Torso muscle EMG profile differences between patients of back pain and control

Shrawan Kumar a,*, Narshima Prasad b

a Physical Medicine Institute, University of North Texas Health Science Center, Fort Worth, TX 76107, United States
b Department of Mathematical and Statistical Sciences, Faculty of Sciences, University of Alberta, Edmonton, Alberta, Canada

ABSTRACT

Background: Electrophysiological criteria that identify and characterize low back pain can lead to better understanding of the affliction and possibly aid in its treatment.

Method: Nineteen male and 22 female subjects with chronic back pain, without lumbar radiculopathy; and 30 male and 33 female control subjects with no history of low back pain in the last 12 months, were recruited into the study. All subjects flexed, extended, laterally flexed, flexed anterolaterally and extended posterolaterally isometrically to 20% and 100% of their maximal voluntary contraction (MVC). Additionally, patients were asked to do these activities to their pain threshold levels and control subjects to 60% maximum voluntary contraction. Surface electromyograms (EMG) were recorded from lumbar erectors spinae, external obliques and rectus abdominis bilaterally. The electromyogram was subjected to magnitude, Fast Fourier Transform, and wavelet analyses. The median frequency and frequency bands were calculated with their power. The wavelet decomposition was done and a logistic discriminant analysis was carried out to classify patients and normal controls.

Findings: The normalized peak electromyograms of patients were significantly greater than controls (P < 0.01). The muscle conduction velocity was not disturbed by pain. Significant differences were found in total power between patients and controls (P < 0.01). The analysis correctly classified patients and controls 65% and 98% of the time, respectively at 20% MVC, 95.1% (patients) and 86.8% (controls) at pain threshold/60% MVC, and 74.3% (patients) and 86.4% (controls) at pain tolerance/MVC (P < 0.05).

Interpretation: The surface electromyography can be used in discriminating chronic low back pain patients and controls. This would be an objective test over and above other subjective tests, such as pain provocation.

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1. Introduction

Since the underlying etiology of the idiopathic low back pain and ensuing physiological changes remain elusive, the interventions remain nonspecific with variable results. The predominant mechanism of musculoskeletal injury causing pain would be due to injury to these structural components of the low back (Kumar, 2001). An electrophysiological technique is likely to be primarily based on objective rather than subjective factors. The chronic low back pain patients showed significantly increased EMG activity in the swing phase of the gait, a phase where lumbar muscles are normally silent (Arendt-Nielsen et al., 1996). This change correlated significantly with the intensity of the back pain. The authors concluded that the musculoskeletal pain modulates motor performance during gait, probably via reflex pathways. Experimentally induced pain as well as a fear of pain has subtle effects on the erector spinae EMG activity during walking (Lamoth et al., 2004). These authors concluded that the altered gait observed in the low back pain patients was probably a complex, evolved consequence of lasting pain rather than an immediate effect. Postural aberration with the chronic low back pain has also been reported (Christie et al., 1995), likely due to differential muscle activation.

In a sample of 30 chronic low back pain patients and 30 control subjects muscle activity mean values were threefold higher in chronic low back pain patients than controls in a static exertions, and two times greater in dynamic exertions (P < 0.01) (Ambroz et al., 2000). Finneran et al. (2003) have reported that a large-array surface electromyography in low back pain yielded a multi-focal and asymmetrical pattern of EMG activity. Based on this observation the authors concluded that such a method will be useful in evaluating patients with low back pain. Despite the foregoing studies, the changes in EMG due to pain have not been characterized adequately. Understanding the EMG behavior has been tackled by creating experimental pain through injection of noxious substances, and studying the aberrations in EMG characteristics. Some studies have concluded that the experimental pain does not alter the spectral parameters, motor unit properties or the conduction...
velocity significantly (Birch et al., 2000; Farina et al., 2005). Others indicate an alteration in motor unit recruitment due to pain, especially in the time and frequency domain parameters (Lundblad et al., 1998; Hodges and Richardson, 1999). A change in time-domain parameters enabling 97% accurate classification of chronic cervical pain patients has been reported by Kumar et al. (2007). Several studies have indicated a discernible and significant increase in the EMG amplitude due to experimental or pathological pain (Sohn et al., 2004; Geisser et al., 2004; Ervilha et al., 2004, Graven-Nielsen et al., 1997).

This project was designed to investigate time and frequency-domain characteristics of torso muscle EMG from patients of established muscle pathophysiology in low back pain cases, and compare them with normal controls. Such a tool may allow physical diagnosis and perhaps to discern the severity of the problem. Furthermore, it may also serve as a tool to measure efficacy of various pain treatment modalities.

2. Methods

2.1. Sample

Nineteen male (mean age 56 years) and 22 female patients (mean age 50 years) of chronic low back pain were recruited from a neurology EMG clinic. The exclusion criterion was lumbar radiculopathy which was ruled out based on EMG and neuroimaging studies. The mean height and weight of male patients was 176 cm (8 cm) and 91 kg (16 kg). The females, on the other hand, had a mean height of 163 cm (8 cm) and mean weight of 174 kg (11 kg). There were 30 male controls (mean age 30 years) with height and weight of 175 cm (9 cm) and 74 kg (11 kg). The control subjects, who did not have low back pain, were recruited from general population. In addition, there were 33 female control subjects (mean age 33 years) with a mean height of 162 cm (7 cm) and mean weight of 59 kg (10 kg).

2.2. Subject preparation

After obtaining informed consent and suitable skin preparation (which included shaving, where needed, and rubbing skin with alcohol–acetone mixture to improve conductivity) Delsys bipolar active knife edge surface electrodes with a fixed inter-electrode distance (10 mm) were applied to the lumbar erectors spinae, at the level of the third lumbar spinous process, external oblique (10 cm below the costal margin and 14 cm lateral to umbilicus) and rectus abdominis (6 cm above the umbilicus) bilaterally in both patients and control subjects. These electrodes had an on-site pre-amplification of 10 times. The signals were fed to an amplifier for an additional gain of 100 times. Such prepared subjects were seated in the experimental set up for testing.

2.3. Testing device

The testing device consisted of an adjustable chair, sliding platform, and floor mounted strength measuring device (Fig. 1). The chair consisted of a molded plastic seat mounted on an iron platform with telescopic metal legs fixed to the base plate. The back rest and seat were fitted with Velcro restraint system to stabilize lower extremities. The chair with its base plate was pivoted in the center and had casters on the periphery for circular motion with stability. The circular plate was graduated in intervals of 5° and holed through which bolts were placed to match the holes in the sliding board of the platform. Two bolts were placed at opposite ends and tightened for a rigid fixation of the chair in the desired position for the subject. The force resisting device consisted of a vertical telescopic 15 cm wide rectangular metal tube welded to a thick iron plate rigidly bolted in the floor (Fig. 1). The 12 cm wide inner concentric tube could be raised or lowered and securely locked into place. Experimental subjects were fitted with a non-stretchable Velcro belt, mounted perpendicular to the tubing by means of an aircraft cable with an intervening load cell (Interface Technology Inc., Walnut, CA; Model I-250 with force range of 1000 N). Thus, any force exerted on the Velcro belt was registered on the load cell, which was fixed in its mechanical path and remained in line with the cable at all times during all tests.

2.4. Tasks

After signing the informed consent form, subjects were measured and weighed and their ages recorded. Finally, they were seated and stabilized in an erect and upright posture. Previously prepared subjects were seated in the experimental set up for torso strength testing. The subjects were asked to exert in isometric flexion, extension, left lateral flexion, left antero-lateral flexion, and left posterolateral extension. The sequence of these exertions was fully randomized. Prior to the start of the trial, the subjects were instructed to bring their contraction to the subjectively determined target level in the first two seconds and hold it there for another three seconds. At this time the trial was terminated. The patients were asked to exert to their 20% maximum voluntary contraction (MVC), pain threshold, and pain tolerance levels. The patients were instructed to stop exertion as soon as they reached their self assessed subjective 20% maximum voluntary contraction (MVC) and as soon as the pain was evoked (for pain threshold exertion) but to continue to exert as hard as they could for pain tolerance level. This level of contraction among low back pain patients was also assigned as their MVC. The control subjects were asked to exert to their 20% MVC, 60% MVC and maximum voluntary contraction. The exertion levels of 20% and 60% of MVC were subjectively assessed by the subjects. All exertions were required to be five seconds long. While the subjects exerted force, the EMG of all six muscles and force of exertion were sampled at 2 kHz.

3. Data analysis

3.1. EMG

The raw EMG signals were band pass filtered with low cutoff frequency of 20 Hz and high cutoff frequency of 450 Hz. The signals in this frequency band were pre-amplified and EMG activities were...
marked and selected for Fast Fourier Transform analysis. These activities were isometric and data segments were stationary, as such chosen for such analysis. However, a test of the stationarity of the data was carried out by calculating autocorrelation before proceeding with the rest of the analysis. The spectral data analysis of each muscle, in each of the 15 activities for the trunk muscles, was done separately for patients of back pain and control subjects. From the spectral analysis, the lower and upper 3 dB frequencies and the bandwidth was extracted for patients and control subjects. Each of these parameters was calculated for 20% MVC (patients and controls); pain threshold (for patients), 60% MVC for controls; and, pain tolerance (for patients) and MVC (for controls). The median frequency of each of the torso muscle, in each of the activities of the patients and controls were extracted. Similarly, mean power frequency, total power and peak power were calculated for the above mentioned muscles from the spectral analysis.

Descriptive statistics of the variables of EMG magnitude, normalized peak EMG, median frequency, mean power frequency, total power, peak power, frequency at peak power, time to onset and time to peak EMG were calculated. Each of these variables was also subjected to a one-way analysis of variance. This ANOVA was carried out to determine any significant difference between patients and controls.

3.2. Time and frequency domain analyses

The EMG signals were first rectified and subjected to wavelet analysis to obtain eight levels of decomposition of signals for each subject under each condition and for each muscle. Daubechies wavelet transformation was used for this purpose. The eight levels or scales, of the raw signals decomposition, were confined to following frequency bands:

1. 0–7.8125 Hz.
2. 7.8125–15.625 Hz.
4. 31.25–62.5 Hz.
5. 62.5–125 Hz.
6. 125–250 Hz.
7. 250–500 Hz.
8. 500–1000 Hz.

At each of the above eight scales the following were computed as frequency features.

- Eight RMS values (RMS1, RMS2, ..., RMS8).
- Mean (m), dispersion (d), skewness (s) and kurtosis (k).

For time-domain features, rectified EMG signals were subjected to fourth-order autoregressive analysis using the 'arfit.m' in Matlab using the fourth-order autoregressive model.

From this fourth-order autoregressive model, autocorrelations (rxx1, rxx2, rxx3, rxx4) and autoregression coefficients (phi1, phi2, phi3, phi4) up to order four were extracted to describe time-domain features, namely dependency of the signals. All these signals were also subjected to Wavelet Analysis and Time Series Analysis to obtain time and frequency domain features on all subjects (patients and control).

Logistic regression analysis was applied to identify best frequency-domain and time-domain features in classifying subjects to ‘control’ and ‘Low Back Pain Group’ by testing group as a binary response variable and all above mentioned frequency-domain and time-domain features as predictors. Separate logistic models were fitted for three exertion levels. After identifying the ‘best model’ with minimum number of predictors, classification procedure was formed based on the ‘best model’ by classifying a subject to ‘Low Back Pain Group’ if predicted probability from the model was greater than or equal to 0.5, otherwise the subject was classified to ‘Control Group.’ Based on one fold (delete one) and cross-validation approaches miss-classification errors were computed to evaluate the performance of the proposed classification scheme.

With the selected features from the logistic regression analysis we also performed linear discriminate classification to examine the discrimination power. Two-sigma bar plots on linear discriminate scores were plotted separately for ‘Control’ and ‘Low Back Pain’ groups to demonstrate the appropriateness of the proposed feature selections in classification of subjects into two groups.

4. Results

4.1. Strength

The body weight normalized means and standard deviations of all strength of patient and control samples for 20% MVC, 60% MVC (control)/pain threshold (patients), and MVC (control) and pain tolerance (patients) for flexion, left antero-lateral flexion, left lateral flexion, left postero-lateral extension and extension are presented in Table 1. Low back pain patient’s pain threshold strength values were between 18% and 23% of their body weight for males and between 14% and 21% for females. Pain tolerance values of the patients were similar to those of the maximum voluntary contraction efforts of the control subjects except in flexion where patients were 5% lower than control subjects. The ANOVA revealed that there was no significant difference between the body weight normalized strength between the groups. However, there were significant difference between patients and controls for flexion in 60%/pain threshold and MVC contraction efforts (P < 0.001).

4.2. EMG

4.2.1. EMG magnitude and pattern

The normalized peak EMG scores in activities of flexion, left antero-lateral flexion, lateral flexion, left postero-lateral extension, and extension activities of patients were higher than those of controls for both genders at all levels of contractions. The data for patient pain threshold and 60% contraction of normal controls is presented in Table 1. Also, these peak EMG scores progressively increased with the levels of contractions for all subjects. However, the general magnitude relationship as indicated above was maintained at every level of contraction. There was no obvious difference between the groups in pattern of the recorded EMG.

4.3. Spectral parameters

The median frequencies of various muscles were found to be different. For the left external oblique, the median frequency ranged between 81 Hz and 157 Hz for both male and female patients and controls. Similarly, the ranges for the right external oblique, left erectors spinae, right erectors spinae, left and right rectus abdominis were between 72 and 87, 82 and 130, 92 and 156, 95 and 159 and 100 and 172, respectively. The median frequency of individual muscles also varied slightly between the five different activities of flexion, left antero-lateral flexion, left lateral flexion, left postero-lateral extension and extension. The ANOVA revealed sporadic differences between patients and controls in the median frequency of the torso muscles and also showed sporadic significant differences between patients and controls in different activities. Generally, the external obliques and right erectors spinae had the highest amount of total power in their signals, but did not discriminate between patients and controls consistently. When the total EMG bandwidth was divided into 10%...
intervals and the power contained in those bandwidths were compared between patients and controls, activity specific differences emerged. In flexion, the right rectus abdominis in pain tolerance/MVC contraction showed significant differences in each of the 10 bands \((P < 0.01)\) and the right erectors spinae showed difference significant in 6 out of 10 bands. Others were significant in fewer bands \((P < 0.05)\). In left postero-lateral extension for the pain tolerance/MVC contractions, the left erectors spinae were significant in all bands \((P < 0.05)\). In extension, the left and right erectors spinae were found to be a discriminating factor only in pain tolerance/MVC contraction \((P < 0.01)\) in all 10 bands.

5. Classification results

At 20% MVC exertion level the logistic discrimination resulted in classification of low back patients correctly 64.9% of the times by both re-substitution and cross-validated methods (Table 3). However, the control subjects were correctly classified 97.7% of the times.
Mal patterns of muscle activity during spinal movement may also activity which could result in mechanically induced pain. Abnormal patterns of muscle activity during spinal movement is affected by abnormal patterns of muscle activity which could result in mechanically induced pain. Abnormal patterns of muscle activity during spinal movement may also predispose the spine to an unstable state therefore result in abnormal loading, causing neuromuscular dysfunction resulting in pain (Panjabi, 1992; Cholewicki and McGill, 1996). Asymmetry of the muscle activity can occur and thereby decrease or increase inactivity compared to normal symmetrical response. The decreased activity is attributed to the reflex inhibition and the increased activity has been attributed to muscle spasm which would prevent painful movement (Price et al., 1948).

The EMG of the six torso muscles for flexion and extension demonstrated a significantly different pattern (Fig. 3) and magnitude of activity (Table 2) between patients and controls. In this patient sample, given the lower strength, high EMG amplitude indicates to the fact that there is hypersensitivity. This has been assigned as muscle spasm which would prevent painful movements (Price et al., 1948). If this pattern was present in only pain threshold contractions, the magnitude of force could explain some of this difference. However, given the fact that in the MVC/pain tolerance contractions the pattern of EMG remained unchanged indicated a clear presence of increased EMG activity.

Significant differences in normalized peak EMG were reported both in pain threshold/60% MVC and pain tolerance/MVC contractions. However, there were more muscles which were showing significant differences in the pain threshold/60% MVC contraction. In these, the left erector spinae and external oblique's in both males and females were significantly different in patients as compared to controls for all five contractions ($P < 0.01$) (flexion, left anterolateral, left lateral flexion, left postero-lateral extension and extension). In addition, all muscle's normalized peak EMG were significantly different between patients and controls for all five contractions ($P < 0.03$). The left rectus abdominis and right external oblique's were also significantly different for males for all activities ($P < 0.02$) and many in females ($P < 0.001$). It would clearly appear that the role of the erectors spinae and external oblique's were the major extensor and flexor muscles and they had to balance the mechanics of the torso as agonists, synergists or antagonists. In extensor activities, as one would expect, that the erectors spinae muscles were significantly different in patients as compared to normals. It would, therefore, appear that when pain threshold contractions are compared with the submaximal 60% MVC contractions of normal controls, there is a significant difference and that can be used as a useful classifier. This suggested twitch force may be a passive compensation mechanism to maintain constant force output in painful muscles. It has been demonstrated that in repeated contraction of shoulder muscles, there was a shift in the mean frequency of the surface EMG which was greater in patients than in

<table>
<thead>
<tr>
<th>Method</th>
<th>Effort</th>
<th>Subject type</th>
<th>Predicted group membership (per count of total)</th>
<th>Total patient</th>
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<tr>
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<td>Control</td>
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<td>100</td>
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<td>Pain threshold and 60% MVC</td>
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<td>64.9, 35.1</td>
<td>100</td>
</tr>
<tr>
<td>Re-substitution</td>
<td>PT/60% MVC</td>
<td>Patient</td>
<td>95.1, 4.9</td>
<td>100</td>
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<tr>
<td>Cross-validated</td>
<td>PT/60% MVC</td>
<td>Control</td>
<td>13.2, 86.8</td>
<td>100</td>
</tr>
<tr>
<td>Pain tolerance and MVC</td>
<td>Subject type</td>
<td>Patient</td>
<td>95.1, 4.9</td>
<td>100</td>
</tr>
<tr>
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<td>100% MVC</td>
<td>Patient</td>
<td>74.3, 25.7</td>
<td>100</td>
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<td>Cross-validated</td>
<td>100% MVC</td>
<td>Control</td>
<td>13.6, 86.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Fig. 2 shows 95% confidence intervals for mean discriminate scores at 60% exertion level for back pain patients and control subject groups.

6. Discussion

The torso is a mechanical structure which has both, strength and flexibility. It has been suggested that the biomechanics of the spinal movement is affected by abnormal patterns of muscle activity which could result in mechanically induced pain. Abnormal patterns of muscle activity during spinal movement may also

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controls (Sohn et al., 2004). No consistent significant differences between the mean frequency or the median frequency of the torso muscles, between patients and controls, indicates that they had similar spectral characteristics and insignificant differences in the conduction velocity of the muscles (Pullman et al., 2000). However, when a comparison in total power in different 10% bands was conducted (especially for pain tolerance/MVC), the rectus abdominis and external oblique’s showed significant difference between patients and controls in many of the flexor activities. The erectors spineae similarly, showed significant differences in extensor activity for all bands. These differences can have some value as classifier.

However, the time and frequency domain analyses subsequent to wavelet analysis and logistic regression discrimination model were deemed most useful in classifying patients and controls more accurately and reliably. It is clear that the classification accuracy of low back pain patients, obtained here, is lower than that of the cervical pain patients as published by Kumar et al. (2007) using the same methodology. It is possible that the complexity of the lower back pain and its motor pattern may have some obscuring effect. It may also be possible that inclusion of several muscles in multiple activities may have played an interactive role. In future studies carefully selected homogenous patient groups, muscles, and muscle specific activities may produce single discriminative variable with even better results with higher percentages being accurately discriminated.

7. Limitations

The study has a few limitations. First, though the patients met the inclusion and exclusion criteria, the sample is likely to have had different etiology of low back pain, which could not be determined for the study. Furthermore, the age matching between patients and controls could not be achieved, though no significant differences were found in strength of exertion between the two groups except in flexion at pain threshold for patients and 60% MVC for controls. Another limitation of the study is that surface electrodes were used for EMG recording. Every care was taken to avoid any cross talk but, surface EMG being volume conducted could carry signals generated from neighboring muscles. However, these activities would have been synergistic. Additionally, the pick up from inserted electrodes would have been from a very small volume of tissue and may not have reflected the general state of activity of these muscles.

8. Conclusions

(1) The strength of exertion between control and patients were not significantly different at 20% MVC and MVC. However, there was a significant difference in the strength of the two groups during flexion at 60% MVC (controls) and pain threshold (patients) ($P < 0.001$).

Fig. 3. Magnitude and pattern of EMG traces obtained from patients and controls in a pain threshold/60% MVC contraction during trunk flexion.
(2) The EMG scores in patients in all activities were greater than those of controls at all levels of contraction.

(3) The median frequencies of different torso muscles were different and they also varied with activities within the same muscles.

(4) A frequency banding into 10 percentile groups demonstrated significant differences in rectus abdominis ($P < 0.01$) and erector spinae ($P < 0.05$) in several bands between patients and controls.

(5) Logistic discrimination at 20% MVC classified LBP patients 64.9% of times and controls 97.7% of times correctly. At pain threshold the patients were correctly classified 95.1% of times but the controls at 60% MVC were classified 86.8% of times correctly. At pain tolerance/MVC levels patients and controls were classified 74.3% and 86.4% of times correctly respectively.

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