency parameters for LBP-related muscle disorders to be more effective than conventional clinical parameters that quantify spinal mobility and static trunk extensor strength.[29]

Despite the proven capability of median frequency parameters to differentiate normal from abnormal muscle functioning in patients with LBP and in normal control subjects, the potential application of this technique to clinical assessment has not been fully explored. Few studies have described its effectiveness in monitoring changes in back muscle function associated with rehabilitation. In fact, surprisingly few studies have documented the consequence of rehabilitation on EMG spectral measurements, even in muscles of the extremities where the technique was first applied.[4,14,48]

The applicability of recent findings to more diverse groups of patients with LBP also remains uncertain. Most of the studies to date have been limited to evaluating relatively young, "white-collar" males with nonspecific spinal disorders. The yet-to-be-confirmed applicability of the technique to the population at large raises further questions regarding the possible influence of subject physical characteristics (*e.g.*, height, weight, and strength) on median frequency parameters. Studies that have reported impressive classification results for LBP-related muscle impairment based on discriminant functions using median frequency parameters have not tested the procedure in subjects whose data were not included in the original formulation of the discriminant function. The present investigation was conducted to address these questions.

■ Methods

The Back Analysis System. The system used to acquire and process the EMG and force data is referred to as a Back Analysis System and is shown in Figure 1. Details of this system were described in a previous report.[29]

A restraint device stabilizes the pelvis and lower limbs during standing using adjustable front and rear molds and knee pads. The plastic molds conform to the pelvic and thigh regions and act as a regional body brace, tightly fixing the pelvis between the front and rear molds. Pelvic motion is minimized to within the limits of soft-tissue compliance during the test protocol. The forces generated during isometric extension of the trunk are measured using a padded strap across the scapular region of the back attached to two load cells, each having high stiffness (3.70 N/μm). The target force level and resulting force exerted by the subject are displayed on a monitor to provide visual feedback. Signals from the force transducers are processed on-line using custom personal computer hardware and software.

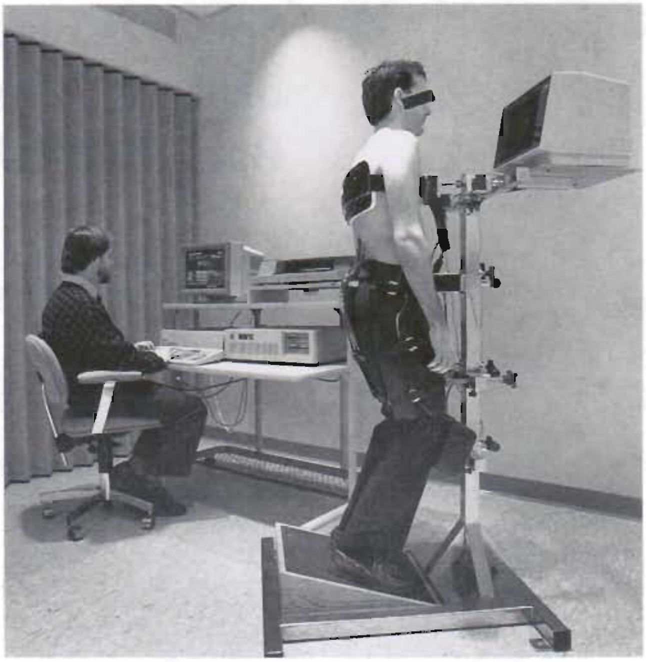

Figure 1. A subject being tested in the Back Analysis System.

Electromyographic signals in the present study were detected from six active, bipolar surface electrodes, similar to ones described by De Luca et al.[16] The electrodes have a gain of 10 with a −3 dB bandwidth of 20 to 400 Hz and a roll-off of 12 dB/octave. The EMG signals were further amplified to achieve an output amplitude of 1 to 2 V peak-to-peak. Electromyographic signals were processed in real-time by specialized hardware integrated with a personal computer. This acquisition and processing system, called a Muscle Fatigue Monitor, tracks the median frequency as a function of contraction duration.[14,24,25,40] The median frequency data were further analyzed in software to extract three parameters: 1) the initial median frequency (IMF), 2) the median frequency slope (MF slope), and 3) the median frequency recovery (MF recovery; Figure 2). The IMF was calculated as the y intercept of a first-order linear regression using the method of least-squares. The MF slope was calculated as the coefficient of the regression for the full duration of the contraction. The MF recovery was calculated as the difference in IMF for two successive contractions separated by a 1-minute rest period. Data were coded in a way that individuals performing the processing were blinded to subject identity or phase of the protocol.

Protocol. Twenty-eight patients (24 males and four females) with a history of chronic LBP and work-related back injury were tested just before and 4 weeks after participating in a

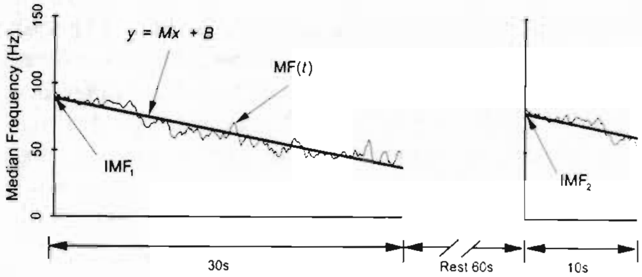

Figure 2. Illustration of how the EMG MF data were parameterized into initial median frequency (IMF), median frequency slope (MF slope), and median frequency recovery (MF recovery). The coefficient of a least-squares linear regression defines the MF slope, its zero intercept defines the IMF, and the difference between the IMFs of two successive contractions at the same % MVC defines the MF recovery.

multi-disciplinary functional restoration program for LBP. An additional 57 male patients with chronic LBP in the same program, who had work-related back injuries, were tested at baseline entry into the program. The resulting data from this second LBP population was used to determine whether the classification function derived from the first LBP population could be generalized to other populations. The descriptive characteristics of the patient populations are provided in Table 1.

Enrollment of patients in the rehabilitation program followed a comprehensive medical examination, physical capacity evaluation, psychological testing, and a work-history evaluation. Patients tested at the beginning and end of the rehabilitation program participated in the program for an average of 40 hours per week according to a fixed schedule that included approximately equal time for daily physical therapy, occupational therapy, circuit weight training, work-hardening, back pain school, and psychological counseling. The patients in this study were recruited at random from the total number of patients enrolled in the program during 1 year. All participants signed an informed consent form approved by an institutional review board for human subject use, and no patient received monetary compensation for their participation.

The test protocol was similar to that described in a previous report.[50] Briefly, each subject was positioned and secured in a postural restraint apparatus. Six surface EMG electrodes were secured by tape to the skin overlying the longissimus thoracis muscle at L1, the iliocostalis lumborum muscle at L2–L3, and the multifidus muscle at L5, bilaterally. Several practice trials were conducted so the subject could become familiar with the apparatus and the desired task. After a 5-minute rest, the subject performed a maximal isometric trunk extension for approximately 3 to 4 seconds. The peak of the force trajectory was sampled and averaged over a 2-second window and stored as the MVC parameter. This procedure was repeated for a maximum of five trials until the MVC was consistent within 10% variability. Patients were disqualified from the study if they could not achieve this minimal level of consistency. The largest MVC value was used for normalizing the force of the subsequent contractions.

After these trials and a 2-minute rest period, the subject performed a contraction at 40% of his or her MVC (40% MVC) for 30 seconds. Precisely 1 minute after the termination of the sustained contraction, another contraction at the same percentage of MVC was sustained for 10 seconds to monitor recovery from fatigue. A similar series of contractions specified at 80% of the subject's MVC (80% MVC) were then conducted as a part of the same trial. The same test protocol was repeated at the end of the rehabilitation program for those patients who received follow-up tests. Although the patient's MVC was re-assessed at the follow-up test, the test contractions during the follow-up tests were normalized with respect to the baseline MVC value. In this way, patients performed the same trunk extension torques for the baseline and follow-up tests. Relocation of the EMG electrodes for the follow-up tests was facilitated by the use of a template. The subjects were constrained to maintain the same posture for baseline and follow-up tests by adjusting the restraint apparatus to numerical settings. All testing was conducted by personnel uninvolved with the rehabilitation program. Reliability results for median frequency parameters have been reported previously and have been found to have reliability estimates between 0.73 and 0.98, depending on the parameter being considered and whether electrodes were removed and subsequently relocated between testing.[7,31,49]

Table 1. Characteristics of Subjects—Means (Standard Deviations)

	LBP (n = 28)	Normal (n = 42)	LBP (Holdout) (n = 57)	Normal (Holdout) (n = 6)
Age (yr)	35.3 (8.9)	26.7 (5.2)	37.1 (8.9)	23.8 (2.5)
Height (m)	1.8 (0.1)	1.8 (0.1)	1.8 (0.1)	1.8 (0.1)
BMI (kg/m^2)	27.0 (4.6)	23.0 (2.5)	27.4 (5.0)	25.7 (3.7)
Weight (kg)	84.2 (16.2)	70.5 (9.7)	86.4 (19.0)	81.4 (11.1)
MVC (lbs)	140.7 (57.0)	184.8 (73.0)	120.5 (70.5)	241.3 (77.5)
Surgery (%)	43	—	1	—
HNP (%)	75	—	27	—
Duration LBP (mo)	26.3 (31.4)	—	15.2 (12.2)	—

LBP = low back pain. BMI = body mass index. MVC = maximal voluntary contraction. HNP = herniated disc.

Data Analysis. For patients tested at the beginning and end of the rehabilitation program, the baseline data were compared with normative data from healthy volunteers (n = 42) with no history of debilitating LBP or other musculoskeletal disorders (Table 1). The IMF and MF slope from each of the six electrode sites for each subject were entered stepwise into a two-group discriminant analysis procedure to formulate a function to classify subjects into LBP and normal groups. Discriminant analysis was restricted to the data acquired at 80% MVC. The discriminant function from this "learning" sample then was used without modification to test its classification ability on a "holdout" population of patients and healthy subjects without LBP not included in the original database (Table 1). No other analyses were conducted on the "holdout" sample populations.

Data acquired before and after the rehabilitation program were analyzed using a repeated-measures, four-way analysis of variance (ANOVA) to study the influence of the following main effects on the median frequency parameters: time (pre- and post-rehabilitation), % MVC (40% MVC and 80% MVC), lumbar level (L1, L2, and L5), and lumbar side (left and right). Each of the main effects was analyzed as a paired variable because measurements were repeated in the same

Table 2. Results of Discriminant Analysis

	Percent Correct Classification		
Population	LBP (%)	Normal (%)	Total (%)
Learning sample (n = 69)	85	86	86
Holdout sample (n = 63)	88	100	89

LBP = low back pain.

individual. The influence of MVC and history of spinal surgery also were studied using an ANOVA procedure. A multiple regression analysis was conducted to study the association between MF slope and the following physical characteristics of the subjects: age, height, body mass index (a measure of obesity defined as (Weight)/(Height^2), and MVC. A similar analysis was implemented to determine the proportion of variance in MVC accounted for by the physical characteristics of the subject.

■ Results

The stepwise discriminant analysis procedure selected the following median frequency parameters to formulate the classification function: IMF and MF slope from the L1 electrode site and IMF from the three left lumbar sites. This function correctly classified 85% of the patients with LBP and 86% of the subjects without LBP (Table 2). Fisher discriminant function values, representing the distance from the group classification cutoff point, are displayed for each of the LBP and normal subjects in Figure 3A. The four LBP subjects identified in the figure with a negative Fisher score represent false-negative classifications, whereas the six normal subjects with a positive Fisher score represent false-positive classifications. The classification results were independent of the subject's ability to exert a maximal trunk extension, because the stepwise discriminant analysis procedure rejected the attempt to include MVC into the classification function. Forcing MVC into the function did not change the accuracy of the classification. The classification function performed as well among the holdout sample as it did among the learning sample, with 88% of patients and 100% of normal subjects correctly classified (Table 2). The Fisher discriminant scores for this data set are depicted in Figure 3B.

The results from data collected at the beginning and end of the rehabilitation program are described for each of the median frequency parameters and the MVC parameter separately.

Median Frequency Slope (MF Slope)

The results of the ANOVA for MF slope are summarized in Table 3. Significant results were found for the following main effects: time ($P = 0.002$), % MVC ($P = 0.0001$), lumbar level ($P = 0.0001$), and lumbar side ($P = 0.031$). Median frequency slope was less negative after rehabilitation, a finding consistent with a decrease in muscle fatigability. The reduction in MF slope after rehabilitation was similar for % MVC, lumbar level, and lumbar side. The changes in MF slope after rehabilitation are more clearly illustrated in Figures 4A and 4B, which contain plots of mean MF slope differences for 40% MVC and 80% MVC, respectively. Approximately 65% of patients had an improvement in their MF slope (*i.e.*, MF slope was less negative). A common method of quantifying the change in a parameter associated with a treatment is to calculate the effect size.[12] The effect size for the change in MF slope was computed according to the formula:

$$\text{Effect Size} = [\text{Mean MF slope}_{\text{post-rehabilitation}} - \text{Mean MF slope}_{\text{pre-rehabilitation}}] \div [\text{Standard Deviation of MF slope}_{\text{pre-rehabilitation}}]^{12} \quad (1)$$

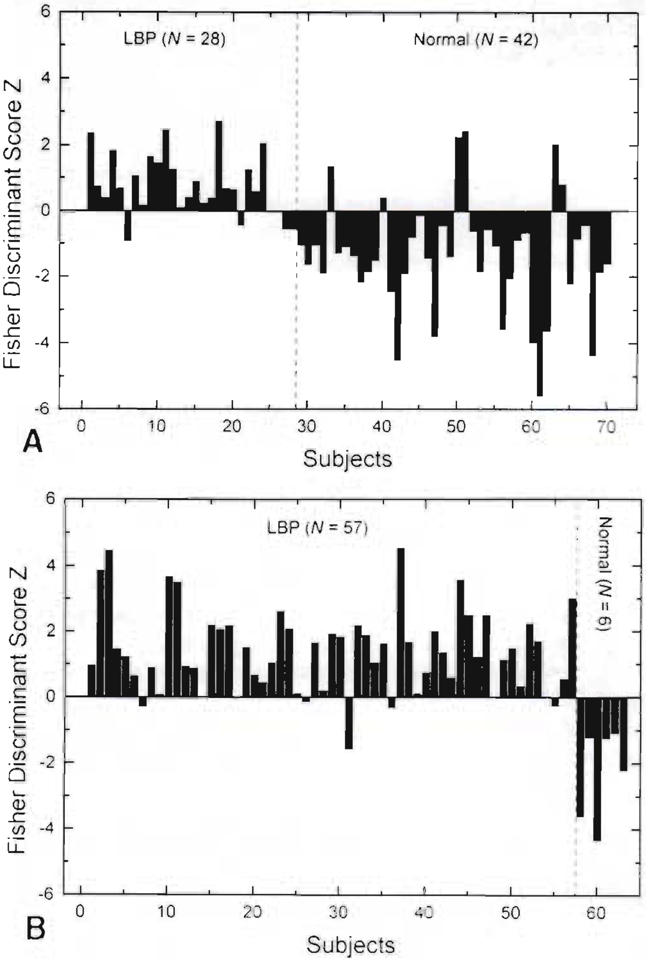

Figure 3. Fisher discriminant function scores, a measure of the distance from the classification cutoff point, are presented for: (**A**) each of the LBP patients and normal subjects who form the "learning set" for the discriminant function and (**B**) LBP patients and normal subjects making up the "holdout" sample. A positive score indicates an LBP classification, a negative score indicates a normal classification. Subjects are divided along the x axis according to those who are known *a priori* to be a LBP patient or healthy. Incorrect classifications are identified in the lower left quadrant for LBP patients (false-negative) and the upper right quadrant for normal subjects (false-positive).

Table 3. Significant Analysis of Variance Results—Patient Data

Variable	Source	*P*
MF Slope (Hz/sec)	Time	.002
	% MVC	.0001
	Lumbar level	.0001
	Lumbar side	.031
	% MVC × lumbar level	.002
IMF (Hz)	Lumbar level	.0001
	Lumbar level × lumbar side	.001
MF recovery	Lumbar level	.001

MF = median frequency. Time = pre- versus post-treatment. MVC = maximal voluntary contraction. Lumbar level = L1, L2, L5. Lumbar side = left vs. right side. IMF = initial median frequency.

This analysis resulted in relatively moderate effect sizes of 0.41 for 40% MVC trials and 0.35 for 80% MVC trials.

The MF slope was greater (more negative) for 80% MVC than for 40% MVC trials. Median frequency slope also differed according to lumbar level—a Scheffé pair-wise comparison identified that mean MF slope from L1 and L5 were significantly more negative than mean MF slope from L2 ($P = 0.001$). Similarly, mean MF slope from L5 was more negative than mean MF slope from L1 ($P = 0.06$), but at borderline level of significance. The influence of lumbar side (left versus right) on MF slope was significant ($P = 0.03$), with muscles from the right side of the back having steeper MF slopes than those on the left side of the back (Table 3). The ANOVA analysis of MF slope also was recomputed with baseline MVC as a covariate. The results demonstrated a significant interactive effect for time and baseline MVC ($P = 0.03$). This interactive effect is plotted in Figure 5 and demonstrates that patients with low baseline MVC values had the most "improvement" in MF slope (*i.e.*, MF slopes were less negative). A similar ANOVA analysis revealed a nearly significant interactive effect for time and surgery ($P = 0.06$). A plot depicting this interaction indicates that patients without a history of back surgery had more "improvement" in MF slope after the rehabilitation program than patients with a history of back surgery (Figure 6 and Table 4). The change in MF slope after rehabilitation was not influenced by a diagnosis of herniated disc among patients without back surgery (Table 4).

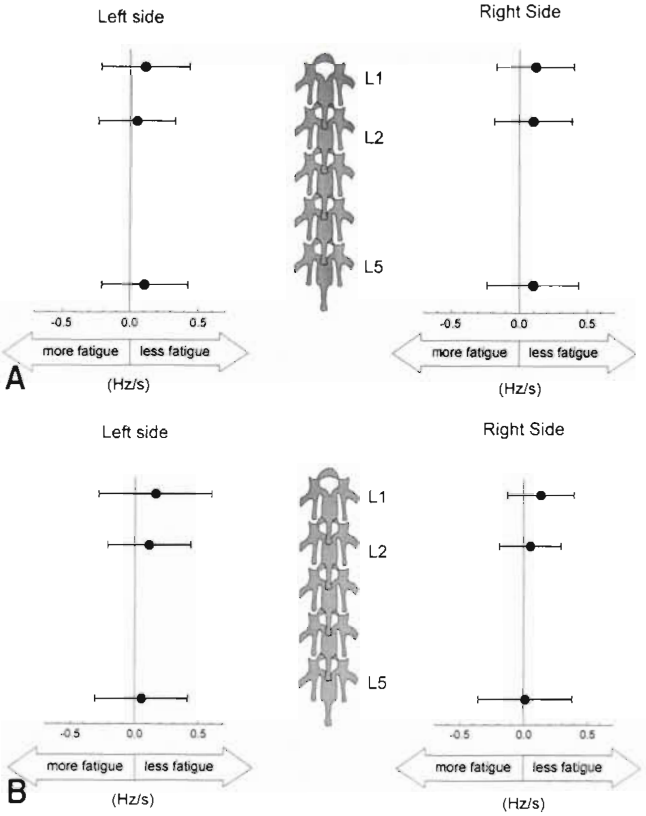

Figure 4. Plots of MF slope differences (post-rehabilitation, pre-rehabilitation) for each of the six electrode sites from (**A**) 40% MVC tests, and (**B**) 80% MVC tests. Mean values (±SD) are displayed separately for each of the six electrode sites.

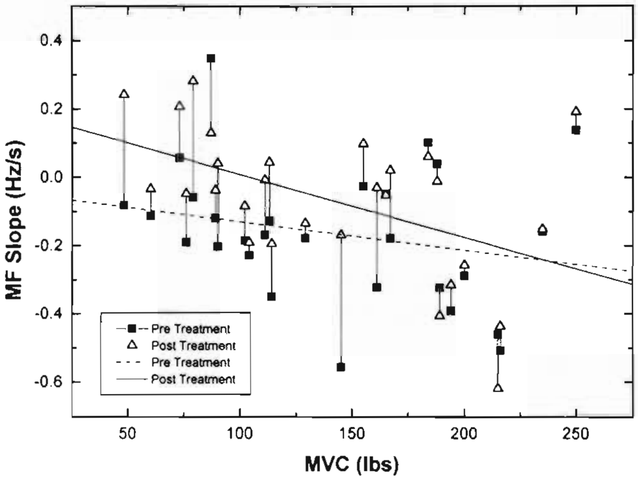

Figure 5. The interactive effect of baseline MVC and time (pre- and post-rehabilitation) on MF slope. Mean MF slope (for all electrode sites and % MVC trials) for pre-rehabilitation (open triangles) and post-rehabilitation (filled squares) are connected for each individual patient. Median frequency slope is plotted according to the baseline MVC for each patient. Least-squares linear regressions are displayed separately for pre-rehabilitation and post-rehabilitation data points.

The influence of the physiologic factors age, height, body mass index, and MVC on MF slope was studied separately for patients and normal subjects. The results of the multiple regression models are described in Table 5 and demonstrate that for the patients, none of the variables significantly accounted for the variance in MF slope ($P = 0.159$), whereas for the normative data, approximately one-half of the variance in MF slope was accounted for by the statistical model ($P = 0.001$). For the normative data, the factor MVC contributed more to the variance in MF slope than did the other factors studied.

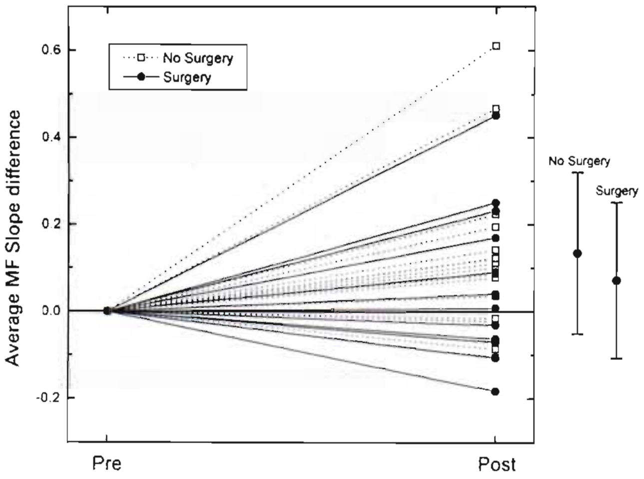

Figure 6. The interactive effect of surgery and time (pre- and post-rehabilitation) on MF slope. Mean MF slope differences (±SD) with respect to baseline were combined for the six electrode sites and the 40% MVC and 80% MVC trials. Data are presented separately for patients with and without back surgery.

Initial Median Frequency (IMF)

The results of the four-way ANOVA for IMF demonstrated only one significant main effect of lumbar level ($P = 0.0001$; Table 3). Scheffé pair-wise comparisons between the three lumbar levels revealed that all possible pair-wise combinations were significantly different ($P = 0.001$). A significant lumbar level by lumbar side interaction also was present ($P = 0.001$).

Median Frequency Recovery (MF Recovery)

A four-way ANOVA for MF recovery also resulted in lumbar level as the only significant main effect ($P = 0.001$; Table 3). Scheffé pair-wise comparisons demonstrated that MF recovery for L3 was greater than that for L2 ($P = 0.003$) and L1 ($P = 0.0001$). The analysis resulted in no significant interactions between main effects. History of back surgery did not significantly influence the change in MF recovery with rehabilitation ($P = 0.307$; Table 4).

Table 4. Means (Standard Deviations) of Back Analysis System Results for Patients With and Without Surgery

	n	Pre-treatment	Post-treatment	*P*
MVC		(lb)	(lb)	
Surgery	12	153.3 (62.2)	186.3 (66.5)	NS
Nonsurgery	16	131.3 (52.9)	186.2 (50.1)	
Herniated disc	9	161.6 (45.9)	208.1 (38.5)	NS
Normal disc	7	92.3 (32.2)	158.0 (51.5)	
MF slope		(Hz/sec)	(Hz/sec)	
Surgery	12	−0.13 (0.40)	−0.09 (0.39)	.008
Nonsurgery	16	−0.18 (0.31)	−0.04 (0.32)	
Herniated disc	9	−0.25 (0.34)	−0.13 (0.32)	NS
Normal disc	7	−0.09 (0.24)	0.08 (0.27)	
IMF		(Hz)	(Hz)	
Surgery	12	84.4 (24.8)	83.7 (25.9)	NS
Nonsurgery	16	85.1 (25.2)	85.1 (26.6)	
Herniated disc	9	85.7 (25.4)	86.2 (25.4)	NS
Normal disc	7	84.3 (24.9)	83.7 (28.0)	
MF recovery		(Hz)	(Hz)	
Surgery	12	5.40 (10.4)	2.88 (9.1)	NS
Nonsurgery	16	4.17 (9.9)	3.65 (10.4)	
Herniated disc	9	4.67 (10.3)	5.92 (14.5)	NS
Normal disc	7	3.54 (9.2)	0.76 (9.6)	

EMG data combined for 40% and 80% MVC and six muscle sites.
MVC = maximal voluntary contraction. NS = nonsignificant *t* test ($P > .05$).
MF = median frequency. IMF = initial median frequency.

Table 5. Results of Regression Analysis Between Back Analysis System Parameters and Physical Characteristics

Dependent Variable	Independent Variable	Standard Coefficient	Adj. Sq. R^2	*P*
Baseline MVC (n = 28 patients)	Age	0.306	0.156	0.071
	BMI	0.445		
	Height	−0.001		
MVC (n = 42 normal subjects)	Age	−0.104	0.364	0.001
	BMI	0.350		
	Height	0.561		
Baseline MF slope (n = 28 patients)	Age	−0.003	0.109	0.159
	BMI	−0.126		
	Height	0.257		
	MVC	−0.337		
MF slope (n = 42 normal subjects)	Age	−0.076	0.482	0.001
	BMI	0.407		
	Height	−0.141		
	MVC	−0.624		

MVC = maximal voluntary contraction. BMI = body mass index. MF = median frequency.

Maximal Voluntary Contraction (MVC)

Baseline MVC was highly variable across patients with LBP (range, 48–250 lb) and on average well below that of the normative sample (Figure 7A). The influence of the factors age, height, and body mass index on baseline MVC was studied by a multiple regression analysis (Table 5). The results indicated that the regression was not significant for the patient population studied ($P = 0.07$). However, for the normative data the regression was significant ($P = 0.001$) and the factors age, body mass index, and height accounted for 36% of the variance of baseline MVC. The factors body mass index and height were positively related to baseline MVC, whereas age added minimally to the statistical model.

The influence of the main effect time on MVC is summarized in Figure 7. A paired *t* test found that the mean value of MVC post-rehabilitation was significantly larger than baseline MVC ($P = 0.001$). Twenty-four of the 28 patients improved their MVC values (Figure 7B). Although the MVC post-rehabilitation was not significantly different from normal ($P = 0.06$), after rehabilitation approximately 50% of the patients still were below the lower quartile of the normative MVC (Figure 7A). The effect size for MVC was equal to 0.75, which was larger than the effect size for MF slope. Patients with no history of back surgery had a larger increase in MVC after rehabilitation than patients with a history of back surgery. However, this difference was not significant ($P = 0.133$; Table 4). Within the group

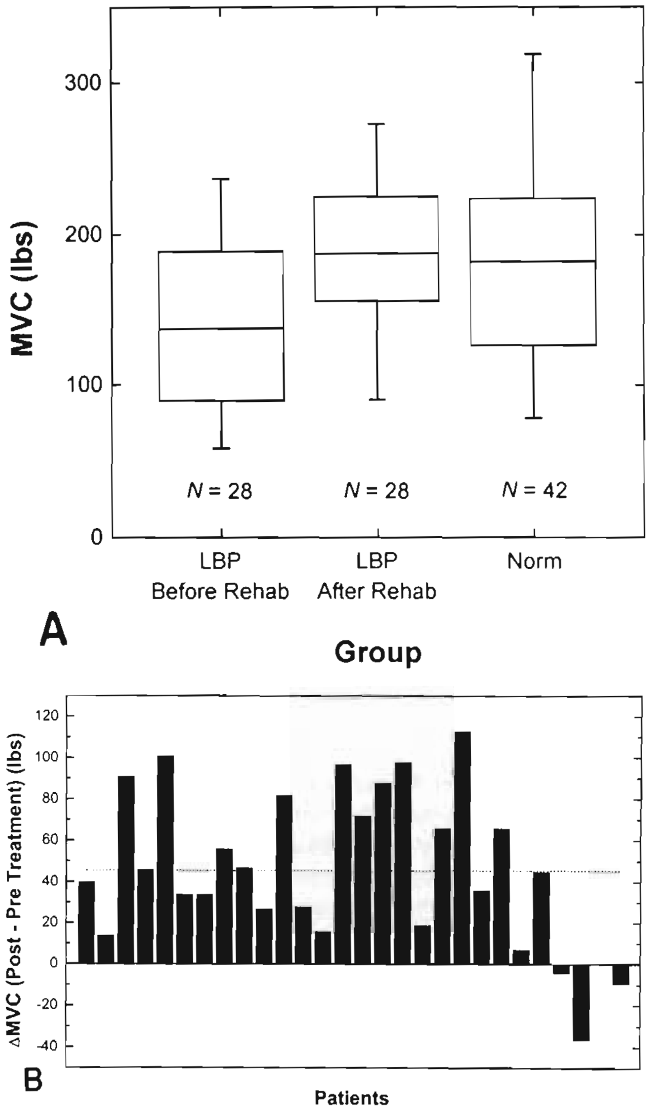

Figure 7. (**A**) A box-plot of MVC for patients with LBP (before and after rehabilitation) compared with normative data (norm). The "box" identifies the range of values between the 25th and 75th percentiles. The horizontal line in the box identifies the median value (50th percentile). The hatched bars identify the range of the upper and lower quartiles. (**B**) Change in MVC (post- and pre-treatment) for each patient with LBP. The horizontal dashed line indicates the mean difference in MVC for all patients.

of patients without surgery, increases in MVC after rehabilitation were not influenced by the presence or absence of herniated disc (Table 4).

■ Discussion

The patients recruited for this study were undergoing rehabilitation for LBP in an intensive, full-time program that emphasized improvement of muscular performance as one of its primary treatment goals. Unlike other rehabilitation approaches that have emphasized the control of pain and pain behavior as primary goals, this program was guided by setting and attaining progressively more demanding physical goals. The effectiveness of this approach in improving outcome has been demonstrated in LBP patient groups similar to the ones recruited in our study.[34,35] It was not our goal, however, to test the efficacy of this approach at improving performance compared with some other program, or no program at all. We recognized that a control population would have been necessary for that.

The discriminant analysis procedure provided the same high level of accuracy (an average of 87% correct classification) as in our previous study, despite that very different LBP populations were studied.[29,49,50] These results are encouraging because they suggest that the technique may be useful in identifying muscle impairment among different sub-populations of patients with LBP. The relatively high levels of correct classifications in the present study cannot be explained as a consequence of the stepwise regression overfitting the model, because it selected parameters from a rather large sample pool. The size of our sample should have been adequate to avoid overfitting the data because it was about 14 times the number of MF parameters used.[58] The favorable classification results among the holdout sample further dispel the likelihood of overfitting. It also demonstrates that the classification can be highly accurate even in a population that was not included in the initial learning set. We are not aware of other back assessment procedures that have demonstrated similar classification results for population samples outside of those that made up their learning set.

The patients who participated in the present study were similar to those described in one of our earlier published studies regarding their age, height, weight, and duration of LBP.[49] In other important respects, however, these patient groups differed. For instance, many of the patients in the present study had either a verified herniated intervertebral disc or spinal surgery, conditions that were excluded from our previous study.[46] Also, we did not limit our selection of subjects in the present study to patients in remission from pain, as was specified in a previous study.[49] All of the patients tested described the presence of pain localized to the lumbar region. Furthermore, the patients in the present study were manual laborers who had incurred a work-related back injury and who were on disability leave. This group differed from subjects tested previously, who were recruited from among students and "white-collar" professionals not on disability leave, or the patient population was mixed or unspecified.[29,49,55]

Regarding another difference, unlike most of our previous studies,[29,46,50] many patients in the present study had lower than normal MVC values. Because MF slope and IMF have been shown in the present and other studies to be influenced by the MVC value,[14,48,49] we explored whether differences in MVC between patients with LBP and normal subjects could explain the classification results. If this were the case, failure of a subject to attain a true MVC (*e.g.*, due to unfamiliarity with the apparatus, fear, pain, or secondary gain) could confound the test results. We tested this possibility by forcing MVC into the discriminant function in addition to the five MF parameters. The classification accuracy essentially was unchanged, implying that the original results were unrelated to the subject's ability to exert a maximal extension torque. This finding implies that the discriminating power of the MF parameters is not simply a manifestation of the fact that patients with LBP had lower MVC values than the normal sample population. Although it was beyond the scope of this study to verify the nature of the muscle impairment identified by the classification function, it has been suggested in previous studies that MF parameters differ between patients and normal subjects as a result of a different pattern of muscle activation and load sharing between the different paraspinal muscles in response to pain or fear of re-injury.[15,49]

The MF parameters were not only sensitive to modifications in muscle performance associated with LBP, as indicated by the relatively high classification results of the discriminant analysis, but they also were sensitive to changes in muscle performance associated with the rehabilitation program. The overall effect of the rehabilitation program on the MF parameters was most evident for the behavior of the MF slope. In general, patients at the end of the rehabilitation program had less negative MF slope values, a finding consistent with reduced muscle fatigability.[14] The majority of patients (15 of 18) who demonstrated this reduction in MF slope also were the weakest based on pre-rehabilitation MVC data. The change in MF slope after rehabilitation most likely represented a physiologic adaptation in the neuromuscular system, because in the present study the subjects were constrained to produce the same mechanical output at each test, eliminating the effect of motivation on producing inconsistent maximal efforts. Some of the more common adaptive processes associated with exercise, such as muscle hypertrophy and changes in muscle bioenergetics, have been associated with MF.[13,14,38,48] The EMG test procedure therefore may serve as a useful electrophysiologic method for the clinician to monitor back muscle treatment progression and isolate specific muscle groups that are functioning abnormally. However, further research is needed to identify the exact cause of this suspected impairment.

Other studies among patients with LBP reported changes in EMG spectral parameters from back muscles after exercise. Mayer et al[36] used a Roman chair to fatigue the trunk and reported that patients had a significantly lower (less negative) MF slope after a multidisciplinary rehabilitation program. Another study used a weight-holding task to fatigue the lower back muscles and monitored MF from four lumbar muscle sites.[55] Two groups were studied—1) sedentary women participating in a 12-week fitness class and 2) patients with LBP who underwent a 10-week back care exercise program. Testing was conducted at the beginning and end of the intervention. The results indicated that during the weight-holding task the MF decreased by a lesser amount at the follow-up test sessions compared with baseline. These independent studies support our finding that EMG spectral parameters can change in a manner consistent with improved fatigability after rehabilitation.

That many of the patients recruited in the present study had a history of back surgery was an opportunity to identify whether this was a factor influencing the change in MF associated with rehabilitation. We found that MF slope changed to a lesser extent in individuals with a history of back surgery than in those without a history of back surgery. It is unclear whether the history of back surgery was the primary factor affecting MF slope in this instance or whether it was the result of some other related factor. Surgical procedures may directly interfere with muscle contractile ability or vascular supply, impeding the beneficial muscle adaptation normally associated with rehabilitation. However, the impairment also can be explained by the patient's apprehension and avoidance of activity that may follow surgery, even in this instance, where surgery had occurred more than 1 year before testing.

Median frequency parameters also were significantly influenced by such characteristics of the test procedure as electrode location (lumbar level and left versus right side) and % MVC. These results were consistent with previous reports.[49] Differences in MF slope among the three lumbar levels may reflect different proportions of Type I and Type II muscle fibers in the paraspinal muscles underlying the electrode sites, or they may reflect the effects of biomechanical factors that influence the distribution of the external load among the different muscle groups.[49] Although several anatomic studies have described muscle fiber-type composition of back muscles, none have differentiated their findings for different lumbar spinal levels.[3,20,21,51] However, researchers who have formulated biomechanical models of the lumbar spine report that paraspinal muscles in the lower lumbar region contribute proportionately more force than muscles located at higher lumbar levels.[57]

Muscles with the greatest change in MF during a contraction (*i.e.*, those having steeper MF slopes) also had the least amount of recovery in this study. Recovery of MF after fatigue is attributed in large part to the ability of venous blood to remove metabolites that have accumulated as a result of ischemia and anaerobic metabolism.[14] Muscles with a compromised endurance capability also have been found to have fewer muscle capillary networks.[9]

The effect of increasing the force output of the trunk extensors from 40% MVC to 80% MVC was significant for MF slope, which became more negative. This finding would be expected if ischemia and recruitment of more Type II fibers occurred as the force level was increased.

The IMF was lower for the 80% MVC trials compared with the 40% MVC trials ($P = 0.09$), which followed the same trend reported in our previous studies.[49] This inverse relationship between IMF and % MVC is a peculiarity of paraspinal muscles that has been explained by the findings that in these muscles the Type II fibers have smaller cross-sectional areas than the Type I fibers,[3,21,51] and therefore have lower conduction velocity and MF.[14,48,49] In most other skeletal muscles of the body, the opposite relationship between % MVC and IMF has been reported.[11]

One of the main questions concerning the applicability of this technique to LBP populations relates to the ability of a subject to generate a forceful contraction when compromised by pain, apprehension of re-injury, or the presence of "true" muscular weakness.[5,6,31,36,53] Kondraske et al[31] analyzed the effects of MVC magnitude on MF slope in a study they conducted on normal subjects using a spectral EMG technique. They found that approximately 35% of the variability in MF slope was the result of the variance in MVC. We found a similar result for the normative data but not for the LBP patient population, where the association was much less. This difference may be related to the fact that LBP patients had significantly lower MVC than normal. Median frequency slope is less responsive to changes in force when measurements are conducted over relatively low contractile force levels compared with higher force levels.[48] Our methods were designed to decrease the possible confounding influence of MVC on evaluating impairment based on MF parameters. We were able to control for differences in MVC before and after rehabilitation by conducting all tests at a percentage of the subject's baseline MVC. Monitoring treatment progression using this procedure essentially results in comparing MF parameters in an individual for the same extension torque.

In addition, classification of LBP was based on a specific combination of MF parameters rather than relying on a single parameter, such as MF slope. It was demonstrated that this combination of parameters classified subjects independently of MVC. However, there is considerable debate in the literature regarding the relationships between pain, muscular function, and EMG results.[1,33] Our findings in the present study demonstrated that MVC influenced the MF slope but not the ability of the MF parameters to identify muscle impairment among subjects with and without LBP. This finding suggests that the muscle impairment recognized by the EMG technique is distinct from that of muscular weakness. We have demonstrated in other studies among patients with chronic LBP in remission (*i.e.*, without pain) that EMG manifestations of back muscle impairment can be associated with increased muscle fatigability without the presence of back strength deficits.[49] It is possible that because these studies were performed on very different clinical populations, they identified distinct muscle impairment entities with different patterns of MF findings—one a manifestation of deconditioning, the other a manifestation of muscle inhibition or "guarding" in response to pain or fear of re-injury. Further research is needed to verify these possibilities.

■ Conclusions

The following are the most important findings of this study.

1. Median frequency parameters derived from lumbar muscle EMG signals were able to classify subjects into LBP and normal groups with relatively few misclassifications. These results demonstrate that the patients with LBP in this study had a distinctly different pattern of MF behavior than normal, suggesting that abnormal muscle functioning or impairment was present. Furthermore, the finding that the discriminant function derived from this analysis also was able to classify a "holdout" sample population of patients and normal subjects with similar accuracy demonstrates that this technique may be generalized to other populations.
2. Low back pain and normal classifications based on MF parameters were independent of the subject's maximal trunk extension force. This finding implies that the abnormal muscle functioning measured by the MF parameters in this population was not influenced significantly by differing abilities of subjects to exert a maximal contraction.
3. Median frequency slope significantly changed in a manner consistent with improved muscle fatigability in patients with LBP undergoing rehabilitation. No other median frequency parameters (IMF or MF recovery) changed significantly in association with LBP rehabilitation.
4. Change in MF slope was consistent with a reduction of muscle fatigue after rehabilitation and was of significantly less magnitude for patients with a history of back surgery than for patients who never had back surgery.
5. Changes in MF slope after rehabilitation were not significantly influenced by test protocol factors such as the lumbar spinal level of the EMG detection site or the % MVC of the trial.
6. Median frequency slope was only minimally related to the physical characteristics of the patients with LBP. For normal subjects, however, the variance in MF slope was significantly associated with MVC and body mass index.

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