Comparison of lumbar muscle sEMG between health and LBP patients during dynamic back extensions

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Abstract: Nonlinear sEMG signal complexity and recurrence quantification analysis (RQA) methods together with the traditional linear spectrum analysis were used to compare the differences between non-specific chronic low back pain patients and healthy subjects, and to evaluate the active physical therapy effects on LBP patients during dynamic isoinertial extension test.

I. Introduction

The use of surface electromyography (sEMG) techniques has played a major role in our understanding of the functional activity of lumbar muscles both in healthy and low back pain (LBP) subjects. Numerous studies have used sEMG to identify the relationship between LBP and lumbar muscle fatigue¹²³. Specifically, the shift towards lower frequencies in sEMG spectrum has been found to be associated with localized muscle fatigue and these parameters have been used to identify muscle impairments associated with LBP during isometric lumbar muscle extension test. However, sEMG signal consists of many motor unit action potentials (MUAP) and has some chaos and non-stationary characteristics⁴⁵. Therefore, the traditional linear spectrum analysis could not reflect all the natural sEMG signal features. Also, because of the “load-sharing effect” between bilateral muscles and gluteus maximums muscles during different kind of isometric tests , the conclusions reached by these studies are not always comparable and sometimes contradictory in the accuracy and repeatability of LBP diagnosis and therapy effect evaluation⁶. In this study, we use nonlinear signal complexity and recurrence quantification analysis(RQA) methods together with the traditional linear spectrum analysis to compare the signal differences between non-specific chronic low back pain(NLBP) patients and healthy subjects, and to evaluate the active physical therapy (APT) effects on LBP patients during dynamic isoinertial extension test.

II. Methods

2.1 Subjects

19 middle-aged NLBP patients and 19 healthy control subjects participated in the study after signing an informed consent. Patients were recruited through Kuopio Occupational Health Care Center (Kuopio, Finland) and the cause of the back pain was confirmed nonspecific.

2.2 Rehabilitation

Active rehabilitation included 24 exercise sessions during 12 weeks in an out-patient clinic. Each session lasted about 1.5 hours. The treatment included physical exercise with specific equipment , together with stretching and relaxation exercise.

2.3 Isoinertial Back Extensor Endurance test

Subjects were seated on a special designed measurement unit(DBC110,Finland) in which a fixation mechanism restricted the movement below L3.In the device, the load was placed on the weight back and the resistance mechanism created a variable resistance (isoinertial loading), simulating the natural force output of the back extensor muscle. The level of loading was calculated on the basis of...
the subject’s upper body mass (UBM) as follows:

\[ \text{UBM} = (0.6 \times \text{weight in kilograms}) \times (0.4 \times \text{height in meters}) \]

The calculation was based on the assumption that 60% of body weight and 40% of height are above the iliac crest. Finally, the load in the weight stack of the device was calculated as follows:

\[ \text{Load} = \text{UBM} \times 0.82 \]

During endurance test, the subjects performed repetitive extension against a movement bar at the rate of 30 repetitions per minute (the movement amplitude was adjusted between 25° flexion and 5° extension, The test was continued up to 90 seconds).

2.4 Electromyography

Two pairs of disposable Ag-AgCL surface electrodes were attached bilaterally from the middle of the spinal processes at L5-S1 of both sides with 2-cm inter-electrode spacing. ME4000 system was used to record the sEMG signals in condition of 1000Hz sampling rate. Spectral mean power frequency (MPF) was determined by using FFT algorithm in which a 1024 data-point window slides over the whole recorded signal area with 50% overlap. sEMG signal complexity (C(n)) was defined by Lempel-Ziv definition and calculated by Kaspar-Schusyer method [7]. For RQA, determinism% which indicates the presence of more parallel trajectories was calculated by software provided by Charles L. Webber Jr. The slopes of AEMG, MPF, C(n) and %DET time series and averaged AEMG, MPF, C(n) and %DET during 90 seconds dynamic extensions were calculated for determination of signal features between LBP and normal subjects, and active physical therapy effect.

III. Results

The dynamic changes of AEMG, MPF, C(n) and %DET time series in L5–S1 left side during dynamic isoinertial lumbar muscle extension test were shown in Fig1. Both averages of MPF and C(n) was lower and %DET was higher in LBP group than those in healthy subjects. After 12 weeks active physical rehabilitation, averaged C(n) and MPF increased, while averaged %DET decreased. MANOVA analysis showed subject groups appeared to
have significant effect on C(n) slopes and averaged AEMG, MPF, C(n) and %DET, while not significant effect were observed on MPF and %DET slopes. Logistic regression analysis showed C(n) slopes was less effective both in LBP and healthy control subjects identifications despite significant subject groups effect was shown, while both MPF and C(n) averages could give much better discrimination accuracy (68%~79%) both for LBP and healthy control subjects (Table 1).

### IV. Discussion

The results of the present study showed that averaged MPF and C(n) were lower and %DET was higher than those in normal healthy subjects during dynamic lumbar extension. After 12 weeks active physical rehabilitation, averaged C(n) and MPF increased, while averaged %DET decreased in LBP patients.

SEMG spectrum and their shift towards lower frequencies during isometric test conditions have been validated as a tool to objectively monitor local lumbar extensor fatigue both in healthy and low back pain populations; However, because of the “load-sharing effect” between bilateral muscles and gluteus maximums muscles during different kind of isometric contractions performed, the conclusions reached by these studies are not always comparable and sometimes contradictory. In present study, a new dynamic back extensor muscle training and measurement unit was used, in which a fixation mechanism restricted the movement below L3 vertebra and the “load-sharing effect” of gluteus maximums muscles were minimized. In this conditions, the present study found the sEMG activities of LBP patients showed some features of low frequency, less complicated and more periodic than those without back pain subjects. Moreover, a much higher classification rate (68%~79%) and satisfied therapy evaluation were also observed by using averaged MPF and C(n). These results are in agreement with the results of previous studies of isoinertial back extensions, but different from those use initial mean frequency (MF\textsubscript{init}) or MF/MPF slopes during isometric fatigue test.

The changes of sEMG during exertions appears to be the result of both central and peripheral factors. Centrally, it may be due to synchronization of the motor units \cite{8}, recruitment of different motor units and motor unit firing time statistics \cite{9}. Peripherally, these signal activities are the consequence of changes in muscle fiber conduction velocity (CV) and muscle fiber composition features \cite{10}. Lumbar muscle is the predominance of type I muscle fibers it contains. The slopes of MF/MPF during exertions depend on the muscle fiber compositions, the more type I fibers and areas occupied by type I fibers, the more slowly MF/MPF decreased \cite{11}. Some previous clinical studies found that LBP patients usually accompanied with increased type II percentage and areas occupied by type II fibers, this fact could explain well the features of MF/MPF decline found by some other studies, but can not give the satisfied explanations of our results. Signal complexity defined by Lempel-Ziv and Determinism% calculated by RQA are

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### Table 1. Classification of LBP and normal subjects using Logistic regression.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Electrode arrangement</th>
<th>Averages</th>
<th>Slopes</th>
</tr>
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<tr>
<td></td>
<td>LBP</td>
<td>Normal</td>
<td>LBP</td>
</tr>
<tr>
<td>AEMG</td>
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<td>63.2</td>
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</tr>
<tr>
<td></td>
<td>47.4</td>
<td>63.2</td>
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<tr>
<td>C(n)</td>
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<td>68.4</td>
<td>57.9</td>
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<td></td>
<td>73.7</td>
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<td>68.4</td>
</tr>
<tr>
<td>MPF</td>
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<td>68.4</td>
<td>52.6</td>
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<tr>
<td></td>
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<td></td>
<td>63.2</td>
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recently used as nonlinear variables to describe the signal periodicity which are proved valuable and sensitive index of muscle fatigue. Farina et al developed a very useful computer simulation model that could manipulate motor unit synchronization and conduction velocities respectively and generates EMG signals subjected to RQA. They found the increases in synchronization and conduction velocities within the large population of fictive motor units could be clearly detected as an increases in \%DET\(^{[13]}\), this simulated results are partly agreement with our present findings, but it can not crinimate the effects between synchronization and conduction velocity. In one study about the mechanisms of sEMG signal variations during exertions we reported recently, the peripheral conduction velocity is not proved an important and crucial factor, while the central motor control strategy more likely synchronization mechanisms were emphasized. However, the more direct physiological evidences are needed in this theoretical explanation.

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