SPECTRAL CHARACTERISTICS OF THE ELECTROMYOGRAPHIC SIGNAL TO ASSESS THE QUALITY OF THERAPY AND REHABILITATION IN PATIENTS WITH LOW BACK PAIN

Zhemchuzhkina Tatyana, candidate of technical sciences, associate professor of Biomedical Engineering Department 
Kharkiv National University of Radio Electronics, Ukraine
Kurochkin Ivan, postgraduate student of Biomedical Engineering Department 
Kharkiv National University of Radio Electronics, Ukraine

Summary. Disorders and diseases of the musculoskeletal system are the most important factor in the global need for rehabilitation services. Low back pain is the leading cause of the global burden of musculoskeletal disease. Objectification of the assessment of the state of the musculoskeletal system can help in diagnosing and differentiating the patient’s conditions, assessing the quality of therapy and rehabilitation. This work is devoted to the analysis of quantitative criteria for assessing the state of the musculoskeletal system according to objective data of electromyographic research.

Keywords: diagnostics, electromyography, informative feature, low back pain, rehabilitation, spectral analysis, statistics.

Relevance of Low Back Pain Problem
Data from the recent 2019 Global Burden of Disease (GBD) study [1] suggests that about 1.71 billion people worldwide are living with musculoskeletal conditions that include low back pain, neck pain, fractures, other injuries, osteoarthritis, amputation and rheumatoid arthritis. Although the prevalence of musculoskeletal disorders varies with age and diagnosis, they affect people of all ages throughout the world. High-income countries are the hardest hit in terms of the number of people (441 million people), followed by those in the Western Pacific Region (427 million people) and the Southeast Asia Region (369 million people). Musculoskeletal disorders are also the largest contributor to years of living with a disability (YLD) worldwide, with approximately 149 million YLDs, representing 17% of all YLDs worldwide.

Disorders and diseases of the musculoskeletal system are the leading cause of disability worldwide, and lumbago (pain in the lumbar region of the spine) remains
the leading cause of disability among these diseases in 160 countries. Due to population growth and aging, the number of people with disorders and diseases of the musculoskeletal system is rapidly increasing.

Disorders and diseases of the musculoskeletal system significantly limit mobility and motor skills, leading to premature termination of employment, reduced levels of well-being and reduced opportunities for participation in society.

Low back pain is the leading cause of the global burden of musculoskeletal disease (570 million cases worldwide, representing 7.41% of global years lived with disability (YLDs) with an annual increase 0.053%).

In Ukraine, YLDs caused by LBP are 11.13%, which is 1.5 times more than in the world, and its annual change is 0.43%, which is 8 times higher than the global annual change of this indicator.

In addition, disorders and diseases of the musculoskeletal system are the most important factor in the global need for rehabilitation services. They are among the main reasons for the demand for such services for children, and about two thirds of the adult population in need of rehabilitation services are people suffering from disorders and diseases of the musculoskeletal system.

According to WHO data, among all categories of diseases requiring rehabilitation, about 2% of those aged 5-9 years and about 80% of those aged over 95 years need rehabilitation because of musculoskeletal diseases. Among musculoskeletal diseases, as the reasons for the need for rehabilitation, low back pain is from 2% for 10-14 years ages with a constant increase to 20% for the 75 years aged in the world, and in Ukraine from 3.7% for 10-14 years aged up to 32% for 80 years aged, totaling 5.8 million people in 2019 in need of rehabilitation due to lower back pain.

The WHO Rehabilitation 2030 Initiative, launched in 2017, draws attention to the acute unmet need for rehabilitation worldwide and highlights the importance of strengthening health systems to ensure rehabilitation. The initiative is a call to action that brings together stakeholders for concerted and coordinated global action to scale up rehabilitation. To achieve this, 10 priority areas of action were identified, including, among others, the need to improve health information systems, including rehabilitation data, as well as building research capacity and increasing the availability of reliable data for rehabilitation.

Objectification of the assessment of the state of the musculoskeletal system can help in diagnosing and differentiating the patient’s conditions, assessing the quality of therapy and rehabilitation. This requires finding quantitative criteria for assessing the state of the musculoskeletal system according to objective data from medical research. The results of electromyographic research can serve as such objective data.

Electromyographic method of medical research

Surface EMG is a non-invasive research method that allows assessing the total bioelectrical activity of muscles at rest and under various stress modes. With this technique, the electrodes are located on the surface of the skin above the motor points of the muscles, which ensures the registration of the total activity of the functioning motor units.

When using skin derivation of an electromyographic signal, some pathological forms of electrical muscle activity can be detected: fasciculations, sparsification, increased muscle tone, etc.
Fasciculations or muscle twitches, which are caused by the excitation of a group of muscle fibers. They are recorded as spontaneous potential fluctuations, similar to the action potentials of motor units (in contrast to fibrillations, which are the excitation of a separate muscle fiber and are accompanied by the registration of short fibrillation potentials). Fasciculations can take the form of single pulses or a series of rare needle-like oscillations with frequency 5-20 pulses per second, the amplitude is 100-300 μV or higher. They are characteristic of anterior horn lesions of the spinal cord (amyotrophic lateral sclerosis, neural amyotrophy, syringomyelia, spinal tumors, etc.).

In the case of paresis caused by damage to motor neurons, EMG recorded from an arbitrarily tense muscle is sparsed to varying degrees; at extreme degrees of sparsification, EMG has a "palisade" shape. The second factor that plays a significant role in the formation of sparsed EMG is the simultaneous excitation of a large number of muscle fibers. This may be due, on the one hand, to the formation of large motor units as a result of compensatory reinnervation of the fibers of dead motor units by intact axons, and on the other hand, to the synchronous discharge of functioning motor neurons, which is very characteristic for anterior horn lesions.

An increase in muscle tone, which manifests itself in the appearance of a pronounced electrical activity of the muscle in a state of its arbitrary relaxation, is observed in a number of diseases of the nervous system. An increase in tonic electrical activity is a typical electromyographic manifestation of spasticity in patients with pyramidal lesions. Electrical activity with a synergistic increase in tone can have an amplitude 250 μV or higher. An increase in tonic electrical activity is also observed in the rigidity characteristic of Parkinson's syndrome. In this case, the increase in resting electrical activity is mostly in the form of a tremor. Increased, compared with the norm, the electrical activity of "rest" can be observed in the absence of specific violations of tone as a result of pain, emotional arousal, as well as in patients with neuroses. Irregular bursts of activity of varying duration are observed on the EMG of various muscles in the cases of chorea, athetosis, etc. Such EMG reflects the prevalence and passivity of hyperkinesis, the features of coordination reflections of different muscles in violent movements.

In pathological tremor, EMG has a characteristic intermittent form. Bursts of activity are interspersed with periods of inactivity with a frequency about 5-10 oscillations per 1 s. However, it must be taken into account that the electrical activity of an arbitrary voltage may have an intermittent form, similar to tremor EMG, due to muscle weakness of any origin [2].

According to classification proposed by Yu.S. Yusevich (1972), on the basis of three features (presence of activity, frequency of oscillations and shape of the pattern), four types of electromyograms are distinguished: type 1 – saturated, type 2a – palisade and 2b – sparsed, type 3 – bursting, type 4 – bioelectrical silence.

Type 1 includes saturated high-frequency asynchronous activity, which is recorded both in normal conditions and in pathology (suprasegmental type of lesion) during muscle activation and at rest (in pathology). The oscillation frequency is 60-100 Hz, the pattern is uniform. The formation of an electromyogram of this type is due to the presence of a sufficient number of motor units, which is associated with the absence of damage to the peripheral motor neuron.

Type 2 occurs when a small number of motor units are activated, which is usually associated with their damage. In some cases, with synergistic activation of
resting muscles, this type of electromyogram is observed in the norm. Therefore, the use of the term “anterocorneal type of lesion” is valid in the presence of a palisade form of EMG in the mode of maximum voluntary muscle tension. Type 2a includes a palisade EMG with a frequency to 20 Hz with a uniform pattern (type 2a); type 2b includes a sparsed EMG with a frequency from 21 Hz to 50 Hz with a uniform pattern.

Type 3 is characterized by burst activity with a frequency from 60 Hz to 100 Hz; associated with suprasegmental extrapyramidal lesions.

Type 4 is manifested by the absence of muscle bioelectrical activity both at rest and during synergistic, voluntary and involuntary activation. This type reflects muscle degeneration.

The pathology of the spinal roots, plexuses, and peripheral nerves changes EMG similar to the pattern of damage to the anterior horns of the spinal cord (low-amplitude saturated, sparsed, palisade). With primary muscle lesions, a decrease in the amplitude of the global electromyogram occurs without its structure violation, since the number of motor units remains unchanged, and their size decreases.

Hysterical paresis is not accompanied with qualitative changes in the electromyogram. To differentiate hysterical paresis from organic paresis, the EMG amplitude is compared with arbitrary tension and involuntary activation of the muscle during the performance of complex motor acts (turning over on the couch, walking, etc.); with movements that are not consciously controlled, the amplitude is several times higher than with voluntary muscle tension in patients with hysterical paresis [3].

In [4], [5], system that makes it possible to objectify the evaluation of the results of electromyography with parallel control of the level of pain and the degree of flexion of the back muscles to assess the degree of dysfunction of the back muscles and the quality of the performed therapeutic, surgical or rehabilitation activities was proposed. The system is an electromyographic complex for recording EMG in the “boat” position with control of the degree of flexion of the back muscles with an ultrasonic distance measurer with parallel EEG recording to control the level of pain during exercise and an audio signal to control the maintenance of tension in the back muscles as a percentage of the maximal tension.

**EMG signal processing**

Currently, various quantitative characteristics of the EMG signal have been proposed [6] – [9].

The most common method of EMG analysis is spectral analysis. Analysis of the frequencies of the electromyographic signal is preferable due to the large variability of its amplitude characteristics. The frequencies of the electromyographic signal are in the range to 400 Hz, and the predominance of certain frequencies is associated with the functional state of the muscle under study [10].

The spectral characteristics of EMG were studied in [11]. It was found that neither in groups of patients with degenerative diseases of the spine, nor in groups of practically and conditionally healthy volunteers, the spectral characteristics of men and women are not statistically significantly different, so, for spectral analysis EMG signals not need to be grouped by sex.

Groups of healthy persons with pain and patients with scoliosis differ by median and mean frequencies. Groups of patients with vertebrological diseases and patients with scoliosis differ by the median frequency parameter. Groups of healthy
persons and patients with vertebrological diseases differ by the parameters of the total power.

In [12], an analysis of the dynamics of spectral indicators for different groups of subjects was made and it was concluded that two spectral indicators (median frequency, lower frequency of the effective width of the occupied spectrum) can be useful.

In this work, we studied the following quantitative characteristics of the spectrum:
- median frequency ($\text{MedFreq}$) is the frequency which divides the power spectral density (PSD) into two equal by area parts;
- average frequency ($\text{MeanFreq}$) is the frequency at which PSD takes the average value;
- peak frequency ($\text{PeakFreq}$) is the frequency at which PSD takes the maximum value;
- average power ($\text{Power}$) is average signal power in a given frequency range (10 Hz – 500 Hz), estimated by applying the Hamming window and using a periodogram of the same length as the input vector;
- spectrum width ($\text{BW}$) is 99% occupied bandwidth of the signal spectrum, estimated from the power spectral density using a rectangular window; the bandwidth is computed from the frequency intercepts where the integrated power crosses 0.5% and 99.5% of the total power in the spectrum;
- lower frequency of the spectrum ($\text{Flo}$) is left frequency border of the occupied bandwidth of the signal spectrum;
- higher frequency of the spectrum ($\text{Fhi}$) is right border of the occupied bandwidth of the signal spectrum;
- average spectral power in the frequency band for 6 bands (<20 Hz, 20-60 Hz, 60-100 Hz, 100-150 Hz, 150-300 Hz, >300 Hz), selected according to Yusevich classification ($\text{Aver\_band\_PWR}$) is the average value of the power spectral density in a given frequency band;
- frequency band with the maximal average spectral power ($\text{BandMax}$).

**Experiments and results**

The research was carried out within the framework of cooperation between the Department of Biomedical Engineering of the Kharkiv National University of Radio Electronics and the Department of Pathophysiology and Functional Diagnosis of the Sytenko Institute of Spine and Joint Pathology of National Academy of Medical Sciences of Ukraine.

For electromyogram recording, surface electrodes were placed on the trunk extensor (m. Erector Spinae) 2-3 cm to the right and left of the midline of the back, at the level of the fifth lumbar vertebra (L5) of the human body. The recorded signal from the muscles was amplified and pre-filtered directly in the Neuro-EMG 4-channel computer electromyograph (Neurosoft), after which it was transferred to a personal computer for further processing and analysis [10]. All signals were filtered with a 10 Hz – 500 Hz Butterworth bandpass filter.

An analysis of the spectral parameters of the EMG signal without grouping by sex was carried out in five groups of subjects:
1. healthy volunteers without complaints of back pain (96 myograms);
2. conditionally healthy with complaints of back pain without identified organic pathology (dysfunctional pain) (45 myograms);
3. vertebrological patients with degenerative diseases of the spine (54 myograms);
4. patients with functional pain (235 myograms, including 103 after surgery);
5. patients with scoliosis (24 myograms).
Spectral features for greatest group 4 with functional pain which contains patients before and after surgery was analyzed on the difference between subgroups before and after surgery.

Summary statistics for all calculated spectral characteristics for 5 groups (without myograms after surgery) and for group 4 before and after surgery is shown in fig. 1 and fig. 2 in the form of box plots showing the median, lower and upper quartiles, minimum and maximum values, and outliers. Neighboring boxes allow to visually compare the distribution of features in groups. The confidence interval for medians is shown as a narrowing shaded area (notch). If notches of box plots do not overlap it means that groups have different medians at the 5% significance level.

Fig. 1. Box plots for spectral characteristics in 5 groups
As can be seen from the results of the statistical analysis (fig. 1), group 1 (without pain) is significantly different by median frequency with group 3 (vertebrological) and 5 (scoliosis) (in group 1 it's lower); by mean frequency with group 4 (functional pain) and 5 (scoliosis) (in group 1 it's higher than in group 4 and lower than in group 5); by peak frequency it's different with group 2 (dysfunctional pain) (in group 1 it's higher); by average power it's different with all groups except group 5 (in group 1 it's less than in group 2 and greater than in others); by bandwidth it's different with all groups except group 2 (in group 1 it's narrower than in groups 3 and 5 and wider than in group 4); by lower frequency of bandwidth it's different with group 4 (in group 1 it's higher); by higher frequency of bandwidth it's different with all groups (except group 2) (in group 1 it's higher); by average band power <20Hz it's different (in group 1 it's lower); by average band power 20-60Hz and 60-100Hz it's different with all groups except group 2 (in group 1 it's greater); by average band power 100-150Hz and 150-300Hz it's different with groups 2 and 4 (in group 1 it's less than in group 2 and greater than in group 4); by average band power >300Hz it's different with group 4 (in group 1 it's greater).

Group 2 (dysfunctional pain) is significantly different by median and mean frequencies with group 3 (vertebrological) and 5 (scoliosis) (in group 2 it's lower); by peak frequency it's different with all groups except group 4 (functional pain) (in group 2 it's lower); by average power it's different with all groups (in group 2 it's greater); by bandwidth it's different with groups 3 and 5 (in group 2 it's narrower); by lower frequency of bandwidth it's different with group 4 (in group 2 it's higher); by higher frequency of bandwidth it's different with all groups except group 2 (in group 2 it's higher); by average band power <20Hz it's different with group 2 (in group 1 it's less); by average band power 20-60Hz and 60-100Hz it's different with all groups except group 2 (in group 1 it's greater); by average band power 100-150Hz and 150-300Hz it's different with groups 2 and 4 (in group 1 it's less than in group 2 and greater than in group 4); by average band power >300Hz it's different with group 4 (in group 1 it's greater).

Group 3 (vertebrological) is significantly different with groups 1, 2, 4 by median frequency (in group 3 it's higher); by mean frequency it's different with groups 2 and 4 (in group 3 it's higher); by peak frequency it's different with group 2 (in group 3 it's higher); by average power it's different with groups 1 and 2 (in group 3 it's less); by bandwidth it's different with groups 1, 2 and 3 (in group 3 it's wider); by higher frequency of bandwidth it's different with all groups (in group 3 it's higher); by average band power <20Hz it's different with group 2 (in group 3 it's less); by average band power 20-60Hz and 60-100Hz it's different with groups 1 and 2 (in group 3 it's less); by average band power 100-150Hz group 3 differs from group 2 (in group 3 it's less); and by average band power 150-300Hz and >300Hz it's different with groups 2 and 4 (band power in group 3 is less than in group 2, but greater than in group 4).

Group 4 (functional pain) by median frequency is different with groups 3 and 5 (in group 4 it's lower); by mean frequency it is different with all groups, except group 2 (in group 4 it's lower); by average power it's different with groups 1 and 2 (in group 4 it's less); by bandwidth it's different with groups 1, 3 and 5 (in group 4 it's narrower); by lower frequency of bandwidth it's different with groups 1, 2 and 3 (in group 4 it's lower); by higher frequency of bandwidth it's different with all groups except group 2 (in group 4 it's lower); by average band power <20Hz it's different with group 2 (in group 4 it's less); by average band power 20-60Hz and 60-100Hz and 100-150Hz it's
different with groups 1 and 2 (in group 4 it's less); by average band power 150-300Hz and >300Hz it's different with groups 1, 2 and 3 (in group 4 it's less).

For group 5 (scoliosis) median, mean and peak frequencies have higher values than for other groups. Group 5 is significantly different by median frequency with all groups except group 3 (vertebrological); by mean frequency it's different with all groups and by peak frequency with group 2 (in group 5 median, mean and peak frequencies are higher); by average power it's different with group 2 (in group 5 it's less); by bandwidth it's different with all groups except group 3 (in group 5 it's wider); by higher frequency of bandwidth it's different with all groups (in group 5 it's higher); by average band power <20Hz it's different with group 2 (in group 5 it's less); by average band power 20-60Hz and 60-100Hz it's different with groups 1 and 2 (in group 5 it's less); by average band power 100-150Hz and 150-300Hz it's different with group 2 (in group 5 it's less).

Fig. 2. Box plots for spectral characteristics in group 4 before and after surgery
As we can see from fig. 2 median and mean frequencies and average band power >300Hz are significantly less after surgery.

Conclusions

Based on the results of the analysis, we can conclude that the most informative indicators for determining dysfunctional pain are the average power indicator over the entire spectral band and in three bands separately <20Hz, 100-150Hz, 150-300Hz. According to these indicators, this group differs both from healthy people without pain and from patients with other causes of pain. For dysfunctional pain spectral power indicators are greater than for other groups. By median, mean and peak frequencies, dysfunctional pain differs from pain in the presence of degenerative diseases of the spine, including scoliosis. These frequency indicators are less in the case of dysfunctional pain. These types of pain are also different by bandwidth, it is narrower for dysfunctional pain, due to the less lower frequency in dysfunctional pain in contrast to pain in diseases of the spine.

Functional pain (not vertebrological) can be differed from vertebrological (including scoliosis) by median and mean frequencies (they are higher in vertebrological pain); and by bandwidth (it’s wider in vertebrological pain due to higher frequency of bandwidth). Median and mean frequencies and average band power >300Hz get less after surgery in functional pain.

Quantitative spectral characteristics of EMG signals from patients with low back pain can serve both as quantitative characteristics for diagnosing a patient’s condition and as a quantitative expression for assessing the quality of performed therapeutic, surgical, or rehabilitation procedures; to assess the dynamics of the state of the patient’s neuromuscular system.

References:


