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Application of EMG-signal phase portraits for differentiation of musculoskeletal system diseases

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ABSTRACT

This article examines the dependence of the set of parameters of the phase portrait of an EMG signal on age, sex, and the diagnosis of the examined by methods of statistical analysis. the work is carried out on the basis of the results of the examination in four groups of patients: practically healthy without complaints; conditionally healthy with complaints of back pain; vertebral patients; patients with scoliosis. the studies were conducted in collaboration with the laboratory of pathophysiology of the Sitenko institute of spine and joint pathology Ukrainian academy of medical sciences. the study was performed with 102 people of both sexes aged 18 to 76 were examined. statistical processing of samples to identify statistically significant correlations of the parameters of the phase portrait of the EMG signal with the age and sex of the subject was conducted. statistically significant differences were not found. statistical processing of the sample to identify statistically significant correlations between the group to which the patient belongs, and each indicator of the phase portrait was conducted. the groups of practically healthy patients without complaints and conditionally healthy patients with complaints of back pain are not statistically significantly different for each parameter of the phase portrait. However, between patients without pathologies, vertebral patients and patients with scoliosis, a statistically significant difference was found for seven parameters of the phase portrait. The perspective of the work is the construction of models for classifying patients according to the parameters of phase portraits of surface electromyography data.

Keywords: muscle, statistics, phase portrait, electromyogram, ellipse

1. INTRODUCTION

The human musculoskeletal system is a complex consisting of bones, joints, ligaments, tendons and muscles that form the framework, making shape of the body, giving it support, ensuring the protection of internal organs and the ability to move in space. In this case, the bones and joints constitute the passive part of the musculoskeletal system, and the muscles able to contract and change the position of the bones in space are active [1].

Pathologies of the musculoskeletal system have a significant prevalence. According to the World Health Organization (WHO), almost 80% of the population suffers from various diseases of the musculoskeletal system. And the majority are of working age from 30 to 50 years. In various countries, the frequency of this pathology ranges from 69 to 3467 cases per 100,000 population per year. In Ukraine, the incidence rate is 3182 per 100,000 population [2]. Since many of the diseases of the musculoskeletal system occur chronically and often lead to a complete loss of working ability, their timely diagnosis and, if necessary, surgery [3] is one of the pressing issues of modern medicine.

Computer systems using specialized software significantly expand the diagnostic capabilities of modern medicine [4,5,6]. This also applies to electromyography – a method of studying the human musculoskeletal system through the registration of the electrical potentials of the muscles. Electromyographic studies allow not only to establish the nature of the disease, conduct its topical diagnosis, but also objectively monitor the effectiveness of treatment, predict the time and stages of recovery. Surface electromyography is safe and completely painless. In addition, it does not require sophisticated hardware, except for electrodes and a personal computer equipped with specialized software [6,14,15].

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The use of nonlinear dynamics methods is a promising way of creating new software for computer systems, which allows expanding the diagnostic capabilities of biomedical signal evaluation. The method of phase portraits is a significant addition to the traditional methods, which consider signals as linear stationary, and therefore do not provide an opportunity to trace in detail and characterize numerically the dynamics of changes in the signal structure over time. Therefore, the actual problem is to obtain informative parameters of the phase portrait of an electromyographic signal, which characterize the state of the muscular system in normal conditions and in the disease progression.

2. EXPERIMENTAL RESEARCH

Analysis of recent research and publications. Pain in the lumbar spine is a multifactorial problem, including pathoanatomical, neurophysiological, somatic and psychosocial aspects. A potential source of pain is the primary microdamage of an element of the vertebral motor segment (intervertebral disk, endplate or tendon), which produces microdamage to the ligamentous collagen structures and reflex excitability of the partitioned muscles, aimed at protecting the segment and, thus, accelerating reparative processes. At the same time, excessive stiffness of the partitioned muscles changes the level of stimulation of their muscle mechanoreceptors, which reduces the amplitude of muscle activation during free contraction. As a result, muscular dysfunction progresses, ultimately leading to a deterioration in the physical condition of the muscles, i.e., a decrease in their strength, endurance and impaired control of active movements with changes in the amplitude and frequency of muscle contraction [7,16,17].

Surface electromyography is relatively simple and inexpensive, but it is quite an effective method for diagnosing diseases in patients with complaints of back pain [8,18,19]. The results of the endurance test in the study of differences in electromyographic signals of healthy people and patients suffering from chronic back pain showed that subjects from second group have less pronounced signs of fatigue relative to the EMG signal at rest [9].

To date, the classification of diseases according to the results of surface electromyography is produced mainly using the methods of spectral and correlation analysis. An important criterion for their use is the stationarity of the signal. Using the Dickey-Fuller test, it was found that it is advisable to apply the methods of spectral correlation analysis only on certain short signal segments that are stationary, but the fully registered EMG signal is non-stationary. With this in mind, for the diagnosis of diseases based on the results of surface electromyography, it is recommended to apply non-linear dynamics methods [10,11,20].

The aim of the work is to identify statistically reliably different parameters of phase portraits for the following groups of subjects:

- healthy volunteers without complaints;
- conditionally healthy with complaints of back pain;
- vertebral patients;
- patients with scoliosis.

The objectives of the study are:

- calculation of the parameters of phase portraits of EMG signals obtained in the above groups, and the formation of samples based on them;
- analysis of the probability of differences in the parameters of the phase portrait of the EMG signal of the studied groups relative to the age indicator;
- analysis of the probability of differences in the parameters of the phase portrait of the EMG signal of the studied groups relative to the gender indicator;
- analysis of the probability of differences in the parameters of the phase portrait of the EMG signal between groups of healthy, conditionally healthy, vertebral patients and patients with scoliosis.

3. RESULTS AND DISCUSSION

The studies were conducted in collaboration with the Laboratory of Pathophysiology of the Sitenko Institute of Spine and Joint Pathology Ukrainian Academy of Medical Sciences. To complete the tasks, 102 people of both sexes aged from 18 to 76 were examined. Registration of electromyogram was carried out on a 4-channel computer electromyograph Neuro-EMG (Neurosoft). Surface electrodes were placed on the body extensor 2-3 cm to the right and left of the midline of the back, at the level of the fifth lumbar vertebra of the human body. For further processing and analysis, the signal was transmitted to a personal computer in the form of a sound file (wave format) [12,21,22].

An EMG signal is a volumetric process, that is, it has a vector that changes its direction in time and space. The construction of the phase portrait allows to restore the trajectories of this vector and analyze its nonlinear characteristics. When constructing a phase portrait, a coordinate system in which the values of the variable are plotted on the abscissa, and the values of the same variable with some delay – on the ordinate, is used. The delay τ is chosen from autocorrelation function when it's equal to zero first time [23,24].

The geometric method of analysis allows us to obtain quantitative indicators of the phase portrait by approximating it with a geometric figure. In this paper, the resulting phase portrait of the EMG signal is approximated by an ellipse, and then its parameters are calculated:

- area of ellipse S;
- size of the major semiaxis a;
- size of the minor semiaxis b;
- coefficient of eccentricity e;
- tilt angle of the major semiaxis relative to the abscissa axis phi;
- shift of the center of the ellipse relative to the origin r.

When constructing an ellipse at the extreme points of the phase portrait, part of the ellipse encompasses the empty phase space. To solve this problem, a second ellipse is constructed that covers a given percentage of points of the phase portrait (Fig. 1). Then its parameters are also calculated:

- area of ellipse S1;
- size of the major semi-axis a1;
- size of the minor semi-axis b1;
- coefficient of eccentricity e1 [13,25].

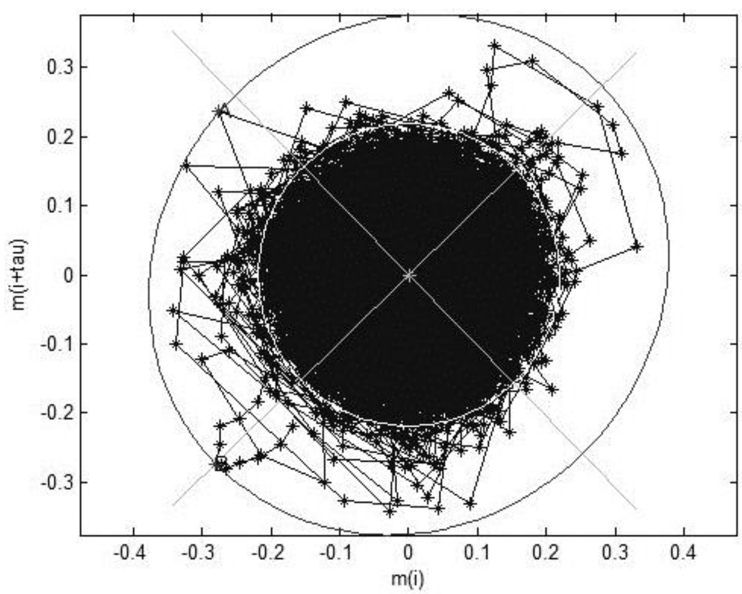

Fig. 1 – Phase portrait of an EMG signal with two approximating ellipses: full and percentage (99.9% of points)

Thus, the state of each subject in the group was characterized by ten parameters of the phase portrait: phi, r, a, b, S, e, a1, b1, S1, e1.

The geometric method of analyzing the phase portrait of an EMG signal was implemented in the MatLab software environment. After obtaining the parameters of the phase portrait of electromyograms, the samples were formed for statistical processing and to identify statistically significant correlations between the group to which the patient belongs and each indicator of the phase portrait, as well as the sex and age indicators. The calculations were carried out using the SPSS Statistics 21.0.

Among the methods for assessing the reliability there are parametric and non-parametric methods. Parametric criteria are applied for numerical data when the distribution law is normal. For a statistical analysis of the reliability of differences in indicators of the phase portrait of an EMG signal according to the diagnosis, gender and age of the subjects the Kolmogorov-Smirnov criterion, the parametric Student's t-test, and the non-parametric Mann-Whitney U criterion were selected [26,27,28].

The Kolmogorov-Smirnov criterion is based on a comparison of the accumulated frequency series of two independent samples. It includes checking all kinds of differences in distributions, especially differences in average positions (mean, median), scattering, asymmetry and kurtosis, i.e. any differences, any parameters, without specifying which ones. The null hypothesis of homogeneity means the identity of two distribution functions. Acceptance of this hypothesis automatically means the equality of all relevant parameters of these distributions. However, the rejection of the null hypothesis and the adoption of an alternative hypothesis do not answer the question what parameters are not equal in the compared distributions.

Student's parametric t-test is used to determine the statistical significance of differences in averages. It can be used both in the case of comparing independent samples, and in comparing related sets. To apply Student's t-test, it is necessary that the original data have a normal distribution. In the case of the use of a two-sample criterion for independent samples, the condition of equality of variances is also necessary. If the calculated value of the Student's t-test is equal to or greater than the critical one, we conclude that the differences between the compared values are statistically significant. If the value of the calculated Student's t-criterion is less than the critical value, then the differences of the compared values are not statistically significant.

The non-parametric Mann-Whitney U-test is used to compare two independent samples by the level of any indicator measured quantitatively. The method is based on determining whether the zone of intersecting values between two variational series is small enough (ranked number of parameter values in the first sample and the same in the second sample). The smaller the criterion value, the more likely it is that the differences between the parameter values in the samples are significant.

Each criterion of significance of differences passes through the following stages:

- determination of the used statistical model. Here they put forward a certain set of prerequisites regarding the law of distribution of a random variable and its parameters;
- selection of a criterion that fits the advanced statistical hypothesis;
- the choice of the level of significance α depending on the required reliability of the conclusions;
- determination of the critical area for testing the null hypothesis. If the criterion value exceeds this area, then the hypothesis is rejected;
- calculation of the value of the selected criterion for the available data;
- the calculated criterion value is compared with the critical one and the decision is made whether to accept or reject the null hypothesis.

Analysis of the phase portrait of the EMG signal depending on age was performed in four groups of subjects according to the WHO classification:

- A1 – young age (18-44 years);
- A2 – middle age (45-59 years);
- A3 – elderly age (60-74 years);
- A4 – old age (75-90 years).

The calculations of the probability of the difference between the indicators of phase portrait of the EMG signal and the patient's age for groups A1, A2, A3, A4 showed that the difference in parameters between age groups from 18 to 76 years is not statistically significant for all studied parameters ($p > 0.05$) in all groups of subjects. This allows for further analysis of electromyograms, not taking into account the age of the subject.

The analysis of the phase portrait of the EMG signal by sex was carried out in four groups of subjects:

- B1 – practically healthy volunteers without complaints (16 women; 16 men);
- B2 – conditionally healthy with complaints of back pain (9 women; 11 men);
- B3 – vertebral patients (9 women; 11 men);
- B4 – patients suffering from scoliosis (16 women; 14 men).

The calculations of the probability of differences between the indicators of the phase portrait of the EMG signal and the patient's sex for the B1, B2, B3 and B4 groups showed that the difference in the EMG signals between women and men is not statistically significant for all studied parameters ($p > 0.05$) in all groups. This allows for further analysis of electromyograms, not taking into account the sex of the subject.

Analysis of the phase portrait of the EMG signal, depending on the diagnosis was performed in four groups of subjects:

- B1 – practically healthy volunteers without complaints (32 myograms);
- B2 – conditionally healthy with complaints of back pain (20 myograms);
- B3 – vertebral patients (20 myograms);
- B4 – patients suffering from scoliosis (30 myograms).

In determining the differences among the indicators of the phase portrait of the EMG signal between patients without pathologies and with pathologies of the musculoskeletal system, the following results were obtained:

- the difference in the EMG signal parameters between the B1 and B2 groups is not statistically significant ($p > 0.05$);
- the difference in the EMG signal parameters between the B1 and B3 groups, B1 and B4 is statistically significant ($p < 0.05$), except the r, e and e_1 parameters ($p > 0.05$);
- the difference in the EMG signal parameters between groups B2 and B3, B2 and B4 is statistically significant ($p < 0.05$), except the indicators r, e and e_1 ($p > 0.05$);
- the difference in the EMG signal parameters between the B3 and B4 groups is statistically significant ($p < 0.05$), except the r, e and e_1 parameters ($p > 0.05$).

4. CONCLUSIONS

Statistical processing of samples to identify statistically significant correlations of the parameters of the phase portrait of the EMG signal with the age and sex of the subject was conducted. Statistically significant differences were not found. Statistical processing of the sample to identify statistically significant correlations between the group to which the patient belongs, and each indicator of the phase portrait was conducted. The groups of practically healthy patients without complaints and conditionally healthy patients with complaints of back pain are not statistically significantly different for each parameter of the phase portrait. However, between patients without pathologies, vertebral patients and patients with scoliosis, a statistically significant difference was found for seven parameters of the phase portrait: phi, a, b, S, a1, b1, S1. The perspective of the work is the construction of models for classifying patients according to the parameters of phase portraits of surface electromyography data.

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