Multiple Regression and Statistical Analysis on SEMG of Lumbar Muscles

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Abstract

SEMG has been used as a tool over the past few years for analysing paraspinal muscle function in normal and low back pain populations. Within the group of paraspinal muscles the role of the multifidus muscles is to stabilise the spine. The Relative Strength of Contraction (RSC) of each lumbar segmental multifidus muscle was analysed in order to classify postures. Multiple Regression Analysis (MRA) was used to predict the relationship between the different levels of multifidus muscles in the lumbar region using different regression equations for different postures. In the model the least square fit method was used to make a best fit of the coefficients in the equation.. Analysis of Variance (ANOVA) was used to find the level of confidence (p values) of lumbar multifidus left L2-3 and lumbar multifidus left L4-5 as a combined factor in determining lumbar multifidus right L4-5 activity levels. Results indicate that the relationship between pattern of activity of muscle (multifidus) between the left and right sides can be predictable for a pre-defined static posture.

1. Introduction

There is a high incidence of episodes of acute low back pain (ALBP) of mechanical origin in Australia with a significant proportion (up to 80%) of these suffering further acute episodes within the next twelve months [1]. The mechanism of recurrent acute episodes of low back pain and the development of chronic Low Back Pain (CLBP) is suspected to be lumbar spine instability caused by an increased laxity of the spinal joints secondary to injury of spinal tissues, degenerative changes in spinal joints, disease or muscle weakness[2]. Muscle weakness may occur because of deterioration in the muscle stability function of the intrinsic lumbar paraspinal muscles[2,3]. Surface Electromyography (SEMG) is a measure of muscle activity and may be used to measure the properties of muscles supporting spinal segments. SEMG of lumbar erector spine muscles (LESM) has been used frequently in applied physiology for the assessment of back muscle function during various activities[4, 5]. Researchers have attempted to use the magnitude of the SEMG for the analysis of the relative strength of contraction of the paraspinal muscles for the diagnosis of lumbar back ailments[6].

1.1 Electromyography

Surface Electromyography (SEMG) is the electrical recording from the surface and represents the summation of the electrical activity from all the muscle fibers and thus the summation of all motor unit action potentials (MUAP) in the region of the electrodes. The origin of each of the MUAP is inherently random, non-stationary, and the electrical characteristics of the surrounding tissues are non-linear. Thus EMG is a very complex signal. The amplitude of the EMG recorded from the surface (non-invasive) is stochastic in nature and ranges from peak-to-peak 0 to 10mV or a Root Mean Square (RMS) value ranging between 0 to 1.5mV.

SEMG is also a useful indicator of the strength of contraction of muscles. It may be used to assess the overall functional status of muscles and can be done simultaneously on identical contra-lateral muscles in a number of functional conditions. Researchers have attempted to use SEMG for the analysis of paraspinal muscle function for various lumbar back-related conditions[7]. However SEMG of paraspinal muscles is a noisy signal for example the presence of ECG artifact[8].

SEMG may be affected by various factors. The anatomical/ physiological processes such as properties and dimensions of tissues, and force and duration of contraction of the muscle are known to influence the signal. Peripheral factors such as spacing, type and size of electrodes may also have an influence on the signal[9, 10] and to obtain reliable information, considering such factors is critical. Some of these factors may be handled through careful skin preparation, and by choosing proper anatomical landmarks for the placement of electrodes.

1.2 Static Posture and SEMG

Epidemiological studies have identified work intensity, static work postures, frequent bending and twisting, lifting and repetitions as occupational risk factors associated with LBP[10]. Spine related pain causes hardship to a large section of population. The lack of understanding of the behaviour/relationship between muscle groups (i.e., with muscles located at different vertebral levels) for a given posture can be a barrier for the assessment of back muscle function[11].

Lumbar paraspinal muscles, and in particular the multifidus muscles are responsible for stabilising spinal joints during movement and in the maintenance of posture. Atrophy and dysfunction of the multifidus could permit spinal instability and could be an important factor that contributes to the high recurrence rate in CLBP. Since a recent focus in conservative management of patients with ALBP has been the specific training of the stabilizing muscles, there is a need for quantifying and qualifying the activity patterns of the multifidus before and after training [12].Static posture testing using SEMG has been used for patient education[13], and to provide information to clinicians about the balance of activity of spinal muscles. It is assumed that the technique may also help determine whether muscles are in spasm, or have "shut down" due to fatigue.

SEMG provides a method to estimate the degree of muscle activation that occurs during the execution of a specific movement/posture. However, SEMG of lumbar paraspinal muscles may record the activity from several different muscles during specific postures. Before the clinical and research utility of the SEMG for this task can be assessed it is essential that issues of reliability and validity of the SEMG of lumbar paraspinal muscles be addressed. The ability of the SEMG to reliably record the relative strength of contraction of specific lumbar paraspinal muscles during the maintenance of a specific static posture is an important preliminary step in the validation procedure. Researchers [14]comparing SEMG activity between CLBP subjects and pain free controls have arrived at conflicting results possibly because of failure to measure subjects in different postures and to categorize different types of back pain as cited by Ambroz [11]. Despite the use of SEMG for the assessment of patients with CLBP [11], the effect of different static postures on the SEMG parameters of the lumbar multifidus muscles has not yet been reported.

During SEMG recordings of multifidus muscle activity in different static postures the reliability of the SEMG signal is a major concern with issues such as electrode placement and high noise content in the recordings needing to be addressed. The development of a reliable objective measure of muscle activity would allow investigation into treatment outcomes and the role of muscle dysfunction in the maintenance or generation of LBP[16]. There is also a need to accurately and reproducibly define specific static postures before the utility of SEMG can be assessed.

Based on normalized RMS values this paper has studied the relative strength of SEMG and reports a regression model for analysing posture. The purpose is to explore the functional relationship between the activity levels of the multifidus at different segmental levels of the lumbar spine during specific static postures for normal healthy subjects. The statistical significance for the regression coefficients is found using ANOVA method and the standard error of estimate coefficients is examined for each segmental level. Based on this model, differences of healthy and CLBP patients will be studied in the future.

2. Methodology

The aim of this study is to determine the relative strength of contraction of multifidus muscles as measured by the RMS of SEMG during pre-defined static postures. For this purpose, experiments were conducted and the results were statistically analysed to determine the relationship and thus generate a model. The experimental details are below:

2.1 Experiments

Experiments were conducted on human subjects performing a series of pre-defined static postures during which time the SEMG of lumbar paraspinal muscles was recorded. The experiments were repeated twice for the each subject for each of the postures. Details of the experimental procedure is below:

2.2 Subjects

A total of 20 experiments were conducted on 10 healthy (no history of low back pain) volunteer subjects and in accordance with the University human research ethics committee approved experimental protocol. The subjects were from both genders and their age ranged from 20 to 60 years.

2.3 Electrode Placement

Four pairs of surface EMG electrodes were positioned symmetrically on either side of the spine along the landmark line linking the L1 spinous process and the ipsilateral posterior superior iliac spine (Figure 1). Self-adhesive electrodes were placed at the levels of the L2-3 and the L4-5 interspinous spaces[17]. These electrode sites were considered to represent activity recorded from the underlying superficial fibers of the multifidus muscle[18]. A ground was placed on the upper part of the back midline. Lumbar vertebral interspaces were located through palpation by using the iliac crest as a landmark to the L4-5 interspace.

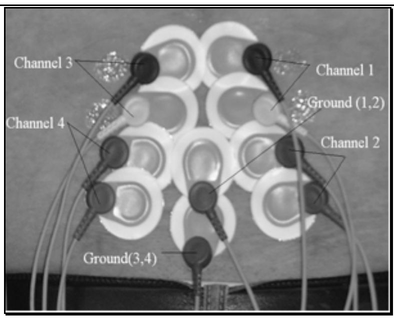

Figure 1: Four channel recording of Multifidus muscles

2.4 Choice of Postures

SEMG recordings were made while subjects maintained standardized sitting, standing and four point kneeling positions looking forward. Specific postures were chosen on the assumption that these specific postures preferentially activated the multifidi muscles of the lumbar spine. The postures also represented steady, static contractions of the lumbar multifidi muscles. Each participant was asked to assume a relaxed position when sitting, standing and during four point kneeling. For the standing posture, participants were asked to stand against a vertical support with their feet approximately shoulder width apart. Each participant was directed that they should position themselves with their back against the support so that the anatomical point most convex from the body (scapulae and/or thoracic spine) lightly touched the vertical support. The back of the head and the buttocks also lightly touched the vertical support. For the sitting posture each subject was asked to sit unsupported and erect .A flat chair was used, the height of which was adjustable so that the angle formed between the thigh and calf measured 90 degrees. Custom-built pointers were positioned against anatomical landmarks at the head (mastoid process), shoulder (greater tubercle of the humeral head) and pelvis (lateral aspect of the iliac crest).

In four point kneeling subjects were asked to kneel down and support the back using both hands and knees. The position of the hands and knees was determined by each participant and recorded by the examiners for reproducibility. Two sets of adjustable space bars were used to ensure consistent spacing between the two knees and the two hands. Solid wooden support ensured the reproducibility of the thigh position. Between the calf and thigh 90-degree angle was maintained. The distance between the thigh and arms was maintained using an adjustable bar placed on the wooden board. A visual focus point was used for all sitting, standing and four point kneeling postures, so that the subject would not make any neck movements.

A total of 11 postures were studied including Sitting Normal (SitN), Sitting Left Arm Up (SitL), Sitting Right Arm Up (SitR), Sitting Both Arms Up (SitB), Standing Normal (StaN), Standing Left Arm Up (StaNL), Standing Right Arm Up (StaNR), Standing Both Arms Up (StaNB), Four Point Kneeling Normal (4PN), Four point kneeling left arm (4PL) and Four Point Kneeling Right Arm Up (4PR) were done. The postures were maintained such that arm flexion was at 90 degrees. A vertical and horizontal scale was used in order to reproduce arm positions during repeated trials.

2.5 Recording of SEMG

The SEMG signal was recorded using the Powerlab data acquisition system (AD Instruments, Castle Hill, NSW, Australia) at a sampling rate of 1000 samples/second. The signal was denoised using spectral filters consisting of an anti aliasing filter with 3db cut-off at 200 Hz, high pass filter of 3 Hz and a 50 Hz notch filter to remove the power line noise. Particular attention was paid to ensure an identical inter electrode distance and good contact between electrode and skin at the recording sites, because poor contact can produce high erroneous readings[19]. For each subject a template was created using a transparent sheet placed on the iliac crest bones to reproduce the electrode placement during repeated experiments. Recordings were monitored on-line for any motion artifacts and those readings that had any motion artifacts were discarded.

3 Analysis of signals

Signals were normalised to overcome differences between different recordings. The recorded signals were processed using Matlab software. A statistical analysis of the SEMG parameters was carried out using MINITAB (Statistical software) to calculate regression equations, Analysis of Variance (ANOVA) and residual coefficients.

3.1 Normalization

Magnitude of SEMG is known to have intra and inter subject variability. To permit comparison between SEMG recordings the RMS-SEMG was normalised with respect to right L2-3 segmental level. This represents the relative strength of contraction (RSC). This method of RSC normalisation is most appropriate when lower levels of activation are studied or assessed compared to percentage Maximum Voluntary Contraction (%MVC). The regression coefficients were calculated and using least square fit algorithm, equations were modelled to determine the relationships between different muscle activations for different static postures.

3.2 Multiple Regression Analysis (MRA) and Analysis of Varience (ANOVA):

Regression analysis is a multivariate analysis used to summarize data and study relations between different variables[20].Regression has been used in many fields for estimation and fore casting. Traditionally multiple regression analysis (MRA) has been used to model the functional relationship between anthropometric measurements[21].A multivariate model of the data is given by Equation 1.

$$y = a_0 + a_1 \times x_1 + a_2 \times x_2 \quad (1)$$

Multiple regression solves for unknown coefficients a_0, a_1, a_2 by performing a least square fit. Thus, the relationship between the RMS of the SEMG for right L4-5 multifidus, left L2-3 multifidus and left L4-5 multifidus was found for each posture. The equation output of this multivariate process gives the correlation coefficients between segmental levels of muscle activity and the standard error estimate (SE) of each segmental level contributing to the regression equation.

Taking the average absolute deviation between the original and the derived values, the cross-validation of the model is achieved. The outcome of this cross-validation is the average error. Confidence in generalizing the regression equation is based on the error coefficients. In order to analyse postures and determine the relationship between the segmental levels of muscle activity assuming ch3 (Left L2-3 multifidus) and ch4 (Left L4-5 multifidus) as responses and ch2 (Right L4-5 multifidus) as predicted, MRA was performed.

4. Results

Multiple regression modelling provides the values of the correlation coefficients and the relationship between various segmental levels by providing the general equation for each posture. From Table 1 we can observe that the standard error of the estimate (SE) is composed of three values including the error constant (δ), left L2-3 multifidus (Ch 3) and leftL4-5 multifidus (Ch 4. δ represents the error occurrence by the constant in the equation.

Posture	Regression Equation	SE			ANOVA
		δ	Ch3	Ch4	P
4PL	$Ch2 = 1.06 + 0.51 \times Ch3 - 0.65 \times Ch4$	0.2738	0.3410	0.4304	0.302
4PN	$Ch2 = 0.33 + 0.80 \times Ch3 - 0.04 \times Ch4$	0.3487	0.4414	0.1822	0.072
4PR	$Ch2 = 0.99 - 0.05 \times Ch3 - 0.14 \times Ch4$	0.2071	0.1054	0.09468	0.227
SitB	$Ch2 = 0.48 - 0.14 \times Ch3 + 0.57 \times Ch4$	0.1169	0.1384	0.2001	0.030
SitL	$Ch2 = 0.44 + 0.03 \times Ch3 + 0.20 \times Ch4$	0.0824	0.0936	0.1004	0.004
SitN	$Ch2 = 0.31 - 0.05 \times Ch3 + 0.71 \times Ch4$	0.2236	0.1932	0.2245	0.013
SitR	$Ch2 = 0.42 - 0.07 \times Ch3 + 0.47 \times Ch4$	0.1415	0.1638	0.1833	0.008
StaN	$Ch2 = 0.68 - 0.34 \times Ch3 + 0.60 \times Ch4$	0.1335	0.1315	0.1201	0.0001
StaNB	$Ch2 = 0.60 - 0.21 \times Ch3 + 0.50 \times Ch4$	0.1160	0.1037	0.0902	0.001
StaNL	$Ch2 = 0.49 + 0.02 \times Ch3 + 0.42 \times Ch4$	0.1100	0.0862	0.1110	0.001
StaNR	$Ch2 = 0.89 + 0.39 \times Ch3 - 0.16 \times Ch4$	0.5244	0.2718	0.2782	0.360

Table 1: Regression equations showing relationships between segmental levels of muscle activity and their corresponding Error coefficients. (SE=Standard Error of Estimate). Ch2 = Right L4-5 multifidus, Ch3 = Left L2-3 multifidus, Ch4 = Left L4-5 multifidus. δ =Error constant.

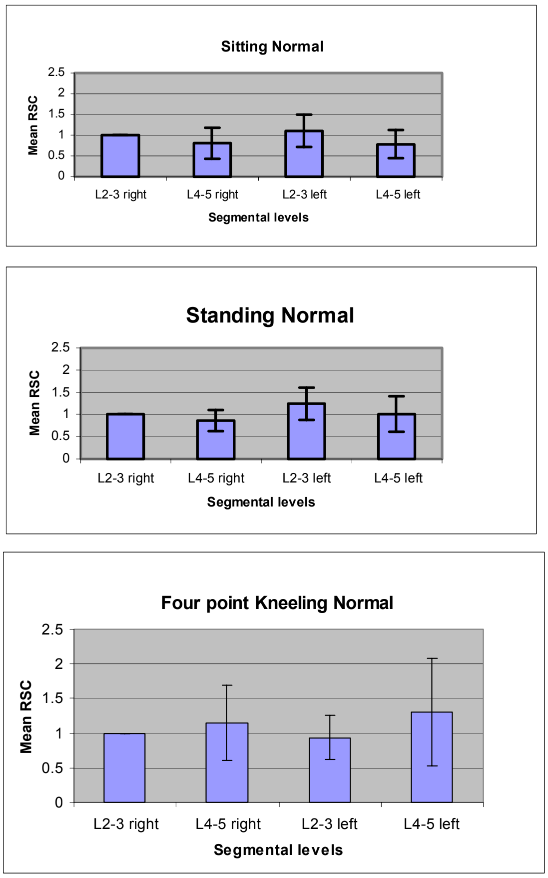

Figure 2: Bar graphs of Mean RSC vs. segmental levels for each static posture.

The values in column $Ch3$ and $Ch4$ provides the error caused by left L2-3 multifidus and left L4-5 multifidus in modelling the equation respectively. The P values given in Table 1 for each posture represents the statistical significance of the predicted value of right L4-5 multifidus activity, given the left L2-3 multifidus, left L4-5 multifidus and right L2-3 multifidus. The mean RSC and the deviation in error are observed from Figure 2. This illustrates the level of activity at different vertebral levels for a given posture.

5. Discussions

The strength (magnitude) of each segmental level can be observed from the graphs and the hierarchy of muscle activity from high to low is determined by the mean RSC of each segmental level for a given posture. Inspection of the mean RSC in Figure 2 shows the extent of exertion (or extent of contraction) for the multifidi muscles at different segmental levels for the static postures we examined.

From the results of regression analysis, it is observed that the relationship between segmental level muscles for sitting and standing postures is stronger while this relationship is weak for kneeling. The average error rate observed from Table 1 shows that the relationship between segmental muscles is strongest for predicting the sitting posture. This suggests that normal human subjects have well defined muscle contraction behaviour pattern for the muscles of the lumbar back for the postures they are familiar with such as sitting and standing, while the muscle contraction pattern for postures they are not familiar with is weaker.

6. Conclusion

In conclusion it is clear that the MRA has an application in assessment of postures based on lumbar multifidus activity, although some models should not be used without a good clinical understanding. In particular extreme caution has to be taken while dealing with four point kneeling postures because of unstable muscle activity. This model will form a ground basis for analysing of Low Back Pain (LBP) caused by multifidus muscles due to different postures and also provide insight about the functionality of the muscles during different daily activities in normal healthy subjects.

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