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Classification of back muscle impairment based on the surface electromyographic signal

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Abstract—A surface electromyographic (EMG) procedure for classifying muscle impairments in persons with low back pain (LBP) is described. The procedure was studied using a device, the Back Analysis System (BAS), to acquire and process EMG signals from six bilateral muscle sites during sustained isometric contractions designed to progressively fatigue the lower back. Back muscle impairment was determined on the basis of the different ways in which the EMG median frequency parameters change as a function of contraction duration and muscle site. The article describes a series of studies that have been useful in developing an automated procedure for identifying back muscle impairment by comparing individual test results to a normative database. To date, the research results have produced multivariate discriminant functions that have identified two muscle impairment categories associated with deconditioning and imbalances secondary to LBP. We have found that the functions can distinguish individuals with and without LBP with an accuracy of approximately 90%. Other studies are described in which the technique is applied to monitoring changes in muscle performance capability that occur following rehabilitation for LBP. Many of our findings here are also compared to the results of independent studies by others using similar procedures. The need for further research and development of the technique to improve its clinical applicability is also described.

Key words: *EMG, low back pain, muscle fatigue, rehabilitation.*

INTRODUCTION

Conservative management of low back pain (LBP) commonly includes treatment to restore paraspinal muscle function to normal. Persons with LBP often have reduced muscle strength and endurance, which may compromise the functional capacity of the spine and increase the likelihood of reinjury (1). Back exercises are among the most commonly prescribed procedures for treatment of LBP (2). Although more research is needed to demonstrate the efficacy of specific exercise techniques, there are numerous studies to support the use of exercise as a treatment modality for LBP (1,3,4). Furthermore, recent task-force guidelines have recommended that back exercises be included as an integral component of acute LBP

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treatment programs (5). Their recommendations were qualified, however, by recognizing that more objective and quantitative methods of measuring impairment in relationship to disability will be needed to fully validate exercise prescription and fulfill the goal of more effective care. The need for improved assessment methods will likely intensify as the costs associated with LBP continue to spiral upward. Advocates of reform are warning that in an effort to contain costs and streamline the delivery of care, only those treatment programs that can be objectively monitored and related to specific impairments and outcomes will be considered for reimbursement in the near future (5).

Historically, paraspinal muscle impairment has been quantitatively assessed by the use of dynamometers to supplement standard clinical assessment procedures (6). Dynamometers provide a means of measuring mechanical variables associated with either the force, velocity, or displacement of the trunk. However, approaches based entirely on mechanical output share a common flaw in that the measured kinematics or force variables are cognitively perceived by the subject, and thus can be voluntarily regulated in a manner that can meaningfully affect the variables being measured (7). Maximal physical performance capability as measured by these procedures cannot be completely isolated from factors related to motivation and secondary gain.

Assessments based on surface electromyographic (EMG) techniques have been proposed to overcome some of the problems inherent in the use of dynamometers for back muscle evaluation and classification (8). The most recent approaches favor the use of EMG variables derived from the frequency spectrum of the signal rather than from signal amplitude, partly in recognition of the fact that during a sustained contraction, the EMG signal propagates at a slower velocity and undergoes an alteration in shape associated with changes to the depolarization zone of the muscle membrane (9). These phenomena are referred to as "myoelectric manifestations of fatigue," and are typically measured during a contraction as a decrease in the median or mean frequency (MF) of the EMG signal. The performance state of the paraspinal muscles can then be described by an information map derived from the spectral variables obtained from an array of EMG electrodes (7). The electrodes are strategically placed at specific anatomical locations corresponding to contralateral and ipsilateral paraspinal muscles. Differences in the information map at the beginning and end of a fatigue-inducing contraction are analyzed to assess impairment. The issue of muscle performance objectivity is addressed by specfying that the test be limited to the performance of submaximal constant-force isometric contractions in which the duration of the contraction is predetermined. Furthermore, the useful information from the EMG signals is not derived from a single muscle group or a single parameter, but rather is the result of the concurrent behavior or mapping of many co-active muscle groups. It is hypothesized that the subject is likely to be unaware of, and cannot volitionally control, parameters derived from such a measurement scheme.

This article provides an overview of the development and implementation of an EMG-based approach to assessing and classifying paraspinal muscle impairment in persons with LBP. An EMG device used to implement this technique, referred to as a Back Analysis System (BAS), is described from its development as a laboratory-based prototype to its current implementation as a system designed specifically for clinical use. The development of test protocols and procedures to acquire normative data using the BAS is described in the first part of this article. Results of recent studies by our group and others to evaluate specific clinical populations with LBP utilizing this approach are discussed in the second part. A summary of ongoing research to improve the clinical usefulness of the technique is provided in the final section.

METHODS

This technique began approximately 10 years ago as a direct outgrowth of the work by our group and others to develop surface EMG procedures for the objective quantification of muscle fatigue. At the time, acquisition and processing technologies were sufficient to begin developing the more complex multi-electrode system needed for evaluating paraspinal muscles.

The technique is comprised of four functional elements: 1) surface EMG signal detection, 2) computer-assisted signal processing, 3) a postural restraint and torque measurement apparatus, and 4) software to facilitate protocol implementation, database organization, and clinical report generation.

A surface electrode unit was developed based on an electrode circuit containing a high-impedance, low-noise-differential pre-amplifier housed in a small molded plastic package located in close proximity to the detection site (10). This configuration has the mechanical and electrical stability necessary for reliable and consistent detection of EMG signals primarily from the superficial paraspinal muscles of the lower back. The electrodes are placed bilaterally to detect EMG signals from the longissimus thoracis, iliocostalis lumborum, and multifidus muscles (**Figure 1**). Signals detected by the electrodes are input to a digital signal processing card where the MF and root-mean-square (RMS) variables of the EMG signal are concurrently calculated for each of the six channels in near real time. At the completion of each test, the results are stored in a relational computer database for retrieval and analysis. An example of data from one trial in the BAS is presented in **Figure 2.**

The postural restraint component of the BAS stabilizes the pelvis and lower limbs of the subject during the test (**Figure 3**). The system is designed to ensure that the sustained, isometric muscle contractions are proportional to the extension torque being monitored. The device is designed to be adjustable to accommodate subjects within the 95th percentile of body height and weight. Contoured and adjustable restraints hold the pelvis in a posterior tilt. Adjustable knee pads provide weight-bearing surfaces and reduce hamstring muscle activity by positioning the knees in approximately 25° of flexion. The force produced by isometric trunk extension is measured using a padded harness positioned across the scapular region of the back and attached to two low-compliance force transducers. Differences in the forces computed from the two load cells provide a measure of the degree to which the contraction is symmetrical. The sum of the forces from the load cells is displayed on a

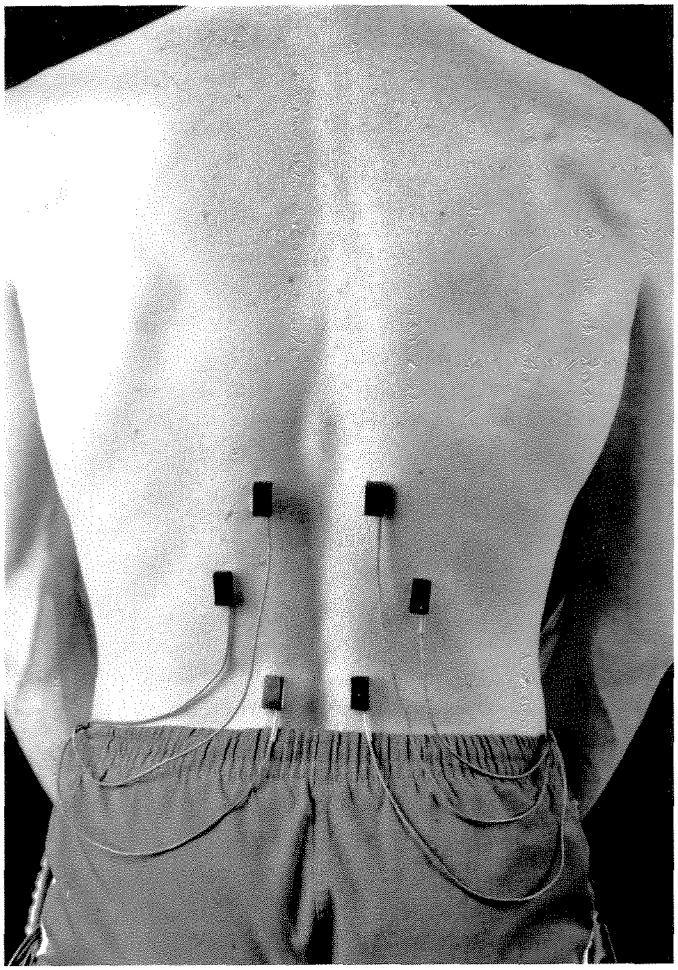

Figure 1.
Bilateral placement of six EMG surface electrodes are shown corresponding to the approximate location of the *m. longissimus thoracis, m. iliocostalis lumborum,* and *m. multifidus* at spinal levels L1, L2, and L5, respectively (with permission from *Spine* 14(9), 1989).

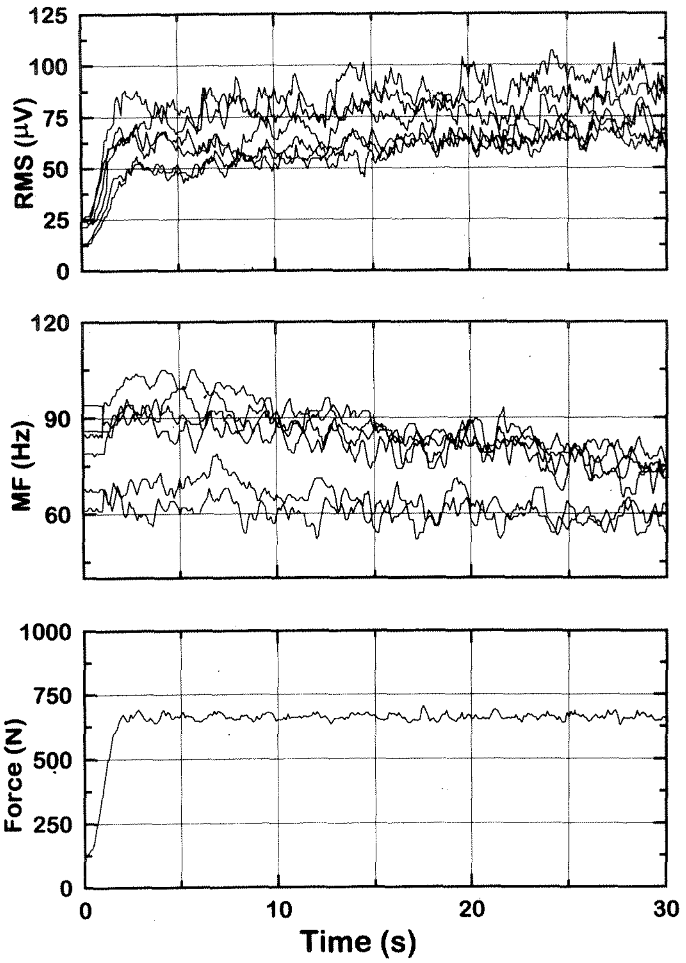

Figure 2.
RMS (in μV, upper plot) MF (in Hz, middle plot) and force (in N, lower plot) variables are plotted as a function of contraction duration from data acquired during a typical test in the BAS sustained at 80 percent MVC×20 s. EMG data from six electrode sites, similar to those depicted in **Figure 1,** are plotted as separate curves.

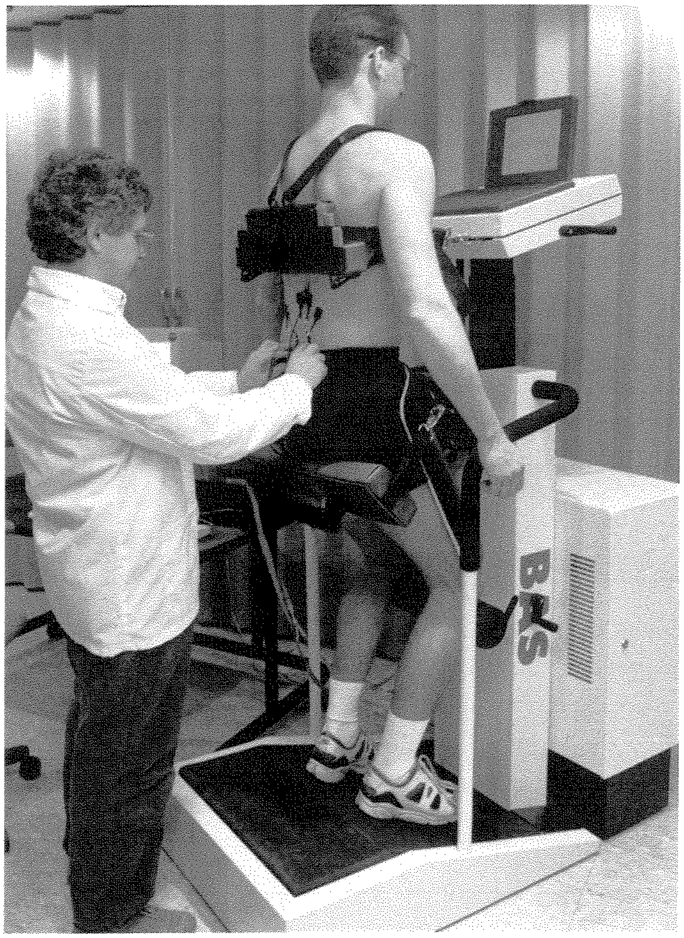

Figure 3.
The BAS used for acquiring EMG and Force data during sustained isometric contractions. A subject is shown positioned in the postural restraint apparatus while surface EMG electrodes are being applied to the lumbar back. Subjects produce trunk extension torques against the scapular pad according to target values depicted on the monitor in front of them.

monitor where the target force level is also displayed to assist the subject in complying with the task.

The software component of the BAS consists of three subparts that respectively perform the functions of system calibration, data acquisition, and analysis. A unique feature of the system is its ability to detect EMG signal and force "errors." The system constantly monitors and indicates to the operator whether specific indices of EMG signal quality (e.g., presence of 60 Hz line noise, inadequate gain) are present and whether the subject has complied with the force specifications of the task. When prespecified levels of critical error or noncompliance are present, the software prevents the operator from continuing with the next trial until the problems are corrected with the help of a troubleshooting module displayed on the monitor. In fact, there are several initial trials specified in the protocol to ensure that the system is functioning properly and the subject is able to comply with the tasks before the trials to identify muscle impairment are begun.

Specifications for clinical reports have been developed for baseline or follow-up test protocols. The brief (1–2 page) reports are divided into the following sections: 1) personal information; 2) assessment summary; 3) compliance; 4) strength; 5) muscle imbalance; and 6) impairment classification. Follow-up reports include clinical report results from all previous tests for that person. The complaince section summarizes the results of the EMG and force errors encountered during a test. Strength assessment is based upon the determination of the subject's maximal isometric voluntary contraction (MVC) and comparison to normative data. Muscle imbalances are measured by the ratio of MF values for contralateral muscle sites (11).

Studies to Acquire Normative Data

All of the studies utilizing the BAS were conducted following written informed consent approved by an Institutional Review Board. A series of tests was conducted upon a subject population without LBP to identify the influence of body posture and electrode position on the reliability of time-dependent EMG spectral parameters (MF) and amplitude parameters (RMS). This phase of development culminated in a single laboratory-based prototype system in which different test protocols could be specified and data acquisition implemented for offline processing.

Effects of Muscle Site and Force

The device has been used to characterize the influence of muscle site (lumbar spinous levels, left and right side) and force production (percentages of maximum) on the behavior of the EMG parameters. In one study (**Figure 4**) of 12 male subjects without a history of LBP (mean (SD): age 27.3 (7.2) yr, height 169.8 (17.0) cm, weight 71.1 (5.9) kg, MVC 105.8 (24.9) kg) the decline in MF (MF slope) during a sustained contraction held for a maximum of 60 s increased nonlinearly with force level for contractions specified at 40, 60, and 80 percent MVC (12). The effect of muscle force level on MF slope is consistent with numerous other reports involving paraspinal muscles (13) as well as for other muscle groups (9,14). It

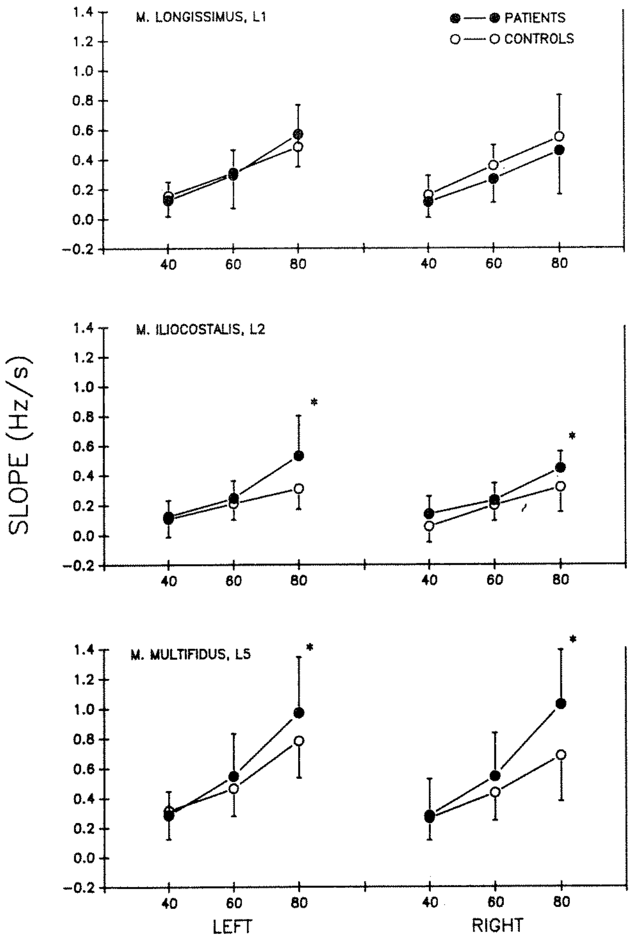

Figure 4.
Mean slope of MF (±SD) acquired from contralateral paraspinal muscle groups for tests conducted at 40, 60, and 80 percent of MVC on 12 subjects with chronic LBP (•) and 12 controls (o). Contractions were sustained isometrically for a maximum of 60 s at each contraction level. The data are plotted separately for the *m. longissimus* (upper), *m. iliocostalis* (middle), and *m. multifidus* (lower) as well as for left- and right-sided muscle groups. $*=P<0.05$. (With permission from *Spine* 14(9), 1989).

is hypothesized that the more fatigable type II muscle fibers recruited at higher force levels result in a slowing of EMG signal propagation and a widening of the depolarization zone as a net accumulation of metabolites take place at the muscle membrane (9).

Of additional interest is the finding that the MF slope is generally steeper at the L5 muscle site than at either the L1 or L2 muscle sites. This likely represents differences in muscle fiber type proportions at these sites as well as a different distribution of muscle loading that has been reported by mechanical models of the back (12). The magnitude of MF slope values for back muscles is in general less negative than skeletal muscles that do not have a postural function (12,14). Muscle force and muscle site also have an influence on the initial median frequency (IMF) value (**Figure 5**). The IMF is the MF value corresponding to the beginning of the contraction, and is of importance in representing the MF prior to the influ-

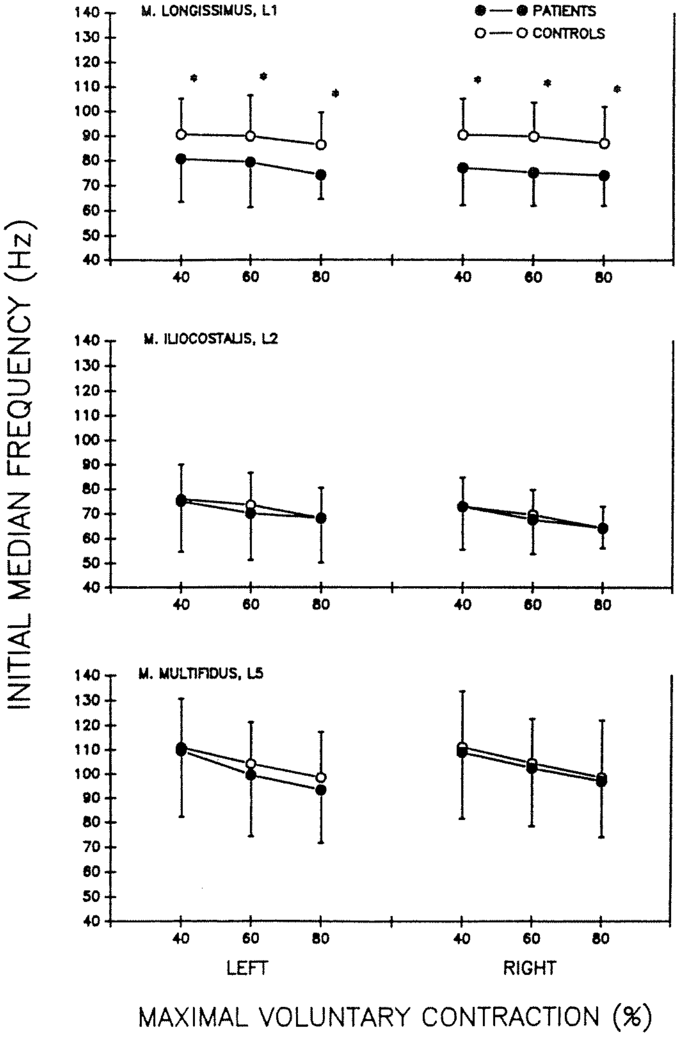

Figure 5.
Mean IMF (±SD) acquired from contralateral paraspinal muscle groups for tests conducted at 40, 60, and 80 percent of MVC on 12 subjects with chronic LBP (•) and 12 controls (o). Contractions were sustained isometrically for a maximum of 60 s at each contraction level. The data are plotted separately for the *m. longissimus* (upper), *m. iliocostalis* (middle), and *m. multifidus* (lower) as well as for left- and right-sided muscle groups. $*=P<0.05$. (With permission from *Spine* 14(9), 1989).

ence of fatigue effects. The decrease in IMF with increasing %MVC is opposite to that reported for most other muscle groups and may reflect the finding that type II muscle fibers in the erector spinae are smaller in cross-sectional area (and therefore have lower conduction velocity and MF) than type I fibers. This peculiar effect of force on IMF has been reported by other research groups as well (13).

Effects of Subject Physical Characteristics

The effects of physical characteristics on MF parameters has been of interest to account for the sources of variability in these parameters (15,16). Physical descriptive parameters, such as age, height, weight, and strength, were measured and related to the MF slope using a multiple linear regression procedure in a study of 42 sedentary male subjects without a history of debilitating LBP. Their mean (SD) measurements were: age 26.7 (5.2) yr, height 180 (10) cm, weight 70.5 (9.7) kg, MVC 84.0 (33.2) kg (16). We specifically analyzed the physical parameters of age, height, MVC, and Body Mass Index (BMI), a measure of obesity defined as $(\text{Weight}) \div (\text{Height})^2$. The results of the multiple regression model were significant ($P=0.001$) and indicated that these variables accounted for 48 percent of the variance in MF slope. The factor MVC and BMI contributed considerably more to the model than either age or height. Interestingly, this same analysis on 28 subjects with LBP resulted in a nonsignificant regression analysis ($P=0.159$) with only 11 percent of the variance in MF slope accounted for by the model. It may be that for persons with LBP there may be other factors, perhaps directly related to muscle impairment or pain, that overshadow factors associated with body size or strength.

Reliability

The reliability of EMG spectral parameters obtained during isometric protocols for back muscles has been reported by our group (12) as well as others (15,17,18). We reported coefficients of reliability of 0.98 and 0.94 for the IMF and MF slope, respectively, for repeated tests on four control subjects conducted by the same investigator during which the electrodes were not removed and replaced between tests (12). Biedermann et al. assessed reliability for experiments performed 5 days apart and found a correlation coefficient of >0.90 for MF values obtained from the multifidus muscle and >0.75 for the iliocostalis muscle (17). No inter-tester reliability was reported. Although further work is needed to evaluate the reliability of these measurements more fully, particularly with regard to identifying the sources of error, results to date indicate that EMG spectral parameter reliability is acceptable for clinical applications.

Studies to Acquire Clinical Data from Persons with Low Back Pain

A series of clinical studies was undertaken to characterize the presence of muscle impairment on the basis of EMG measurements from the BAS. Well-delineated populations of persons with LBP were evaluated and compared to a control population. Differences in behavior of specific EMG parameters or multivariate functions of selected parameters were studied to identify the myoelectric features of these LBP syndromes.

Study of Sedentary Subjects with Chronic Low Back Pain

The first BAS prototype was used to compare BAS test results from subjects with chronic LBP (n=12) and control subjects (n=12) matched for age and height (12). The subjects with LBP were all male, right-handed, and, although in pain remission at the time of testing, reported a history of chronic back pain for an average of 5.2 years. None of the subjects had previous back surgery or radiographic evidence of a structural disorder of the spine. The test procedures included a series of isometric contractions of 1 min duration, each sustained at a constant force of 40, 60, and 80 %MVC. The results of the study identified a characteristic pattern of MF results for control and subjects with LBP derived from the six concurrent EMG signals acquired during the test contractions. There were significant differences in the MF parameters between the two groups that were muscle and force dependent (**Figures 4** and **5**). The findings implied that the subjects with chronic LBP had more fatigable back muscles than their pain-free cohorts. We interpreted this finding as an EMG representation of back muscle deconditioning rather than a direct impairment in response to pain, because the results were symmetrical and the subjects were in pain remission at the time of testing.

A multivariate discriminant analysis procedure was analyzed to describe an algorithm for classifying persons into the LBP and control groups. The procedure uses a step-wise linear regression approach and an F-test for entering and removing variables from the regression to maximize between-group variance and minimize within-group variance (19). The results for MF parameters demonstrated the test's ability to identify the subjects with LBP with an accuracy of 92 percent (11 of 12) and the control subjects with an accuracy of 83 percent (10 of 12) based upon just 4 parameters. Although this analysis was undertaken in a relatively small sample set and is not conclusive, we were encouraged that the classification function selected the same parameters that we found to be significantly different when comparing mean values for the two groups. The successful classification was, therefore, not likely an incidental occurrence that resulted from the possibility that we overfitted the model, which can occur when the ratio of variables to cases is not relatively small. The results also demonstrated that, for this group of subjects, reliance on MVC values or measurements of back extensor strength would have suggested that no dysfunction was present.

Studies of Athletes with Chronic Low Back Pain

A second study comparing subjects with LBP and controls was conducted using a similar protocol, with the exception that a "recovery" contraction was added (20). Muscle fatigue recovery was measured at the completion of the fatigue-inducing contraction as the proportional recovery of MF following a 1-min rest period. The study recruited elite collegiate rowers: 13 port-side and 10 starboard-side. Differences in rowing side were compared to identify the sensitivity of the MF parameters to chronic asymmetrical loading of their muscles. Six of the rowers had a well-documented history of LBP that included discogenic, muscular, and hypomobility/hypermobility spinal problems. Pain was chronic for four of the subjects and acute for the remaining two. The BAS test identified 100 percent of the rowers with LBP and 93 percent (14 of 15) of the subjects without LBP using a discriminant analysis procedure, which selected the MF recovery parameter as the primary discriminating variable. The "recovery" parameter was defined as the value of the MF after a 1-min rest, calculated as a percent of baseline. This result confirmed the use of the BAS technique even in highly conditioned athletes.

A third study, also of athletes, compared conventional clinical measurements with BAS measurements of muscle function (21). Twenty-four freshman rowers were recruited, eight of whom had LBP (four chronic, four acute). None complained of more than minimal pain during the test. The clinical measurements consisted of the range of motion of the trunk in forward, backward, lateral, and rotational direction as well as the maximum isometric extension torque. MF variables identified 88 percent (7 of 8) of the subjects with LBP and 100 percent (n=16) of the controls. In contrast, the conventional clinical parameters identified only 57 percent (4 of 7) of the subjects with LBP and 67 percent (10 of 15) of the controls. MF measures were shown again to be highly sensitive and highly specific for LBP, confirming previous findings, while spinal mobility and isometric trunk strength were not.

Studies of Persons Undergoing Rehabilitation

The technique has also been studied to determine the sensitivity of the BAS measurements to changes in muscle function in persons undergoing LBP rehabilitation (16). A total of 92 persons with chronic LBP (average duration 1.6 years) were tested at baseline and a subset (n=28) were retested following LBP rehabilitation. Most of these subjects could be categorized as "failed back syndromes," for their having undergone unsuccessful back surgery or prolonged physical therapy treatment. They were studied while in an intensive multidisclipinary rehabilitation program that they attended 40 hrs per week for a total of 4 weeks.

A discriminant function for classifying subjects into LBP and control groups was formulated using the EMG results from a subset of the LBP subjects tested (n=28) and a normative sample (n=46). Classification results for this learning set were compared to classification results using the same function on the remaining "holdout" sample of subjects (n=64) and an additional normative sample (n=6). The discriminant function classified subjects into LBP and control groups with 86 percent and 89 percent correct classification for the learning set and holdout set of data, respectively (**Figure 6**). The classification results were independent of trunk extensor strength differences between subjects.

Studies from Other Researchers

Many of the findings from this series of clinical investigations have been strengthened by the results of research groups independent of ours. The discriminating ability of EMG spectral measures were compared for controls and subjects with LBP classified according to a Pain Behavior Checklist (22). A weight-holding task was utilized to fatigue the paraspinal muscles and two bilateral paraspinal electrode sites from the upper and lower lumbar regions were selected for detection. The pain scale categorized subjects with LBP into "confronter" and "avoider" groups based on their behavioral response to pain (23). The results of the analysis found that only

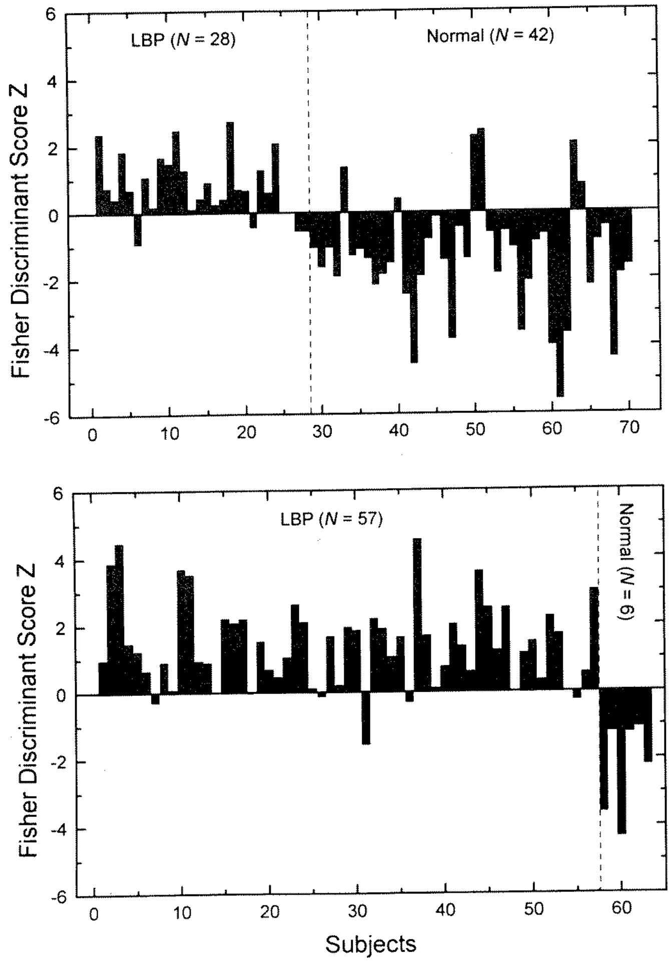

Figure 6.
Fisher discriminant function scores, a measure of the distance from the classification cutoff point for LBP and non-LBP are presented for: a) each of 28 subjects with LBP and 42 control subjects who form the learning set for computing the function; and b) each of 57 subjects with LBP and 6 control subjects comprising a holdout sample. A positive score indicates a LBP classification, a negative score indicates a non-LBP classification. Subjects are divided along the X-axis according to those known a priori to be LBP or control. (With permission from *Spine* 20(1), 1995).

the avoider category of subjects with LBP could be accurately discriminated from the non-LBP control group. The rate of decay of MF from the lower lumbar muscle groups was significantly greater in the avoider group and was selected as the primary discriminating variable. The results are relevant to gaining a better understanding of what these EMG measures of impairment signify from a functional perspective. It was postulated that the avoider group tends to refrain from physical activity, which they believe is harmful to their back disorder, and as a result develops signs of increased muscle fatigability. In contrast, the confronter group does not have evidence of impairment, and members were classified by these same variables as indistinguishable from the control. The development of these muscle characteristics as a response to changes in functional demand should be considered as a basis for treatment among similar persons, with the EMG assessment procedure as an integral part of monitoring outcome. Pain avoidance behaviors can account for a large part of the disability associated with LBP (24,25) and can be treated successfully when specifically targeted (26).

Recent studies have focused on whether back exercise results in improvements in muscle performance that are detectable by surface EMG procedures. The results appear to be strongly dependent on the intensity of the exercise. For instance, Mayer et al. studied 10 industrial subjects participating in a 3-week comprehensive functional restoration program for chronic disabling spinal disorders (27). Participants were not employed and presumably led restricted physical activity lifestyles. Following intensive rehabilitation, lasting 10 hrs/day, the subjects showed significant improvements in the MF slope of the EMG when comparisons were made with respect to baseline measures and a non-LBP control population. Testing was conducted using a Roman Chair exercise apparatus, where the subject had to maintain unsupported trunk extension while prone. The EMG test sessions were also accompanied by isokinetic sagital trunk strength assessment that significantly improved following rehabilitation. Although no mechanical tests for endurance were conducted in this study, the discriminating ability of the EMG assessment technique was judged poor by the authors because some of the individual subjects had MF slopes that could be considered within a normal range. It is unclear whether these individuals were truly false positive results, since this finding was based on the untested assumption that all of them had compromised endurance. Other researchers have utilized a similar fatigue-test protocol to study the interrelationship between endurance, training, and myoelectric manifestations of fatigue for back muscles. The reader can refer to studies by Moffroid and Mannion et al. in this publication describing additional findings for LBP and pain-free subjects (28,29).

Other investigators studying the effects of back exercise on EMG spectral parameters found these parameters to be sensitive to back muscle adaptations. Thompson and Biedermann report results from a controlled study of sedentary females without LBP (13). Those who participated in a 12-week aerobic fitness program had a decrease in an MF fatigue index for lower lumbar muscles, while a control group did not. In this same report, they described the results for a second study, this time among subjects with LBP (n=15) participating in a 10-week program of back exercises. At the completion of the program, subjects had a significant decrease in their MF fatigue index for both upper and lower lumbar muscle groups. The sensitivity of the EMG spectral parameters to exercise in these instances must be considered rather high, because the exercise programs were not particularly intense or, in the case of the aerobic fitness class, even specifically focused to back muscles.

For our clinical trial using the BAS on subjects with LBP in an intensive work-hardening program reported earlier in this article, differences in EMG parameters before and after rehabilitation were analyzed (16). Changes in MF following the rehabilitation program were consistent with improvements in back muscle fatigue. Persons without a previous history of back surgery for prolapsed intervertebral disc showed greater resistance to fatigue as measured by the change in MF compared to those with surgery (P=0.008). Furthermore, those with abnormally low back extensor strength prior to the rehabilitation program made the most gains in their MF measurement of fatigue (P=0.03). The effect size is often used to quantify the change in a parameter associated with a treatment and is calculated as the difference in mean values divided by the standard deviation. For MF slope, the effect size was relatively moderate (0.35–0.41) as compared to the effect size for MVC gains of 0.75. The difference in effect size for these parameters may represent the fact that back muscle strength and endurance may improve at different rates in response to exercise.

CONTINUING RESEARCH AND DEVELOPMENT

Considerable effort is being directed at developing new test parameters and protocols to improve the clinical usefulness of the assessment procedure. An example of this effort is described elsewhere in this publication in greater detail (11). The need for new assessment procedures is based on the recognition that muscle function is often task-specific. Therefore, test results from one particular mode of contraction may not apply to another. Most of the activities associated with work and daily life include tasks in which the paraspinal muscles must function in dynamic as well as static modes. Assessment procedures should characterize muscle capacity under both of these conditions to be considered a comprehensive test battery reflecting a variety of normal functioning. All of the EMG procedures discussed so far in this article are sustained constant-force contractions that are performed in an isometric or static mode. The reason for this restriction pertains directly to the limitations inherent in the specific signal-processing techniques used to extract spectral information from the signal. The discrete-time Fourier transform can be properly considered as a method of calculating the MF without violating the stationarity requirement for this type of analysis (30). The EMG signal is segmenting into shorter epochs (e.g., 0.5 s–1 s) where for static isotonic contractions the processes may be considered stationary. Different time-frequency transforms will need to be considered when trying to extend the technique to EMG signals recorded during dynamic contractions (31). Changing muscle force, fiber length, and motor unit recruitment during these kinds of contractions results in EMG signals that have changing variances and can no longer be considered stationary, even over short time intervals. Once the technical problems of calculating time-varying spectral information from EMG signals acquired during dynamic contractions are resolved, we may be able to address the question of whether muscle impairments identified during static test contractions are also present during dynamic contractions. A practical example of this is whether a person with chronic LBP, identified as having deconditioned paraspinal muscles or muscle imbalances during a static test (such as in the BAS), might also present with similar categories of impairment following tasks which are dynamic, such as during the repetitive lifting of a load. Are deficiencies in paraspinal muscle groups as measured by the change in the EMG signal over time similarly elicited in each test? Further work is obviously needed before we can fully extrapolate results from constrained test conditions to more realistic situations that are closer to activities of daily living and work.

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