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Study of Surface Electromyographic Changes in Paraspinal Muscles Following Spinal Muscle Strengthening Exercises in Non-Specific Chronic Low Back Pain Patients

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Abstract

Chronic low back pain (CLBP) is one of the most common cause of discomfort and demoralizing health problems disabling mostly individuals with age less than 45 years of age. Dysfunction of the erector spinae is one of the most common causes of CLBP. The aim and objective was to study the changes in surface electromyographic (SEMG) signals in paraspinal muscles (erector spinae) of patients with non-specific chronic low back pain before and after undergoing exercise therapy. TECA pre-jelled, disposable, self-adhesive 1 cm silver chloride bar surface electrode were attached to the skin overlying the erector spinae at T7, L2-3 and L4 vertebrae unilaterally on right side with a reference electrode over the right deltoid and SEMG signals were recorded in synergy mobile multimedia EMG and the turns and amplitude of the interference pattern were analyzed before and after undergoing strengthening exercise program. Pain status of the patients was also analyzed by using visual analogue scale and Quebec back pain disability scale (QBPDS).

Sixty patients with CLBP (44 male and 16 female, mean age 38.6+ 6.8) were studied. There were significant changes in the parameters i.e. amplitude and density, of the IP at L2-3, L4 and amplitude of T7 except in density of T7 after therapy. Change in amplitude and density (Increase in amplitude and respective reduction in density) was consistent with the significant reduction of pain shown by change in VAS and significant reduction in disability shown by QBPDS.

Conclusions of the study were (1) erector spinae muscle dysfunction could be one of the most predominant factors in developing nonspecific chronic low back pain. (2) Analysis of interference pattern by using noninvasive SEMG technique could be a useful noninvasive instrument to measure the increase in strength of muscles after exercise. (3) Best exercise in non-specific CLBP might be by using both flexion and extension program.

Introduction

Low back pain (LBP) is one of the most frequent musculoskeletal problem and is a major source of discomfort and demoralizing health problem causing disability in individuals less than 45 years of age, who are in economically most productive age group, giving indirect impact on the national economy.[1,2] Although rarely threatens life, it is extremely disabling, more so in ambulatory patients.[3] Pain is a very subjective personal experience and the presentation of LBP differs from individual to individual and it includes pain, ache, stiffness and fatigue localized in the lower back[4].

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Epidemiological studies from all over the world has demonstrated the enormous societal impact of the low back disorders that caused worker absenteeism.[5,6,7,8,9] At least 75% of all people would at some time of life, have LBP and about 30% of adult population has a back problem on any given date.[10] The cause of LBP is difficult to discern and specific lesion is found in only 10 to 20 percent of persons with acute LBP.[11] Therefore, the majority of patients presenting with LBP can be classified as non-specific.

Complimentary studies has documented compromised lumbar muscle function or weaker trunk muscle strength in patients with chronic low back pain (CLBP) than the normal population, [12,13,14,15,16] There are about 500 hypotheses of origin of CLBP but one of the most significant causes is dysfunction of erector spinae.[2] Electromyography (EMG) has been in use for long to study the electrophysiological properties of nerves and muscles. Since the introduction of Willison's[17] quantitative method of turns and amplitude analysis of interference pattern, many workers had investigated, modified and extended it.[18,19] Many different researchers had used the interference pattern analysis of EMG and an excellent review by Fuglsang-Frederiksen Andres[20] summarized these studies. These methods used the concentric needle electrodes to obtain the EMG data from the muscles tested.

Surface electromyography (SEMG) has been suggested as an objective, noninvasive method of testing and analyzing the degree of muscular activity and function.[21,22,23,24]

Materials and Methods

60 patients (44 male and 16 female) in the age group 30 to 60 years who had been suffering from non-specific low back pain for at least 6 months, who were symptomatic at that time of presentation and who were able to understand and perform the prescribed exercises independently were included in the study.

Using visual analogue (VAS) scale of 0 to 10 cm, and Quebec back pain disability scale (QBPDS), the intensity of pain was assessed initially. Patients were explained about the procedure. Temperature of room was maintained to be comfortably warm. Patients were put in prone position on an examination couch with lower body from the superior border of the iliac crest downwards strapped to the couch (Fig.1). Skin was properly prepared and TECA pre-jelled, disposable, self-adhesive 1 cm silver chloride bar surface electrode were applied unilaterally at three different levels on the right side 3-4 cm away from the midline, one at a time. First was applied at the level of T7 spine, second, between L2 and L3 spine and third, at the level of L4 spine with a reference electrode over right deltoid and ground electrode on left arm. Patients were asked to touch their ears with the hands, elbows out to the sides and level with the trunk and the hands in neutral position. Then they were asked to maintain the unsupported upper part of the body in a horizontal position for two seconds. Patients were made to understand what exactly would be doing by practicing the above-mentioned position 2/3 times before recording the signals and were also constrained to produce the same amount of mechanical (effort) output at each test to eliminate the effect of motivation or producing inconsistent maximal effort.

SEMG signals were recorded from the respective sites while patient was maintaining the horizontal position for 2 sec. Three recordings were taken from each site with a rest period of 2 minutes between each recording in order to avoid the effect of fatigue, and the signals were saved in the synergy mobile for later analysis and comparison.

The filter setting used was 3Hz for the high pass filter and 10 kHz for the low pass filter. The sweep setting was 100 msec per division and sensitivity was 500µV per division.

Data collection

The signals were digitized in a 16-bit AD converter. A turn was indicated when the amplitude of the previous turn and the next peak was more than 100 µV. The amplitude was measured between two accepted turns. Density i.e. the turns per unit time, and amplitude were analyzed on line. Each parameter was taken three times from each of the respective sites and their arithmetic mean was taken for comparison with the signal readings after therapy.

Intervention:
Exercise and back care in ADL

Back strengthening exercises were demonstrated to the patients to do at home. They were asked to do each set of exercise 15 repetitions twice daily for at least 5 days in a week with back care measures. They were emphasized the importance of doing regular exercise as advised and a diagram showing all the exercises and back care measures were provided to each patient. Non-steroidal anti-inflammatory medication, diclofenac sodium 50 mg (Voveran) was given when there was acute exacerbation of pain that could dispel or hindered the patient from doing exercises, for a short period of time. After initial assessment patients were followed up for every 2 wks i.e. on second, fourth and sixth weeks on OPD basis and the VAS (visual analog scale) and QBPDS (Quebec back pain disability score) were recorded on each visit.

Table 1: Descriptive statistics of changes in the parameters of SEMG (Surface electromyography), VAS score and QBPDS score before and after therapy

SEMG Parameters	Before therapy				After therapy				p-Value n=60
	Mini-mum	Maxi-mum	Mean	S.D.	Mini-mum	Maxi-mum	Mean	S.D.	
Density T7	44.0	145.0	84.9	17.7	51.0	132.0	82.3	18.6	.236
Amplitude-T7	327.2	1158	636.6	202.0	314.3	1278	700	224.5	.006
Density L2	73.3	160.0	104.2	19.6	59.9	154.0	97.9	19.4	.001
Amplitude-L2	345.6	1006	600.2	187.3	402.0	1392	678.8	237.7	.000
Density L4	65.0	145.0	108.9	16.9	60.0	158.3	97.8	18.8	.000
Amplitude-L4	330.8	1239	631.4	214.1	374.7	1363	738.3	267.5	.000
VAS	2	9	5.08	1.3	0	7	2.8	1.8	.000
QBPDS	7.4	50.6	27.9	11.3	2	44.2	18.6	11.4	.000

Statistics

All SEMG (surface electromyography) parameters, VAS score, QBPDS score descriptive statistics were worked out in terms of mean, standard deviation, minimum and maximum value. To see the association between qualitative variables Chi-square test/ Fisher's exact test was carried out. To compare the changes in levels of various SEMG quantitative variables (density T7, amplitude T7, density L2, amplitude L2, density L4, amplitude L4) after therapy in comparison to pre-therapy, paired t-test was used. Changes in these variables including those in VAS and QBPDS were used to work out correlation coefficient between them. Differential comparison of changes in each of the SEMG variables including VAS score and QBPDS score was carried out in relation to sex, age, height and BMI using appropriate statistical methodologies like unpaired t-test/ Wilcoxon rank sum test or one way analysis of variance/ Cruskal Walli's test etc. In case of significant results under analysis of variance/ Cruskal Walli's test, multiple comparison tests were carried out to identify the pairs of groups having significantly different results. To compare the use of analgesics before and after intervention, Mc Nemar test was used. The result was considered significant at 5% level of significance.

Results

The change in interference pattern (increased in amplitude and reduction in density) recorded by SEMG technique from the paraspinal muscles after therapy was significant and this could objectively demonstrate the increase in strength of the muscle and clinical improvement of symptoms in nonspecific CLBP. The correlation between this change and change in score of VAS and QBPDS and reduction in the requirement of analgesic medication at the end of the study showed the overall improvement and utility of SEMG in the assessment of non-specific CLBP after exercise and rehabilitation.

Discussion

Low back pain is still a major health problem not only in developed countries but also in developing countries like India. There were cases of back pain associated with organic diseases, which were excluded from the study, many of the cases were without any demonstrable or detectable cause thereby categorizing them as nonspecific after thorough examination and investigation, and almost all of them were suffering chronically for a long time.

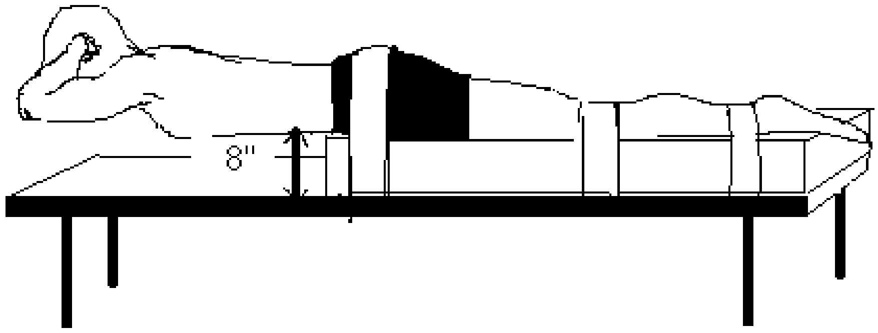

Fig. 1 Patients lower body strapped and maintaining a horizontal position

The simple low back pain also known as nonspecific low back pain or mechanical LBP is of musculoskeletal origin in which symptoms vary with physical activity. There is little correlation between the anatomic identification of pain "generators", clinical syndromes or actual pathology.[25] Muscle weakness is one of the most important causes of chronic low back pain[12,13,14,15,16] with erector spinae muscle being the most concerned one. Erector spinae muscle contracts eccentrically in flexion activities as decelerating muscle. When done excessively and repeatedly, fatigue results. With the weakened muscle, the other structures of the functional unit of spine the disc especially are exposed to excessive and inappropriate stress.

The duration and amplitude of the MUP (motor unit potential) reflex the number and density of muscle fibers comprising the motor unit. At maximum contraction, many motor units begin to fire rapidly. The simultaneous activation of these different motor units precludes recognition of individual motor unit potentials. Thus it produces a dense pattern of multiple superimposed potentials known as interference pattern (IP). A number of factors determine the spike density and average amplitude of the summated response. These include:

- Descending inputs from the cortex
- Number of motor neurons capable of discharging
- Firing frequency of each motor unit
- Waveform of individual motor potentials and
- Probability of phase cancellation.

Despite such complexity, its (IP) analysis provides a simple quantitative means of evaluating the relationship between the number of firing units and the muscle force exerted with maximal effort.[26] It mainly gives information about the number and size of MUPs at higher force level.

Different methods have been established to analyze the IP[17,19,27] such as integrated EMG, frequency spectrum, turns and amplitude (Willison) technique, experts quantitative IP (Equip) analysis. The essential features in all these are use of needle electrodes. Surface EMG has been suggested to be a useful method for diagnosis and assessment.[2,22,28,29,30,31,32,33] For global assessment of interference pattern mean amplitude and mean density is used.[34] Collecting myoelectric signals using surface electrodes is not technically difficult but has been poorly investigated. On the other hand SEMG is not without drawbacks. Signal degradation due to subcutaneous fat is an important theoretical point[31] and some parameters like insertional activities cannot be studied. Also spatial summation resulting from the gap between electrode and signal source leads to phase interference and cancellation at the electrode and consequent lowering of the frequency content.[35]

In this study we used SEMG technique and studied the IP in CLBP patients recording the mean density and mean amplitude and compared the result before and after giving therapy for LBP (exercises and back care). To study IP, the patient has to perform maximal contraction of the muscle; In the original Willison's technique,[17] he used a standard 5 kg, without regard to the force exerted during a maximum voluntary effort. Fuglsang-Frederiksen A and Manson[36] found the best diagnostic yield by using a relative force 30% of maximum. Arnall FA and Koumantakis GA[37] suggested that at 50% maximal voluntary contraction all the parameters were acceptably reliable in functional testing of the paraspinal muscles; here we are comparing the myoelectric signals collected while the patient performs an isometric contraction of the paraspinal muscles while maintaining the unsupported part of upper body in horizontal position, before and after therapeutic exercises. All the patients were constrained to produce the same amount of mechanical effort at each test to eliminate effects of motivation or inconsistent maximal effort as far as possible.

On paired t test there were significant changes in the parameters i.e. amplitude and density, of the IP at L2-3 and L4 ($p=0.001$ and 0.000) and amplitude of T7 ($p=0.006$) except in density of T7 ($p= 0.236$) after therapy (Table 1). Change in amplitude and density (Increase in amplitude and respective reduction in density) was consistent with the significant reduction of pain shown by change in VAS ($p=.000$) and significant reduction in disability shown by QBPDS ($p=0.000$). Regarding use of analgesics during the study period, there was significant reduction in the use of analgesics at the end of the study, 80% of the patients had stopped or needed rarely. But 20% of the patients still needed the medication.

Density indicates the number of motor units and their frequency of recruitment. High frequency or rapid recruitment i.e. increase in mean density is typical of weak muscles and less dense pattern may occur with a loss of motor unit, poor effort, UMN lesion or a strong muscle.[34] When the muscles are weak many motor units are recruited on contraction to perform certain amount of work (in this study the work done was to maintain the unsupported upper part of the body in the horizontal position) and it was shown by the increased density in the SEMG signals. When muscles become stronger, less motor units were recruited to do the same amount of work and this was evidenced by the reduction in density of recruitment pattern.

Exercise increases the strength of muscles is a well known fact.[38,39,40] In this study after exercise, prescribing both spinal flexor muscle strengthening and extension exercises, giving more emphasis on extension exercises therapy there was significant reduction in density of the IP. This could probably be correlated with the increase in the strength of the muscle

On the other hand, amplitude reflexes the density of muscle fibers within the MU territory, their diameter, and synchrony of their contraction[34]. Our finding in the present study demonstrated that there was significant changes in the amplitudes i.e. increased amplitude at different levels of erector spinae muscle (p =0.000). Amplitude tends to increase linearly with the force.[36] This could be correlated that in a patient with CLBP there was drop in the number of muscle fibers, smaller muscle fibers, lower synchronicity (Przemyslaw L)[2] in contraction which after exercise and rehabilitation program there was increase in the size of muscle fibers and there was higher synchronicity of the muscle fibers in contraction i.e. while doing the same amount of work done before therapy.

The probable explanation of some difference in results (Table: 1) in different levels viz. T7, L2-3 and L4 could be because of the difference in the distribution of two main sorts of fibers slow twitch type I fibers and fast twitch type fibers in these parts of the erector spinae.[41]

The diameter of slow twitch fiber is larger than that of fast twitch fibers. In the lumbar region, relative area of the muscle occupied by type I fiber is significantly greater than that in the thoracic region. The predominant activity of the muscle is generated by the slow twitch fibers in such kind of muscles (Przemyslaw L)[2] In concurrence to this Yettram AL et al[42] also demonstrated that the paraspinal muscles in the lower lumbar region contributed more force than muscles located at higher lumbar level while performing an activity.

There was still considerable debate in the literature regarding the relationship between pain, muscular function and EMG results,[43] in our study we found that improvement in the muscle function which was directly shown by the objective changes in the SEMG parameters has a very good linear relationship with the reduction of pain and disability shown by reduction in the scores of VAS and QBPDS. Besides, this also supported the previous investigations suggesting that SEMG is useful diagnostic and assessment tool in the assessment of CLBP.

Conclusions

From the above study it can be concluded that:

1. Erector spinae muscle weakness could be one of the most predominant factor in developing nonspecific chronic low back pain, or turning the acute low back pain to chronicity.
2. Surface electromyography (SEMG) could be a very useful technique for the assessment of treatment response in nonspecific chronic low back pain patients.
3. The analysis of interference pattern by using SEMG technique gives useful information about the changes in the muscle after undergoing strengthening exercise of the muscle. This could probably be reproducible if we control the force exerted and duration of contraction during which the signals were recorded. But it would need a multivariate discriminant statistical analysis for a more significant interpretation.
4. The actual association between pain, muscle strength/weakness and disability and their relation with the SEMG parameters could be established.
5. The best exercise for nonspecific CLBP might be by using both spinal flexion and extension exercises. But the exercise should be monitored in the initial period of therapy for an optimum level of performance without pain and gradually increasing the degree/intensity to a prescribed level. The basis for exercise regimen should be to strengthen and condition the weak muscles thereby stabilizing the spine.
6. SEMG technique is non-invasive, without the risk of infectious complications, technically easy to apply, more patient compliance, rapid assessment, better option for the application or assessment of paediatric patients who generally are reluctant to needles and definitely for patients with bleeding

disorders. With appropriate signal processing this may provide very useful information not only for assessing but also for diagnostic purposes of many neurological and musculoskeletal disorders.

Recommendations

1. Further study with a larger sample size of non-specific CLBP, undergoing muscle strengthening or rehabilitation program to see the difference in the SEMG signal changes among different groups of subjects following therapy is needed.
2. Comparative study may be done between EMG signal changes where changes in data collected by needle electrodes is compared with changes in data collected by surface electrodes
3. Further case control study with control patients of non-specific CLBP who are under treatment with modalities other than muscle strengthening or rehabilitation program and cases who are undergoing strengthening exercise and rehabilitation program, and blinded testing of paraspinal SEMG
4. Technological advances, which are available for automatic analysis of interference pattern with on-line results and statistical values, such as EMG Lab computer system, could be combined with more clinical research on the applicability of surface EMG.

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