Original Article

The investigation of median frequency changes in paraspinal muscles following fatigue

Saeed Talebian, PhD.; Hossein Bagheri, PhD.[1]
Tehran University of Medical Sciences and Health Services, Tehran
Majid Hosseini
Shahid Beheshti University, Rehabilitation Faculty, Tehran
Gholam Reza Olyaei, PhD.
Tehran University of Medical Sciences and Health Services, Tehran

Objectives: There are two sub systems of paraspinal muscles, the global-mobilizing system and the local stabilizing system. The multifidus muscles are assigned to the local system and stabilize the joints. In contrast, the longissimus muscles are assigned to the global system and force exertion. This study aimed to investigate the median frequency changes in mobilizing and stabilizing muscles following fatigue.

Method: A cross sectional study was designed. sEMG measurements were recorded from twenty participants following a fatigue protocol in B200 dynamometer. Participants performed dynamic trunk flexion-extension against a moderate resistance while standing in a static dynamometer until they could no longer performs the task because of fatigue.

Results: Statistical analyses showed significant differences between median frequencies pre and post fatigue ($p<0.05$). Median frequency of the right and left multifudus muscles reduced from "99.12 and 93.2" to "86.55 and 85.85" respectively. Also Median frequency of the right and left longissimus reduced from "76.54 and 76.82" to "66.43 and 68.55" respectively.

Conclusion: Median frequency shift toward low values following fatigue in global and local paraspinal muscles was seen. However, median frequency values for the local stabilizer muscle were higher than median frequency values for the global muscles.

Key words: median frequency, electromyogrhphy, fatigue, multifidus, longissimus

Introduction

Following fatigue, motor control activates muscles in an inappropriate way. Improper muscular contractions and relaxations of the stabilizers may lead to injury. Understanding muscle activation patterns and muscle fatigue is necessary for prevention and rehabilitation of low back pain (1). Low back pain is (LBP) is one the most common types of musculoskeletal pain (2). Also many investigators have reported alterations in motor control in low back pain patients (3). Motor control is very important in the management of musculoskeletal dysfunctions even in patients with an intact CNS (4). Fatigue includes processes at all levels of the motor pathway between the brain and the muscle(5). Several mechanisms, ranging from the accumulation of metabolites within muscle fibers to the production of an inadequate motor command in the motor cortex, contribute to fatigue (6). Muscle fatigue is the inability of the muscle to apply the required force (1). Fatigue may affect CNS control in muscle activation(7). Chronic low back pain patients often suffer from Back muscle impairments (weakness, fatigability).Therefore in many researches back muscle impairments were investigated through the power spectral analysis of the EMG signals. Fatigue is accompanied by changes in muscle electrical activity. Piper was the first who noticed frequency reduction in sEMG following fatigue (8). sEMG is an invasive method that may detect these electrical changes and provide some information about the muscle function and motor control (9). sEMG is able to detect muscle fatigue since the very beginning of a muscle effort although in absence of

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mechanical manifestations of fatigue (10). In sEMG-based studies about muscle fatigue spectral analysis has been used widely to monitor muscle fatigue. Fatigue causes a decrease of the frequency content of the sEMG signal usually described as a decline of the mean or median frequency of the power spectrum (2). Median frequency is the frequency that divides the spectrum into two halves of equal power (11). The purpose of this study was to investigate median frequency changes in local and global paraspinal muscles following fatigue. An increased fatigability of paraspinals is associated with the presence of low back pain (12).

Method

Participants - Twenty healthy male participants volunteered to participate in this study their mean (SD) anthropometric characteristics were age 27.9(3.28) year, height 174 (5.6) cm, body mass 72.3 (6.7) kg and body mass index 25.2 (2.4) kg/m^2. The inclusion criteria specified male adults at least 20 years old and body mass index less than $28kg/m^2$. Exclusion criteria included a history of previous back surgery, neurologic deficit, malignancy, diabetes, symptoms of vertigo, pain in lower limb (hip, knee, ankle), scoliosis with curvature more than 15°, leg length discrepancy(> 1.5cm). All participants gave informed consent to participate in the study, as approved by the ethical committee of Tehran University of Medical Sciences.

Instrumentation - This study performed with these devices: 1) Electromyography device 2) Isoinertial dynamometer

Electromyography - Surface EMG (sEMG) device were used to detect muscle activities. Back muscle activities were recorded using an eight-channel portable surface electromyography (sEMG) data logger (Type NO.P3X8, DataLog, Biometrics Ltd, Cwmfelinfach, Gwent, UK). The EMG signals were recorded with four pre-amplified bipolar active electrodes (Type NO.SX-230, Biometrics Ltd, Cwmfelinfach, Gwent, UK) with a fixed center to center inter electrode distance of 20 mm, with a 10-mm recording diameter, built-in differential amplifier with a gain of 1000, input impedance of 10^{15} ohms, a common-mode rejection ratio of 110 dB at 60 Hz, bandwidth of 25-450 Hz, and sampling frequency of 1kHz. Channel sensivity was 3microvolts. Reference electrode was placed on the left wrist. Signals were digitally recorded by the data loggers on 256 MB flash memory.

Isostation Dynamometer - B200 Isostation, (Isotechnologies Inc., Hillsborough, N.C.), is a triaxial trunk dynamometer that measures torque, range of motion and velocity in three plans. The subject was stand in standing position in B200 Isostation, with the lumbosacral junction aligned with flexion/extension axis of the machine. The subject was firmly restrained using the straps and pads provided, according to the instructions recommended by the manufacturer. B200 dynamometer was used for fatigue protocol. Fatigue assessment with a dynamic protocol is likely to be more relevant to daily function (13).

Procedures - After explaining the experimental protocol and signing of the informed consent, each subject was investigated in 2 sessions. It was tried to put all sessions at the same hour of day to control the effect of circadian rhythms on muscles (12, 14). At the first session participants became familiar with maximal voluntary contractions (MVC) and fatigue protocol. Each subject performed some simple exercises and then was placed in B200 isostation in such a way that L5/S1 is at the level of flexion-extension axis. Then subject was fixed by straps at the level of his ankles, knees, hips, iliac crests, and shoulders. The subject exerted his force during flexion-extension against a pad in front of his chest (for flexion) and a pad in the back against upper thoracic vertebrae, at the T4 level (for extension). Maximum voluntary contraction (MVC) was obtained for back extensors. Participants performed isometric back extension 3 times. Each contraction lasted 10 seconds with 1 minute interval, the maximum value was considered as MVC. Then the subject rested for 3 minutes. Finally the subject was asked to do dynamic trunk flexion-extension against 50% of his MVC in order to get familiar with the procedures for the next.

There was no EMG recording at the first session. At the next session- three days later-, four pre-amplified active surface electrodes were placed on the skin. Skin preparation was done if necessary, using light skin abrasion and cleansing with alcohol. Electrodes were positioned parallel to muscle fiber direction. The electrodes were positioned bilaterally on the multifidus at the level of iliac crest (L_5) 3 cm from the midline of the back and oriented parallel to the muscle fibers. Electrodes were aligned with the line connecting L_1 and the spinae cristiaca posterior superior (3,1,15). For the longissimuss muscles, electrodes were placed 3 cm lateral to the vertebral column at the level of L_1 (14,16). A reference electrode was placed on the left wrist. Then the

subject was stabilized in the static dynamometer.
Surface EMG signals were recorded from muscles while the participants performed the fatigue protocol. Ten seconds were initially allowed to pass while the participants stood motionless without any contraction to ensure a stable EMG baseline (12). The protocol consisted of three static maximal voluntary contractions of back extensors. Each contraction lasted 10 seconds and separated by a 60 s rest period. The best of the three contractions was kept as the MVC. Each subject rested 3 minutes before starting the dynamic fatigue protocol. Then they performed repeated dynamic trunk flexion-extension at their self-selected speed (17) against 50% of MVC in standing position in B200 trunk dynamometer as a fatiguing protocol until they were not able to do the next three repetitions (14) or feel intolerable discomfort (18). Participants were not allowed to take a rest during trunk flexion-extension to prevent recovery, especially for the high capillarized back muscles (14). During the MVCs and fatigue protocol, each subject was encouraged verbally in order to do their best. Median frequencies were computed from the EMG power spectra of each muscle during the first three and last three repetitions. A single examiner performed all experiments.

Results:

The SPSS (version 17) statistical software package was used for all analysis. Since all data were normally distributed (Kolmogrov- Smirnov test), paired t test was used to detect any significant differences between median frequencies pre and post fatigue (table 1). The level of significance for analysis was $p < 0.05$.

Table 1: Median frequency before and after fatigue

	Before fatigue		After fatigue		Sig.
	Mean	Std.Deviation	Mean	Std.Deviation	
Med.fre.Multi.R	99.12	24.12	86.55	25.63	.001*
Med.fre.Multi.L	93.02	20.86	85.85	18.14	.002*
Med.fre. Long.R	76.54	18.08	66.43	16.87	.009*
Med.fre. Long.L	76.82	17.96	68.55	16.69	.004*

Med frq= median frequency, multi=multifidus muscle, long= longissimus muscle, R=right, L=left
P<0.05 was significant

As table 1 indicates, following fatigue protocol median frequency in all muscles reduced. There were significant differences between median frequency of all muscles pre-post fatigue (p<0.05).

Also there were significant differences between median frequencies of multifidus and longissimus muscles pre-post fatigue (p<0.05).
On the other hand, the values of median frequency in the multifidus muscles were higher than the values of median frequency in the longissimus muscles- pre and post fatigue.

Discussion:

Despite the fact that fatigue is an experience of our daily living life, its definition is very complex. During muscle contraction, even in absence of mechanical manifestation of fatigue, many modifications in surface EMG signal occur which is called myoelectric manifestation of fatigue. Therefore, fatigue can be assessed since the very beginning of a muscle effort.
This study showed that fatigue protocol was successful to fatigue paraspinal muscles. Also median frequency shift toward lower values was seen in the multifidus and longissimus muscles. However, the differences in the frequency content of the spectra of the multifidus and longissimus muscle were notable. The frequency spectrum of the multifidus muscles was higher than the frequency spectrum of the longissimus muscles. It seems that because of the muscle fiber distribution in the multifidus muscle and its location, the multifidus should have revealed lower frequency spectrum. The multifidus muscle contains much more type I fiber (slow) than the longissimus muscle. The Longissimus muscle contains more type II muscle fiber (fast). Recruitments of type II motor units can raise the median frequency value because of their higher muscle cross-sectional area and greater rates of depolarization-repolarization (19).
In addition, the multifidus muscle is located deeper than the longissimus muscle. On the other hand, more tissue layers cover the multifidus muscle, which means stronger filtering effects of the surface electromyography can be expected. In contrast to this, the median frequency values of the multifidus muscle were higher than those of the longissimus muscles. One explanation for this result can be the muscle structure. The multifidus muscle has large cross-sectional area and short fiber length. This architectural design is best suited for muscles that provide inherent stability rather than motion.
The longissimus muscle is a global mover while the multifidus muscle is a local stabilizer. In case of any disturbances, a quickly changing activation of small motor units is necessary to hold the equilibrium.

This quick change of activation may produce higher frequencies in the surface electromyography spectrum. Thus, the role of the lumbar multifidus muscle may be to limit excessive motion across individual motion segments (disk and facets) and thereby balances the loads across the spine. In contrast, force exertion and mobilizing tasks needs the co activation of more motor units which leads to lower frequency values in the surface electromyography signal (20). Also findings of other authors are in agreement with the finding of present study (1, 21).

In this study, a dynamic fatigue protocol was used because in daily living activities muscles usually use intermittent contractions at low to moderate level of strength (12, 14). Myoelectric manifestations of fatigue are induced by two physiological factors: the slowing of motor unit action potentials and the synchronization of motor units. The reduction of muscle fiber conduction velocity reflects in the frequency domain as a scaling of the power density function of the EMG signal towards lower frequencies (10).

A method of signal processing which is often used to reveal changes in the electromyographic signal resulting from muscle fatigue is to analyze the frequency spectrum of the signal. With localized muscle fatigue high frequency values shift toward low frequency values. Median frequency is the frequency that divides the frequency spectrum into two parts of equal areas.

Fatigue assessment should be included in rehabilitation protocols. EMG-fatigue analysis has been used in physical rehabilitation, diagnosis of muscle impairment and prediction of functional and endurance deficits. One of the advantages to use median frequency shift to determine muscle fatigue rather than mechanical indices is that spectral electromyographic indices change continuously from the initiation of the contractions. By investigating the frequency shifts of muscles during treatment, a therapist can determine if the muscle is being sufficiently exercised. If median frequency shift toward lower values does not occur over time it may be concluded that other muscles such as synergists were recruited.

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