Electromyography for Assessment of Pain in Low Back Muscles
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Background and Purpose. Pain is currently evaluated with “subjective” methods (eg, patient self-report). This study aimed to test whether fatigue indexes are able to accurately discriminate between subjects with and subjects without low back pain.

Subjects. Sixty subjects separated into 2 groups—a group with low back pain (n=30) and a group without low back pain (n=30)—participated in this study.

Methods. Electromyographic (EMG) and force data were obtained during a muscle fatigue test. The same test was repeated to monitor recovery. Linear regression analysis was used to obtain fatigue indexes.

Results. Subjects with pain produced significantly lower force values than those without pain. The use of fatigue indexes and force values permitted accurate classification in 89.5% of cases.

Discussion and Conclusion. The results confirm that subjects with pain show early myoelectrical manifestations of muscle fatigue and that EMG can be a useful tool in the evaluation of low back pain.
Low Back Pain Assessment

Low back pain is a syndrome of multifactorial etiology that affects 6.8% of the world population at any given time. It is one of the principal causes of absenteeism from work and impairment of the performance of daily activities, thereby affecting an individual’s quality of life.

Traditionally, the clinical diagnosis of low back pain has been made by a physician or physical therapist using methods such as palpation, anamnesis, and the Borg scale. The evolution of low back pain during physical therapy treatment also can be monitored with questionnaires and physical performance tasks. All of these situations involve a great degree of subjectivity; that is, they depend on the patient’s report or the physical therapist’s interpretation. Therefore, sometimes double-blind tests are used.

In 1993, an alternative low back pain evaluation procedure, the Back Analysis System, was proposed. The Back Analysis System allows for more “objective” diagnosis and follow-up. This system is based on muscle fatigue induction monitored by surface electromyography (EMG) in the frequency domain, which allows mapping of the median frequency (MF) during a sustained muscle contraction. During the fatigue process, the MF tends to decrease, reflecting the decrease in the motor unit action potential firing rate during a muscle contraction. On the basis of this spectral variable, an index of muscle fatigue during isometric contractions has been proposed as a guide for evaluating low back pain.

Thus, in recent years, it has been suggested that chronic low back pain is intimately related to localized muscle fatigue. In this sense, muscle fatigue is understood to be a continuous process that starts with the initiation of neuromuscular activity and that is capable of causing changes in electrical activity, electrical propagation, excitation-contraction coupling, and various elements of the contraction process. Scientific evidence has shown that people with low back pain exhibit earlier manifestations of muscle fatigue in low back muscles than people who are healthy. However, in studies in which the objective has been to use EMG to discriminate between people with and people without pain, there has been a tendency to focus on small samples of athletes; people who are not athletes have received little attention. Furthermore, although studies have been carried out with the aim of analyzing the relationship between the EMG signal and low back pain, before considering the capacity of the method to achieve a straight diagnosis, the intrinsic limitations of the technique need to be analyzed. Therefore, the present study, which included methods similar to those used in other studies, such as discriminant statistical analysis, and which focused on sedentary subjects, represents a contribution toward the application of the technique to clinical practice.

The purpose of this study was to verify whether muscle fatigue indexes calculated in the frequency domain are capable of discriminating between sedentary subjects with lumbar pain and those without lumbar pain. If such discrimination is shown to be possible with surface EMG, it can be hypothesized that the same technique can be used to obtain an objective assessment of low back pain.

**Method**

**Subjects**

Sixty subjects who did not perform regular physical activity participated in this study. The subjects were separated into 2 groups: a group with low back pain (n=30) and a group without low back pain (n=30). Interviews and anamnesis were used by a physical therapist to recruit the subjects. The inclusion criterion for the pain group was multiple episodes of pain in the low back muscles in the preceding 3 months, characterized as chronic pain (daily or almost daily). The pain was not scaled; only the number of episodes was considered. The inclusion criterion for the without-pain group was the absence of pain in the low back muscles in the preceding year. Exclusion criteria were as follows: previous surgery, symptoms of nerve root engagement (ie, pain distal to the knee), spondylolisthesis, spinal stenosis, inflammatory disease, and cancer. The subjects signed a written informed consent form.

**Protocol**

For evaluation of the low back muscles, the subjects lay in a prone position on an exercise bench with the low back, hips, and knees securely fixed by straps. The subjects also were secured at the level of the scapula by a leather strap, which was...

Table 1.
Means and Standard Deviations for Various Characteristics of Subjects in the Preceding Year

<table>
<thead>
<tr>
<th>Group (n)</th>
<th>Age, y</th>
<th>Stature, cm</th>
<th>Body Mass, kg</th>
<th>No. of Pain Episodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>With low back pain (30)</td>
<td>27.2 (7.2)</td>
<td>171.0 (10.0)</td>
<td>69.8 (11.4)</td>
<td>11 (3)</td>
</tr>
<tr>
<td>Without low back pain (30)</td>
<td>23.7 (5.4)</td>
<td>170.5 (7.5)</td>
<td>69.0 (10.1)</td>
<td>0</td>
</tr>
</tbody>
</table>
attached to the load cell fixed to the ground. While in this position, the subjects were asked to attempt to extend the trunk; given the impossibility of performing this movement, this attempt led to an isometric contraction of the low back muscles. All subjects performed the protocol once.

The protocol6 consisted of 3 stages: (1) 3 attempts at the maximal voluntary contraction (MVC), each lasting approximately 5 seconds, with a 2-minute interval between attempts; (2) one fatigue test, which consisted of maintaining a calculated submaximal level of 80% of the MVC for 35 seconds; and (3) a postfatigue test (at the same 80% of the MVC) for 10 seconds to monitor recovery. The highest value obtained in the first stage was used to calculate the submaximal level of 80% of the MVC. There were 2-minute intervals between stages. An oscilloscope* was used to make by use of a 16-channel EMG system† with preamplifiers (fixed gain of 20×) located approximately 10 cm away from the electrodes. The input impedance of the system was 10 GΩ, the common mode rejection rate was greater than 100 dB (at 60 Hz), and the signal-to-noise ratio was 3.0 μV root mean square. The force signals were obtained by use of a load cell fitted with strain gauges§ connected to the same EMG module.

Data Acquisition
The EMG and force signals were acquired simultaneously during the protocol with a Pentium 200-MHz PC-compatible microcomputer, through a 12-bit analog-to-digital converter board,‡ with a sampling frequency of 2,000 Hz per channel.

The EMG activity was recorded bilaterally from the longissimus (L1) and iliocostalis lumborum (L2) muscles, in accordance with standards for reporting EMG data.¹⁵ Disposable silver-silver chloride surface electrodes (1.0 cm in diameter) were placed in a bipolar configuration on the bellies of the muscles, along the supposed alignment of the muscle fibers. The reference electrode was placed on the left wrist. Preparation for surface EMG activity detection included shaving and application of alcohol to cleansed skin. Impedance between electrodes was checked and accepted when maintained at less than 5 kΩ. Recordings were made by use of a 16-channel EMG system† with preamplifiers (fixed gain of 20×) located approximately 10 cm away from the electrodes. The input impedance of the system was 10 GΩ, the common mode rejection rate was greater than 100 dB (at 60 Hz), and the signal-to-noise ratio was 3.0 μV root mean square. The force signals were obtained by use of a load cell fitted with strain gauges§ connected to the same EMG module.

Linear regression analysis was used for 30 points, and a linear equation was obtained for each muscle. This equation supplied the linear slope coefficient and the y-intercept value, both of which were considered to be fatigue indexes.¹⁷,¹⁸ For inclusion in the study, the coefficient of determination obtained by linear regression had to be equal to or higher than 0.6. Thus, the EMG response from the fatigue protocol was obtained from 5 muscle fatigue indexes. The use of indexes 3 and 4 (β and y’, respectively; see below) was an attempt to disregard the fluctuations normally present in fatigue protocols.

The fatigue indexes were as follows:

1. The slope coefficient (α) of a straight line that approached all 30 MF values¹²

2. The y-intercept (y) of a straight line that approached all 30 MF values¹²

3. The slope coefficient (β) of a straight line that approached just the first and the last MF values¹⁷,¹⁸

4. The y-intercept (y’) of a straight line that approached just the first and the last MF values¹⁷,¹⁸

5. The recovery index (REC), represented by the following equation¹²:

\[
\text{REC} = \frac{(\text{MF}_{r} - \text{MF}_{f})}{(\text{MF}_{r} - \text{MF}_{f}^{	ext{p}})} \times 100,
\]

where MF_r is the highest MF during the recovery period, MF_f is the final MF, and MF_f^p is the initial MF.

Data Analysis
Analyses were carried out with SPSS 10.0 software.¹¹ The normality of the data (Shapiro-Wilks test) and the homogeneity of the variances (Levene test) were verified and confirmed. A t test for independent samples was performed to test for any differences

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¹ MINIPA Electronics Co, 33 Alameda dos Túpinas, São Paulo, SP 04069-000, Brazil.
² Lynx Tecnologia Eletrônica Ltda, 358 Dr José Elias, São Paulo, SP 05083-030, Brazil.
³ EMG System do Brasil Ltda, 1380 Scóprias, São José dos Campos, SP 12240-570, Brazil.
⁴ Alfa Instrumentos Eletrônicos Ltda, 138 Coronel Mário de Azevedo, São Paulo, SP 02710-020, Brazil.
⁵ SPSS Inc, 253 S Wacker Dr, Chicago, IL 60606.
between groups in relation to force and MF. To assess the ability of fatigue indexes and force data to discriminate between subjects with and without pain, we performed discriminant analysis: Wilks’ test to evaluate the homogeneity of the variances, canonical correlation to verify the linear combination of the variables, stepwise Wilks’ discriminant analysis to classify subjects into groups, and the predicted score for each group. In the discriminant function, all muscles were considered individually and as a single low back muscle group. Thus, a one-way analysis of variance was applied to verify possible differences in the fatigue indexes of 4 low back muscles. Because there were no significant differences in the fatigue indexes of the 4 muscles investigated, these muscles were considered as a single low back muscle group. The level of significance used was .05.

Results
The results showed that subjects with low back pain produced force values significantly lower than those of subjects without pain ($P = .002$). The means and standard deviations for force were 505 ± 213 N for the low back pain group and 678 ± 233 N for the without-pain group. Table 2 shows the means and standard deviations for MF, MF, and MFr. Significant differences between groups were found only on the left side.

The Figure illustrates the MF changes in the left iliocostalis lumbar muscle during the fatigue test in 2 subjects, one with pain (Figure, left) and the other without pain (Figure, right). The fatigue indexes, slope coefficient ($\alpha$), and y-intercept ($y$) are indicated in the regression linear equation in the Figure. In Table 3, only the REC fatigue index showed a significant difference between subjects with and subjects without pain. Again, significant differences between groups were found only on the left side.

Discriminant analysis was used to classify subjects into pain and without-pain groups by use of the fatigue indexes and force values obtained from the MVC. The most accurate results were achieved when the low back muscle group as a whole showed that the variables (force, $\beta$, $y$, $\alpha$, $y'$) were able to correctly classify 86.7% of all subjects (Wilks’ $\lambda = 0.871$, $\chi^2 = 7.970$, $df = 1$, $P = .005$). When the REC was added into the analysis, a decrease in the prediction accuracy was observed; the most accurate results indicated that for the low back muscle group, the variables ($\beta$, $y$, $\alpha$, REC) were able to correctly classify 64.6% of all subjects (Wilks’ $\lambda = 0.894$, $\chi^2 = 15.591$, $df = 5$, $P = .008$) (Tab. 4). When the analysis was performed with all of the muscles individually, the most accurate results indicated that for the left longissimus muscle, the force value and 3 fatigue indexes ($y$, $y'$, and REC) were able to correctly classify 69.4% of all subjects (Wilks’ $\lambda = 0.804$, $\chi^2 = 9.796$, $df = 4$, $P = .044$) (Tab. 4).

Discussion
The results showed that 86.7% of all of the subjects were correctly classified. This result is comparable to those of other studies, because the accuracies of the classifications obtained from the discriminant function were between 85% and 100%, depending on the people assessed.19 Interestingly, these accuracies were achieved only when the spectral variables were associated with the force values obtained from the MVC. Similarly, in another study with logistic regression, which combined force and initial MF, between 78% and 86% of the subjects were accurately classified.9 However, in still another study, in which only the REC and slope coefficient were used and force value was not used, 100% classification accuracy was achieved for 6 rowers with low back pain.12

Although the evaluation method used in the present study was similar to the methods used in the above-mentioned studies, the highest accuracy achieved in identifying sedentary subjects with low back pain was 89.5% (Tab. 4). However, the sample

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**Table 2.**

Means and Standard Deviations for Normalized Initial Median Frequency (MFI), Final Median Frequency (MF), and Highest Median Frequency During the Recovery Period (MFr) in the iliocostalis Lumbar and Longissimus Muscles

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Group</th>
<th>$\bar{x}$ (SD) for:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MFI</td>
</tr>
<tr>
<td>Right iliocostalis lumbar</td>
<td>Without pain</td>
<td>92.63 (14.79)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>94.83 (10.25)</td>
</tr>
<tr>
<td>Right longissimus</td>
<td>Without pain</td>
<td>96.45 (8.61)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>99.15 (9.46)</td>
</tr>
<tr>
<td>Left iliocostalis lumbar</td>
<td>Without pain</td>
<td>91.97 (11.62)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>95.96 (12.98)</td>
</tr>
<tr>
<td>Left longissimus</td>
<td>Without pain</td>
<td>93.15 (8.21)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>97.71 (9.79)</td>
</tr>
</tbody>
</table>

* Significant difference at $P < .05$ between group with pain and group without pain on left iliocostalis lumbar and left longissimus muscles for all variables (MFI, MF, and MFr).
used in the present study was 10 times larger (n=60); accordingly, the discriminatory power was proportionally greater than that presented for the rowers, because the larger the number of subjects, the greater the statistical test power.

Even though the present study failed to accurately classify 100% of the subjects with low back pain, all predictions were significant. This finding confirmed the initial hypothesis suggesting the value of using this procedure for the evaluation of low back pain and the follow-up of its evolution in sedentary subjects, despite the fact that the subjects with pain may not have exerted maximal force during the MVC, even though they were strongly encouraged to do so.

Significant differences were found for force values between subjects with and subjects without pain, and the pain group produced force values that were 26% lower than those of the without-pain group. Pain and disuse, common in people with low back pain, cause changes in EMG activity during induced fatigue and decreases in the force and resistance capacity of the low back muscles. A pain adaptation model suggests that pain decreases muscle activation when the muscle acts as an agonist and increases muscle activation when it acts as an antagonist. This model postulates that changes in motor recruitment may be attributable to some strategic control that the nervous system executes through a specific neural pathway. The effects of this neural mechanism indicate a decrease in the activation of agonists and an increase in the activation of antagonists. Thus, it is understood that pain can affect voluntary activity in painful muscles, producing inappropriate contractions.

Table 3.
Means and Standard Deviations for the Fatigue Indexes in the Iliocostalis Lumbar and Longissimus Muscles

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Group</th>
<th>α</th>
<th>y</th>
<th>β</th>
<th>y’</th>
<th>REC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right iliocostalis lumbar</td>
<td>Without pain</td>
<td>−1.0 (0.3)</td>
<td>101.87 (15.2)</td>
<td>−1.1 (0.5)</td>
<td>98.23 (13.8)</td>
<td>117.57 (42.9)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>−0.9 (0.5)</td>
<td>102.19 (12.8)</td>
<td>−1.0 (0.6)</td>
<td>99.50 (9.7)</td>
<td>100.14 (33.3)</td>
</tr>
<tr>
<td>Right longissimus</td>
<td>Without pain</td>
<td>−0.9 (0.4)</td>
<td>109.64 (14.8)</td>
<td>−1.2 (0.4)</td>
<td>101.44 (12.6)</td>
<td>119.20 (59.0)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>−0.8 (0.5)</td>
<td>104.91 (13.8)</td>
<td>−1.0 (0.7)</td>
<td>100.60 (12.7)</td>
<td>122.33 (67.52)</td>
</tr>
<tr>
<td>Left iliocostalis lumbar</td>
<td>Without pain</td>
<td>−0.9 (0.5)</td>
<td>102.16 (10.4)</td>
<td>−1.1 (0.4)</td>
<td>98.89 (17.0)</td>
<td>119.00 (48.1)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>−0.8 (0.5)</td>
<td>102.16 (10.4)</td>
<td>−1.0 (0.6)</td>
<td>97.71 (13.6)</td>
<td>152.39 (72.8)</td>
</tr>
<tr>
<td>Left longissimus</td>
<td>Without pain</td>
<td>−0.8 (0.5)</td>
<td>102.16 (10.4)</td>
<td>−1.1 (0.5)</td>
<td>97.26 (9.9)</td>
<td>127.33 (29.8)</td>
</tr>
<tr>
<td></td>
<td>With pain</td>
<td>−0.8 (0.5)</td>
<td>102.16 (10.4)</td>
<td>−0.9 (0.6)</td>
<td>99.58 (13.0)</td>
<td>162.27 (78.9)</td>
</tr>
</tbody>
</table>

a = slope coefficient of a straight line that approached all 30 median frequency (MF) values, y = y-intercept of a straight line that approached all 30 MF values, β = slope coefficient of a straight line that approached just the first and the last MF values, y’ = y-intercept of a straight line that approached just the first and the last MF values, REC = recovery index.

Significant difference at P<0.05 between group with pain and group without pain on left iliocostalis lumbar and left longissimus muscle only for REC.
In the present study, although force showed predictive power, this power was seen only when force was used in combination with other spectral variables in the discriminant function. This finding showed the importance of muscle fatigue indexes that indicate early myoelectrical manifestations of muscle fatigue in people with low back pain relative to people who are healthy.\(^5\) The presence of this hypothesized behavior was confirmed and allowed discrimination between subjects with and subjects without pain (Tab. 4).

An evaluation of the MFI and MF values for the longissimus and ilio-costal lumbar muscles on both sides of the trunk revealed higher MF values and lower MF values in subjects with pain than in those without pain (Tab. 2). These findings indicated that in subjects with pain, there is always a greater variation in frequency and therefore a steeper slope. This pattern may indicate that subjects with pain tend to show early EMG responses associated with alterations in muscular contraction processes, such as propagation of cell membrane action potentials and excitation-contraction coupling. The figure illustrates the typical behavior of the MF in the left ilio-costalis lumbar muscle during the fatigue protocol in 2 subjects (with and without pain). Furthermore, with regard to the spectral variables, the statistical analysis showed that significant differences were found only for the muscles on the left side of the trunk (Tab. 2). This finding may have been attributable to the lack of control of trunk rotation during the fatigue protocol. In a previous study\(^12\) in which consistent findings were obtained for both sides of the trunk, trunk rotation was controlled by use of 2 cell loads, thus facilitating visual feedback of the force used on both sides simultaneously.

It has been suggested that people with low back pain have a reduced physiological capacity to remove lactate, thereby maintaining metabolites within the muscle for a longer duration.\(^12\) Although intracellular acidosis is considered to contribute to muscle fatigue, it also plays a role in preserving excitability when depolarization occurs within the muscle during activity; that is, intracellular acidosis has a protective effect during muscle fatigue.\(^25\) Considering recovery capacity (ie, a return to a non-fatigue condition\(^23\)) as an important tool in the analysis of neuromuscular function and low back pain, we also used REC to evaluate low back muscle performance in the present study. In contrast to our initial expectations, the results demonstrated higher values for MF and, consequently, for REC in subjects with pain than in subjects without pain (Tabs. 2 and 3). Accordingly, we surmise that these findings may have influenced the lower level of force exerted by subjects with pain during the MVC. In contrast to a study in which the REC showed high discriminatory power and was probably the most important variable used in classifying subjects with low back pain,\(^12\) in the present study, the REC failed to show any such capacity to predict low back pain. However, when the REC was used in a prediction model with spectral variables, it was found to be useful in discriminating between subjects with and subjects without low back pain (Tab. 4).

In recent years, there has been renewed interest in developing a more effective method to objectively quantify muscle impairment caused by low back pain. In this context, most studies have shown that spectral variables are important in discriminant functions that identify low back pain.\(^5\),\(^12\),\(^24\)–\(^26\) because they are able to identify the EMG pattern that is typical of dysfunction and that can be identified when muscle fatigue is induced.

**Conclusion**

The results of this study support the suppositions that people with no history of performing regular physical activity and with pain in the low back muscles show earlier manifestations of muscle fatigue than healthy people and that EMG can be a useful tool for diagnosing low back muscle pain because the discriminant function accurately classified 89.5% of subjects with low back pain.

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**Table 4.**

Discriminant Analysis of Various Muscles for Correct Classification of Subjects With and Subjects Without Low Back Pain

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Variables Used in the Correct Classification(^*)</th>
<th>% Correct Classification by Group</th>
<th>Canonical Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>With Pain</td>
<td>Without Pain</td>
</tr>
<tr>
<td>Single low back muscle group</td>
<td>Force, (\beta, y, \alpha, y')</td>
<td>89.5</td>
<td>84.0</td>
</tr>
<tr>
<td></td>
<td>(\beta, y', \alpha, \text{REC})</td>
<td>68.2</td>
<td>61.6</td>
</tr>
<tr>
<td>Left longissimus muscle</td>
<td>Force, (y', y, \text{REC})</td>
<td>71.4</td>
<td>66.7</td>
</tr>
</tbody>
</table>

\(^*\) Variables are listed in descending order of discriminatory power. \(\alpha\) = slope coefficient of a straight line that approached all 30 median frequency (MF) values, \(y=y\)-intercept of a straight line that approached just the first and the last MF values, \(y'=y\)-intercept of a straight line that approached just the first and the last MF values, REC = recovery index.
Dr Candotti, Dr Loss, Dr Castro, Ms Melo, and Mr Araújo provided concept/idea/research design. Dr Candotti, Dr Loss, Dr Castro, and Ms Melo provided writing and consultation (including review of manuscript before submission). Dr Candotti, Ms Pressi, Mr La Torre, Ms Melo, Mr Araújo, and Mr Pasini provided data collection and subjects. Dr Candotti, Dr Loss, Dr Castro, Mr La Torre, Ms Melo, Mr Araújo, and Mr Pasini provided data analysis. Dr Candotti, Mr La Torre, Ms Melo, and Mr Araújo provided project management and facilities/equipment. Dr Candotti provided fund procurement and institutional liaisons. Dr Loss provided clerical support. Dr Candotti, Dr Loss, Dr Castro, Mr La Torre, Ms Melo, Mr Araújo, and Mr Pasini provided project management and facilities/equipment. Dr Candotti provided fund procurement and institutional liaisons. Dr Loss provided clerical support.

This study was approved by the ethics committee of Universidade do Vale do Rio dos Sinos.

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References


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