Chapter

Methods and Tools for Assessing Muscle Asymmetry in the Analysis of Electromyographic Signals

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Abstract

The generalized information about the possibilities of assessing asymmetry and the prospects of research tools is presented. The important role of the choice of different methods for processing electromyographic signals, the results of which can be considered as an objective criterion for assessing the asymmetry of the muscles of the extremities, is noted, such as the asymmetry coefficient, a widely used parameter in statistical analysis, which characterizes the asymmetry of the statistical distribution. Also applied is the segmental method of studying the body to obtain estimates of the composition and differences between individual body segments. The isokinetic test method, which makes it possible to assess asymmetry in measuring muscle strength, relies on the randomness of the dynamic processes of the biological system. Use of nonlinear dynamics, the theory of dynamic chaos, and fractal analysis allows for determining the fractal properties of biosignals, and from the classical methods used correlation analysis.

Keywords: electromyography, asymmetry coefficient, multifractal analysis, isokinetic test, correlation analysis

1. Introduction

The connection between the evolutionary processes of complex systems, which include biological ones, is associated with the phenomenon of symmetry breaking. This leads to the need to study the indicators of asymmetry in the study of the behavior of complex systems [1]. Asymmetry is used as the best method for displaying possible variations when examining the limbs of the skeletal system. The observed asymmetry of the limbs of the skeletal system is associated with mechanical and genetic factors. Electromyography (EMG) research has grown in popularity over the past few years. Progressive understanding of the human body, increased awareness to explore the benefits of interdisciplinary research, advances in sensory technology, and the exponential growth of the computational power of computers are all factors contributing to the expansion of EMG research (relevant references will be explained in detail). Functional asymmetry is an integral feature of the human brain, which manifests itself in various forms of human behavior and motor activity [2]. The study of functional asymmetry and lateral preferences is important not only from a theoretical but also from a practical point of view, since both the effectiveness of the fulfillment of sports motor actions and the likelihood of injury can depend on its severity [3, 4]. It is these areas of research on motor asymmetry in

sports that remain the most relevant. The aim of the study in [5] was to study the general and individual features of the asymmetry of the speed-strength indicators of the muscles of the knee joint in Paralympic basketball players and its relationship with the results in jumping exercises.

There are different approaches to assessing the asymmetry of different human organs. The asymmetry coefficient was calculated as the ratio of the difference between the minimum and maximum EMG values of symmetrical muscles to a larger value [5]. The Electroencephalography (EEG) method was used to assess the asymmetry of the normalized quantitative indicator—the coefficient of asymmetry [6]. When visualizing the reconstructed cardiac signal, the asymmetry coefficient was also used and estimated [7].

2. Estimation of the asymmetry of electromyographic signals using the statistical distribution of asymmetry coefficients

Functional asymmetry is an integral feature of the human brain, which is manifested in various forms of human behavior and motor activity [8].

There are different approaches to assessing the asymmetry of different human organs. The asymmetry coefficient (KAs) was calculated as the ratio of the difference in EMG values of symmetrical muscles on the side of its minimum (X1) and maximum (X2) decrease to a larger value [5]:

$$\mathrm{K}_{\mathrm{A}s} = \frac{(X_1 - X_2) * 100\%}{X_1}. \tag{1}$$

The method of a normalized quantitative indicator, the asymmetry coefficient, was used to assess the EEG asymmetry [9, 10]. What is universal for its calculation is the formula

$$(\mathrm{A} - \mathrm{Б})/(\mathrm{A} + \mathrm{Б})\mathrm{x}100\%, \tag{2}$$

where A is the numerical characteristic of the EEG of the left hemisphere, and B is the right one.

2.1 Method

The skewness coefficient is a widely used parameter in statistical analysis that characterizes the skewness of a statistical distribution.

The central moment of distribution can be calculated by the formula [11]:

$$m_k^{(0)} = E(\xi - m_i)^k = \begin{cases} \int (x - m_i)^k f(x)dx, if\ \xi\ uninterrupted; \\ \sum_i \left(x_i^0 - m_i\right)^k p_i, \ \ if\ \ discret. \end{cases} \tag{3}$$

Here k is order; ξ is a discrete random variable with possible values $\boldsymbol{x_i}$ and probabilities of their realization $\boldsymbol{p_i}$, $(\boldsymbol{i} = \mathbf{1}, \mathbf{2}, \mathbf{3}, \ldots)$.

By formula (1), it is easy to understand that if the density $\boldsymbol{f}_{\xi}(\boldsymbol{x})$ (or the sequence of probabilities $\boldsymbol{P}\{\xi = \boldsymbol{x_i^0}\}$ is symmetric with respect to the mean value $\boldsymbol{m_1} = \boldsymbol{E}\xi$ (i.e. $\boldsymbol{f}(\boldsymbol{m_1} - \boldsymbol{x}) \equiv \boldsymbol{f}(\boldsymbol{m_1} + \boldsymbol{x})$), then all odd central moments (if they exist) $\boldsymbol{x}_{\boldsymbol{2k+1}}^{(\mathbf{0})}$ are equal to zero. Therefore, any odd, non-zero torque can be considered as a

characteristic of the asymmetry of the corresponding distribution. The simplest of these characteristics is $m_3^{(0)}$ and is taken as the basis for calculating the so-called asymmetry coefficient γ_1—a quantitative characteristic of the degree of skewness of the distribution [10]:

$$\gamma_1 = \frac{\frac{1}{N}\sum_{i=1}^{N}(S_i - m_x)^3}{\sigma^3} \quad (4)$$

where $m_x = \frac{1}{N}\sum_{i=1}^{N} S_i$ – sample mean, $\sigma^2 = \frac{1}{(N-1)}\sum_{i=1}^{N}(S_i - m_x)^2$ - sample variance, $S_i, \overline{1:N}$ - time series.

All symmetric distributions will have zero skewness. Probability distributions with the "long part" of the density curve located to the right of the top are characterized by positive asymmetry, and distributions with the "long part" of the density curve located to the left of its top are negatively skewed [10].

The range of variability of the asymmetry coefficient is determined from −3 to +3.

At the same time, it is generally accepted that asymmetry above 0.5 (regardless of sign) is significant and less than 0.25 is insignificant. With a symmetric distribution, the kurtosis coefficient Ek = 0. If Ek <0, then the distribution has a flat-topped character, and if Ek > 0, then it is peaked. We determined the fluctuation of qualitative features of the variational series by the total variance, based on the theorem of addition of the variance of the share of a feature.

Thus, the variation statistics for assessing the contractile properties of muscles is based on the asymmetry coefficient. By the degree of deviation of the asymmetry coefficient from the median, as a rule, one can judge the value of the Gaussian distribution density. The closer the skewness indicator is to the median, the higher the Gaussian distribution density. The deviation of the asymmetry from the median is determined by the standard deviation from the mean. For a normal distribution, 95% of the values are within two standard deviations of the mean and 68% are within one standard deviation [11].

2.2 Experimental part

For the experiment, 6 muscles of the lower extremities of a patient with a diagnosis of asymmetry were selected. Measuring signals were received from 12 leads, in pairs from the right and left parts of the limbs (**Table 1**).

To estimate the asymmetry coefficient, formula (4) was used and the skewness function was implemented by Matlab [12]. The experimental results obtained are given in **Table 2**.

As already noted, asymmetry above 0.5 (regardless of sign) is significant and less than 0.25 is insignificant. According to the results of the experiment, we can say that on the left side of the limbs for the muscles a-gm-lp, a-qfm-rf, there is a great tendency to asymmetry, and for a-bfm, both the left and right parts, there is a tendency to asymmetry. For the muscles a-qfm-vm, a-gm-mp, a slight asymmetry can be observed on the left side, and a tendency towards asymmetry for the right side.

To visualize the results, you can present them in the form of a histogram (**Figure 1**).

To assess the method used, the results obtained are compared with the values obtained by the Myograph, which are given in **Figure 2**.

Based on the results in **Figure 2**, we can say that the patient has left-sided asymmetry in the a-qfm-vl muscles, since the highest voltage is observed on the

##	Muscles	Abbreviation
1	Biceps femoris muscle	a-bfm
2	Gastrocnemius muscle – lateral part	a-gm-lp
3	Quadriceps femoris muscle – rectus femoris	a-qfm-rf
4	Quadriceps femoris muscle – vastus lateralis	a-qfm-vl
5	Quadriceps femoris muscle – vastus medialis	a-qfm-vm
6	Gastrocnemius muscle – medial part	a-gm-mp

Table 1.
Measuring muscle signals used in the experiment.

##	Muscles	The asymmetry coefficients	
		Left (L)	Right (R)
1	a-bfm	0.3516	0.3936
2	a-gm-lp	0.4484	0.3735
3	a-qfm-rf	0.4518	0.1304
4	a-qfm-vl	0.0681	0.4413
5	a-qfm-vm	0.2507	0.3110
6	a-gm-mp	0.0709	0.3532

Table 2.
The value of the asymmetry coefficient depending on the location of the muscles.

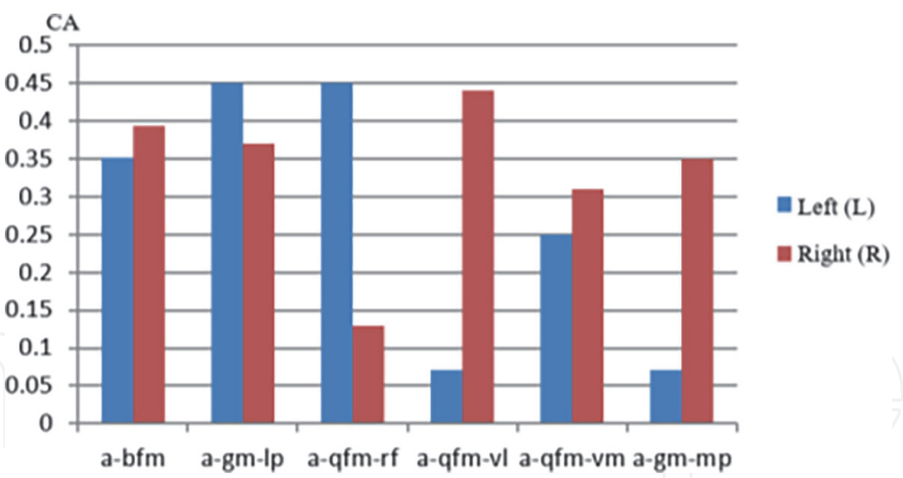


Figure 1.
Diagram of the asymmetry coefficient of paired muscles.

right side (from the bottom of the fourth drain). It is also not very convenient to compare this value with the value of the paired muscles (second line from the top).

The experimental data help not only to conveniently compare the results, but also to give a predictive conclusion about the possibility of the expected muscle pathology. The value between the interval $0.25 < x < 0.5$ can be used as the bias towards asymmetry.

It is also possible to use the difference in the asymmetry coefficients for convenient observation of the results (**Figure 3**).

The results in **Figure 3** show the positions of the asymmetry during the measurement and may allow immediate observation.

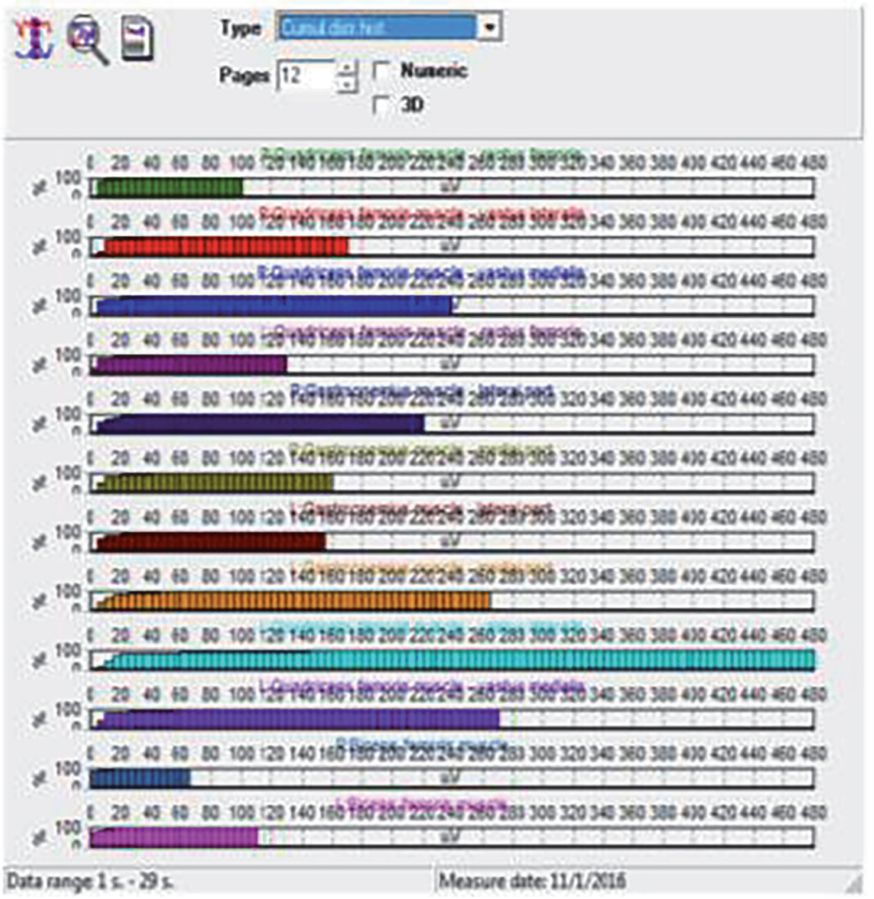


Figure 2.
Measurement results with myograph.

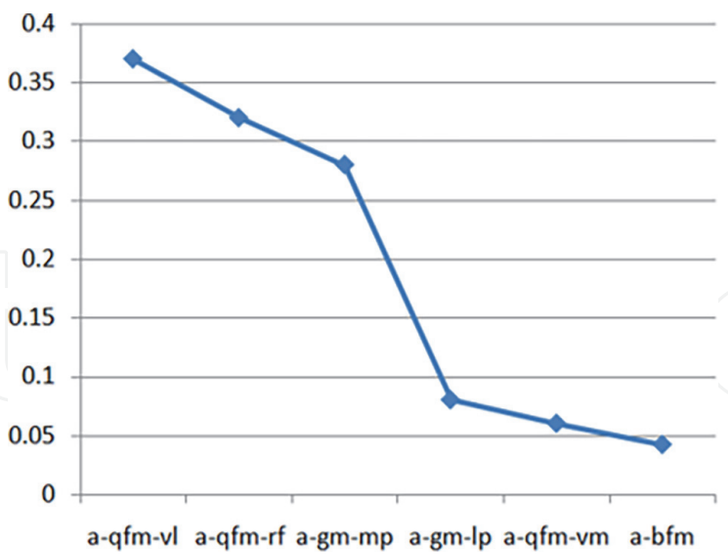


Figure 3.
The difference in the coefficient of asymmetry of paired muscles.

3. Assessment of the degree of asymmetry by the measured muscle strength of the limbs

The main purpose of segmental body examination methods is to obtain estimates of the composition and differences of individual body segments. Such analysis can be performed both statically and dynamically to investigate the differences between

segments under various influences. The body segments analyzed are usually the limbs and trunk, and in some cases the head.

The asymmetry of the structure of the human body, expressed to a greater extent in the limbs, is a widespread phenomenon. The degree of this asymmetry is affected by the way of life, the experience of a person's professional activity, which is manifested in the aggregate of signs of inequality in the functions of arms, legs, halves of the body, and face during the formation of general motor behavior.

Even in relatively uniform cross-sectional areas of the body, the musculoskeletal mass is unevenly distributed. For example, in the overwhelming majority of the world's population, the right hand is superior to the left in strength. This symmetry is expressed by the formula

$$A = S/D,$$

where D - muscle strength of the right, S - muscle strength of the left hand [13]. This ratio is less than one for right-handers, more than one for the left, and equal to one for ambidextra.

There are different methods and means for assessing asymmetry (anthropometric, bioimpedance analysis, assessment of strength indicators, etc.), which allow such comparisons to be made both quantitatively and visually [14–17].

To assess the asymmetry of the limbs of the studied patients, the results of in vivo experiments were used using a 12-channel ME6000-EMG device. We studied the biopotentials of three muscles of the lower extremities, two of them lateral and one medial direction (**Table 3**). Measurement time - 30 sec.

For the studied muscle types, 6 leads were used, thus six signals were recorded for the right (R) and left (L) sides. **Table 4** shows the values for three examples of the maximum amplitudes of biopotentials in microvolts, the values of which are proportional to the muscle strength of the objects under consideration.

For the corresponding leads for the left and right sides, the difference in the maximum amplitude values of the signals can be estimated as follows, for example:

$$\Delta A(QFM.rf) = QFM.rf_{max}(L) - QFM.rf_{max}(R)$$

For one and the same derivation, when calculating the average value of the difference in amplitudes (AVDA), it is necessary to take into account the difference of all measured values. For instance,

$$\mathrm{AVDA} = \Big(\Delta A_{\text{прим. 1}}(QFM.rf) + \Delta A_{\text{прим. 1}}(QFM.vl) + \Delta A_{\text{прим. 1}}(QFM.vm) + \Delta A_{\text{прим. 1}}(QM.lp) + \Delta A_{\text{прим. 1}}(\mathrm{QM.mp}) + \Delta A_{\text{прим. 1}}(BFM)\Big)/6$$

Muscles	Abbreviation
Quadriceps femoris muscle – rectus femoris	QFM-rf
Quadriceps femoris muscle – vastus lateralis	QFM-vl
Quadriceps femoris muscle – vastus medialis	QFM-vm
Gastrocnemius muscle – lateral part	QM-lp
Gastrocnemius muscle – medial part	QM-mp
Biceps femoris muscle	BFM

Table 3.
Studied biopotentials.

Muscles	Measurement values, μV					
	example 1		example 2		example 3	
	L	R	L	R	L	R
Quadriceps femoris muscle – rectus femoris	130	100	165	175	200	235
Quadriceps femoris muscle – vastus lateralis	480	170	135	160	255	205
Quadriceps femoris muscle – vastus medialis	270	240	480	230	290	300
Gastrocnemius muscle – lateral part	150	220	140	175	120	140
Gastrocnemius muscle – medial part	260	160	180	165	175	225
Biceps femoris muscle	110	70	70	100	110	165

Table 4.
The values for three examples of the maximum amplitudes of biopotentials.

Muscles	QFM-rf	QFM-vl	QFM-vm	QM-lp	QM-mp	BFM	C3PA
Example 1	0.3	3.1	0.25	0.7	0	0.4	0.79
Example 2	0.1	0.25	2.5	0.35	0.15	0.3	0.61
Example 3	0.35	0.5	0.1	0.2	0.5	0.55	0.37
...	...	...	...	...	...	...	...

Table 5.
The difference in the maximum amplitudes of the received signals (in percentage terms).

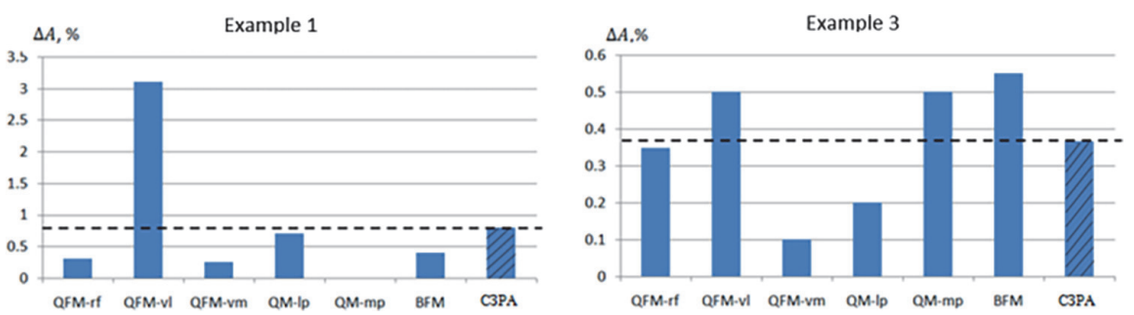


Figure 4.
Comparison of the average values of the measured signals for different leads for two examples.

For the corresponding leads, the difference in the maximum amplitudes of the received signals (in percentage terms), as well as the difference in the average values of the measured signals, are shown in **Table 5**.

Comparison of the average values of the measured signals for different leads for two examples (in the form of histograms) is shown in **Figure 4**.

For example 1, it can be seen that only for one muscle QFM-vl there is a pronounced asymmetry, and for other muscles relative to the mean value there is no tendency to asymmetry. In example 3, the maximum asymmetry is observed in lead BFM; however, there is a tendency to asymmetry in leads QFM-vl and QM-mp. In this case, the average value of the difference in amplitudes can be used as the degree of asymmetry A, since this value is with the difference in muscle strength measured from the corresponding muscle of the limbs.

It is possible to conventionally accept the range of variation of A from 0 to 1. If we accept the degree of asymmetry equal to 0.5 as an average level, then the value <0.5 is estimated as a low degree, and the value >0.5 as a high degree of asymmetry. For the examples shown, the degree of asymmetry can be assessed according to the following scale (**Figure 5**).

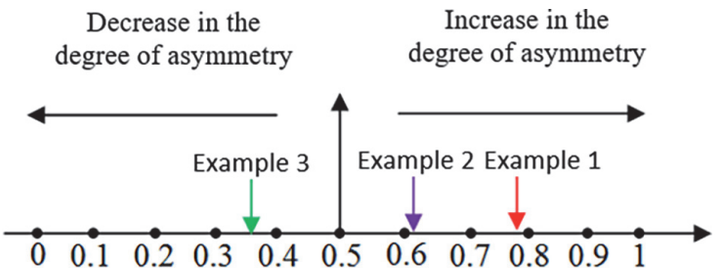


Figure 5.
Scale of the degree of asymmetry.

The proposed approach makes it possible to quantitatively assess the severity of the asymmetry of the studied limbs.

If you use directly the measurement results using the 12-channel ME6000-EMG device, then the measurement results are reflected in the protocol—**Figure 6** (for two examples).

For the leads used (left and right), 12 signals of the studied muscle are recorded during the period of innervation and reinnervation. In this case, the assessment of the measurement results is carried out visually to the values of biopotentials, proportional to the muscle strength of the object under study. As can be seen from **Figure 3**, these values are maximum for the Quadriceps femoris muscle - vastus lateralis.

For the first example, the maximum value of muscle strength corresponds to the 9th line, for the second example it is the 3rd line. However, it is impossible to establish the degree of asymmetry of the studied muscle in a particular patient from the given measurement protocol. It is possible to group the results of measurements of muscle strength for different muscles of patients—**Figure 7a, b**. The obtained histograms for the left and right sides of the studied muscles of patients do not make it possible to assess the degree of asymmetry and the magnitude of this asymmetry, since the maximum values for different leads (QFM-vl and QFM-vm) can be maximum.

Thus, in comparison with the results of direct measurements and with the subsequent visualization of the obtained protocol, the proposed method for assessing the degree of asymmetry, and then the severity of asymmetry of the muscles under study, is more acceptable.

To obtain reliable and reproducible results on the example of 30 patients, all requirements of the measurement procedure were met.

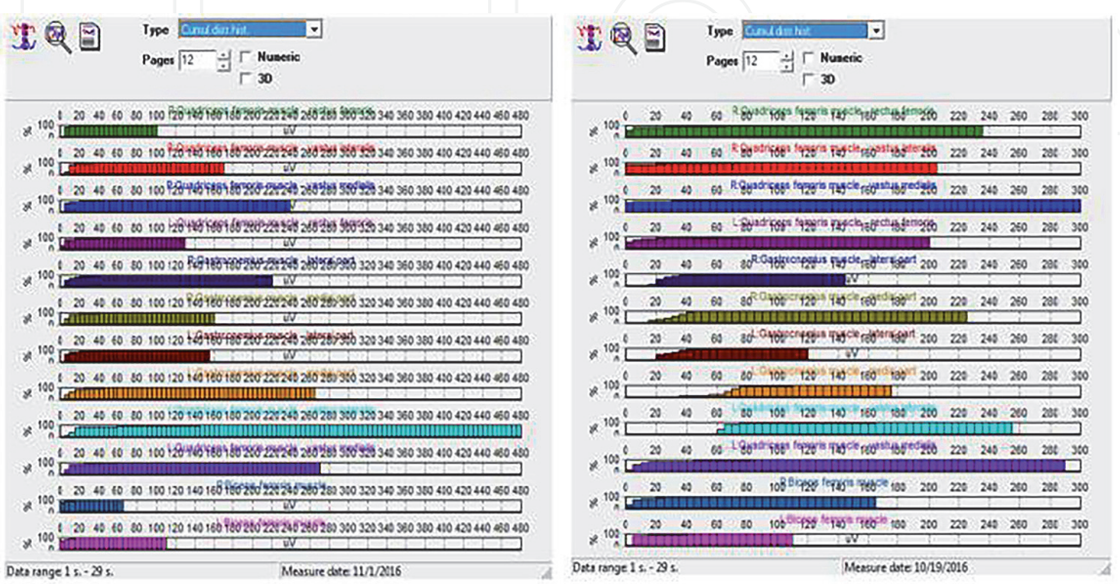


Figure 6.
The measurement results using the 12-channel ME6000-EMG device.

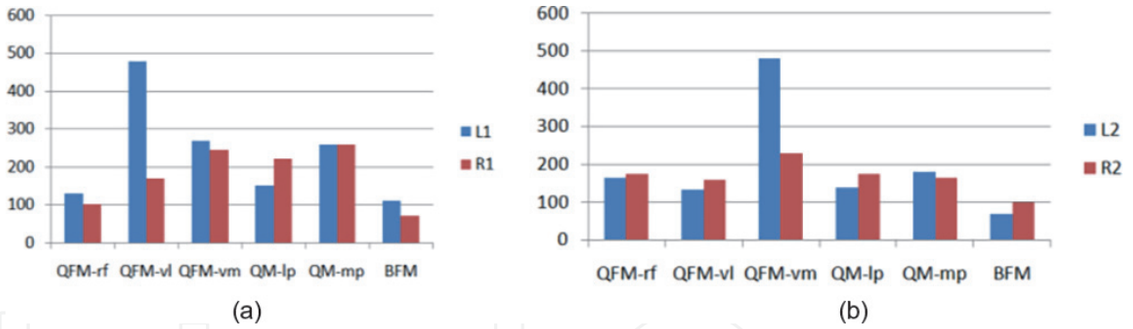


Figure 7.
Grouping results of measurements of muscle strength for different muscles of patients.

Assessment of the degree of asymmetry of muscle strength according to the proposed method allows an expert doctor to accurately assess the differences in the biopotentials of the studied muscles of the limbs and effectively use the treatment method to reduce the degree of asymmetry.

4. Assessment of asymmetry in permanent muscles based on isokinetic test results

The asymmetry observed in the skeletal system can be caused by both mechanical effects and genetic factors. Asymmetry is used in the skeletal system as a method that best reflects the variations that may occur in the study of the limbs. Asymmetry, especially in the upper extremities, is due to the fact that there is more freedom of movement. On the other hand, if the symmetry of the upper extremities is broken in favor of one side, the contralateral side is superior and advanced in the lower extremities. Numerous experiments on the upper extremities have shown that the main cause of bilateral asymmetry is side choice [18–20].

Asymmetry in the muscles can damage not only the esthetic structure, but also health. Muscles of different strengths can cause damage to the spine and other structures by creating completely different pressure points.

This condition is most often seen in people who have an inversely proportional shortness on one side of the hamstring muscles.

In isokinetic compression, the rate of skeletal muscle contraction is constant. In isokinetic compressions, each movement is performed at a constant speed due to the destination. On the contrary, in isotonic compression, it is impossible to keep the speed constant in a certain motion.

In isokinetic compressions, motion occurs in three separate phases.

a. acceleration phase: acceleration phase of motion;

b. isokinetic loading: the phase at which the motion is performed at a constant speed and equal resistance;

c. deceleration phase: the deceleration phase before the movement is completed.

Since the speed is not constant during the acceleration and deceleration phases, the physical activity performed at this stage cannot be considered isokinetic. Since the optimal test speeds for each joint movement are not known, it is important to find the angular velocities with the isokinetic loading range of the joints. In this regard, the estimates made with an isokinetic dynamometer calculate the peak torque, work, and power parameters corresponding to the isokinetic range.

As the speed of the dynamometer increases, the time of the compression and deceleration phases increases, and the phase time with the main isokinetic load decreases. Studies have shown that serious errors in assessment can occur if these three phases are not taken into account during flexion-extension movements performed at different angular velocities. Therefore, the assessment of the isokinetic loading phase, especially at high angular velocities, may be important for the correct interpretation of the data.

With the development of technology, as in many areas, there have been developments in the field of strengthening and rehabilitation of human muscles. In general, isometric and isotonic (concentric- eccentric) compression types are used to strengthen the muscle. This is especially important in the assessment of dynamic neuromuscular capabilities in sports and in the quantitative assessment of outcomes. In order to determine the muscle capacity that can occur during dynamic muscle contraction (construction), it is necessary to measure the force and force exerted at a certain angular velocity. These values are quantified with an isokinetic dynamometer [21–24].

The purpose of the research and the problem statement.

Formulas used in the calculation of muscle strength and research-related terms.

Force (F) is defined as a physical quantity that stops motion or turns stagnation into motion, the unit of which is Newton (N).

Work (W) is the force applied at a certain distance; the unit is the Newton-meter (Nm) or Coul. The work done does not depend on time. Mathematical formula: $W = F \cdot d$ (where d is the distance).

The moment of force (torque) is the force that creates a rotation by applying a point or axis, the unit of which is the Newton-meter.

Power (P) is the work done in a single time; the unit is Watt (W).

$$P = W/\ t; \quad P = F \cdot d/t; \quad P = F \cdot t.$$

Angular velocity is the distance traveled in a single time; the unit is degrees/second (°/sec).

Factors affecting measurements when measuring muscle strength.

Personal characteristics:

- Age: As opposed to an age, person's body mass (fat-free) decreases. As getting older, type II fibers decrease, so muscle strength decreases. Age is an important factor in assessing the torque, speed, and strength characteristics of skeletal muscles.
- Height
- Body mass
- Sex
- Sports past
- Dominant party
- Damage condition
- Action features
- Joint angle: Depending on the length-tension relationship and the biomechanical properties of the joint, the force is different for each joint.

Muscle movement: With isokinetic devices, force, work and force can be measured in both concentric and eccentric compressions. Most studies have shown that the force at eccentric compression is greater than that at concentric compression. This is because in eccentric compression, both contractile and non-contractile elastic components are involved in the formation of force, while in concentric compression only contractile structures are involved.

Test type: Isometric, isotonic, or isokinetic compression types are measured with an isokinetic dynamometer.

Bicycle ergometer is used for the lower extremity and arm ergometer for the upper extremity for warm-up (muscle training) (**Table 6**).

The experiments are warm-up exercises for 5 minutes on a bicycle ergometer with 55 ± 5 rpm. Warm-up loads are regulated according to a person's heart rate, and the heart rate is recorded by a telemetry monitor (S810, Polar, Finland) that visualizes the heartbeat. During the warm-up period, the heart rate is maintained between 100 and 120 beats per minute. The arm ergometer is used in the same way for the upper circumference. Stretching exercises are performed for 5 minutes before and after the test to prevent possible injuries.

As shown in **Table 1**, a protocol of test results is prepared. To allow individuals to adapt to the isokinetic measurements, the test is repeated on the isokinetic dynamometer at 210°/sec and 180°/sec at five maximum positions, with 45 seconds rest between repetitions. Concentric peak values of torque of the Working and power variables. Using a Cybex Norm dynamometer, the angular velocity is measured three times with an increase of 30°/s in each set from 30°/s to 450°/s. There is a time of 30 seconds for a break between measurements. Which of the three iterations has the highest peak torque is used in data analysis.

Angular velocity (degree/sec)	Number of repetitions	Break time (second)
210	5	45
180	5	45
30	3	30
60	3	30
90	3	30
120	3	30
150	3	30
180	3	30
210	3	30
240	3	30
270	3	30
300	3	30
330	3	30
360	3	30
390	3	30
420	3	30
450	3	30

Table 6.
Test protocol.

Angular velocity	Normalized power	
	Right foot (thigh) abduction	Left leg (thigh) abduction
30	30	30
60	50	50
90	80	60
120	70	75
150	110	80
180	90	90
210	90	85
240	80	65
270	105	80
300	80	72
330	65	74
360	70	70
390	65	72
420	65	65
450	60	70

Table 7.
Foot-thigh abduction.

Foot (thigh) abduction: The movement is performed with 59.00 ± 8.2 degrees of articular movement (**Table 7**).

4.1 Discussion of the obtained results

According to **Table 2**, we construct the following graphs to assess the asymmetry in the muscles. The graph shows the results according to the angular values on the horizontal axis and the results according to the power values on the vertical axis (**Figure 8**). As can be seen from the graph, the muscle strengths in the right and left legs differ from each other at certain angular velocity values during abduction. At some angular velocity values, the muscle forces in the right and left legs are the same (30°/sec, 60°/sec, 180°/sec, 360°/sec), and these values indicate that there is no asymmetry. We do not take these prices into account. At different values of angular velocity, the asymmetry

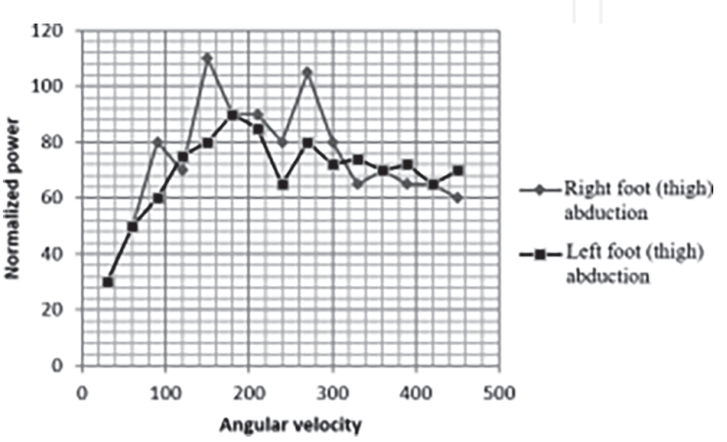


Figure 8.
Abduction of the right and left leg (thigh).

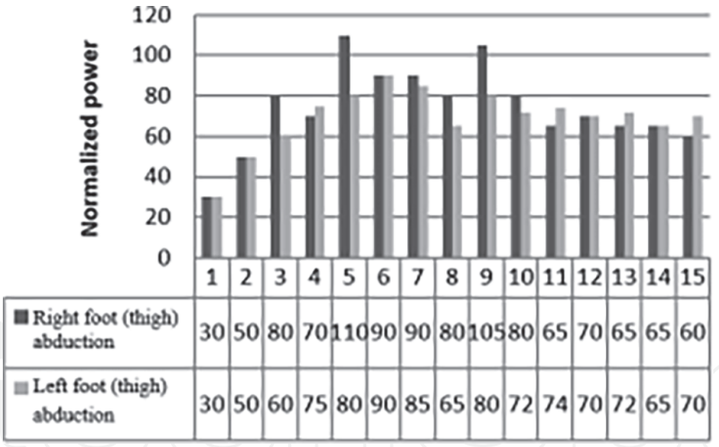


Figure 9.
Histogram for asymmetry assessment during right and left leg abduction.

between the right and left foot is also different. At some values, the asymmetry is less noticeable (120°/sec, 210°/sec, 300°/sec, 330°/sec, 390°/sec, 450°/sec). At some values, there is a sharp asymmetry (90°/sec, 150°/sec, 240°/sec, 270°/sec).

The histogram of the results is shown in **Figure 9**.

4.2 The result

The minimum difference between right and left muscle strength is 5 W/kg, and the maximum difference is 30 W/kg. Given that the difference between these values is 25 W/kg, the difference in power values of 12 + 5, i.e. 17 W kg and below, in the assessment of asymmetry during abduction between the right and left arm is a natural asymmetry, and values above 17 W/kg it would be more correct to accept the existing asymmetry.

The minimum difference between right and left muscle strength is 5 W/kg, and the maximum difference is 70 W/kg. Since the difference between these values is 65 W/kg, differences in muscle strength of 32 + 5, i.e. 37 W/kg and below, can be considered as a natural asymmetry, and differences in muscle strength greater than 37 W/kg can be considered as existing asymmetry.

5. Evaluation of limbs muscle asymmetry on the basis of the method of multifractal fluctuation analysis

The study of signals of biological systems should be carried out with an account of such important factors as the existence of nonlinear interrelationships between different physiological indicators and between reports of organic biological signals. Their non-stationary nature is limited to the application of classical methods of analysis of biological signals.

Chaosticity of dynamic processes of biological systems and fractal properties of biosignals obtained from different structures of the organism require descriptions of the processes occurring in these systems with the use of nonlinear analogical dynamics, theories of dynamism. Based on the application of such methods of analysis, it is possible to obtain diagnostic information indicators, which come from each of the methods that can serve as an early predictor of disease of a particular organ.

In this article, the assessment of fluctuation of random processes using the method of fluctuation analysis of electromyographic signals is considered. The meaning of these signals is represented in the form of a dynamic time series to assess the asymmetry of the limbs of the human body [25–28].

There are not a large number of publications in science-based databases using multifractal approaches for the analysis of myographic signals. The author used fractal analysis to assess the morphological complexities of the surface of the connecting parts, scanned by a 3D scanner [29]. The possibility of predicting the asymmetry of electromyographic signals from the ends (arms and legs) was tested by the method of multifractal multiplicity [16]. The Higuchi fractal size was used to establish the imbalance of the jaw and the loss of muscle strength in the hands by helping the surface electromyography [17].

In the work are given examples of changes in the fluctuation functions of the electromyographic signal for different levels of load on a specific muscle [30].

Electromyographic signals are considered in this work, comparable to the ends: the right and left part of the hip muscle. In contrast to the classical approach to the assessment of asymmetry with the use of a single point (maximum) of the measured signal, we consider the multiplicity of the measured signals of the finite points as heterogeneous unevenly distributed fractional points. To assess the chaosticity of myographic signals, it is possible to use the characteristics of fractal multiplicity, such as the fractal size of Hausdorff, the indicator of Herst, generalized size, correlation, and information size [31–34].

5.1 Materials and methods

In the current period, in clinical conditions, the assessment of asymmetry is carried out at the maximum value of the amplitude of the muscles. This process includes in itself "maximum contraction of the muscle - the achievement of the peak in the maximum relaxation of the muscle", is the informative result and considered only the value of the peak. If you consider the whole process as a dynamic time series, then in order to make a decision it is necessary to include all the elements of the coincidence that creates this process. To examine all the data in a dynamic range and the minimum step size of a window in one report it is necessary to ensure the frequency of record lengths and window sizes. This segmentation is performed in two passages, performed in opposite directions.

The calculation algorithm consists of the following steps.

Initially from the series x(k), k = 0,1,2 ... N allocate the total fluctuation (or fluctuation profile)

$$Y(i) = \sum_{k=1}^{i} [x(k) - \overline{x}], \quad i = 1, 2 \ldots N, \tag{5}$$

where $\overline{\boldsymbol{x}}$ - is the average arithmetic series x(κ).

Divide the full interval $[\mathbf{1}, \boldsymbol{N}]$ by $\boldsymbol{N_s} = [\boldsymbol{N}/\boldsymbol{s}]$ segments, each of which contains s values. The elements of the new interval will be $\boldsymbol{x}_{(\nu-1)s+1}, \ldots, \boldsymbol{x}_{\nu,s}$, ν = 1, ... , Ns. It follows that in the case of $\boldsymbol{s} > \boldsymbol{N}/\mathbf{4}$ the function of the deformed variance loses statistical informativeness due to the small number of $\boldsymbol{N_s} < \mathbf{4}$, used in the medium. At the same time it is necessary to fulfill the inequality $\mathbf{s} < \mathbf{10}$ [35–37].

After changing the random variable $\boldsymbol{Y}(\boldsymbol{i})$ we add $\boldsymbol{y}_{\nu}(\boldsymbol{i}) \neq \mathbf{0}$ to find the polynomial for this function using the method of the least squares, and calculate the variance in the interval ν:

$$F^2(\nu, s) = \frac{1}{s} \sum_{i=1}^{s} \left\{ y[(\nu - 1)s + i] - y_{\nu}(i) \right\}^2 \tag{6}$$

for segments $\nu = \mathbf{1}, \mathbf{2}, \ldots \boldsymbol{N_s}$, in the case of fragmentation is performed in the direct direction, and for the reverse sequence $\nu = \boldsymbol{N_s} + \mathbf{1}, \ldots, \mathbf{2}\boldsymbol{N_s}$ we use the equation

$$F^2(\nu, s) = \frac{1}{s}\sum_{i=1}^{s}\left\{y[N-(\nu-N_s)s+i]-y_\nu(i)\right\}^2 \tag{7}$$

Conduct the distribution of deformed dispersions at intervals

$$F_q(s) = \left\{\frac{1}{2N_s}\sum_{\nu}^{2N_s}\left[F^2(\nu, \mathrm{s})\right]^{q/2}\right\}^{1/q} \tag{8}$$

Coefficient 2 in the signifier and in the upper limit of the sum used only for reflation of the algorithm with two passes.

At zero value of the order q this equilibrium contains indefiniteness, and then by definition

$$F_0(s) = \exp\left\{\frac{1}{4N_s}\sum_{\nu=1}^{2N_s} ln\left[F^2(\nu, \mathrm{s})\right]\right\} \tag{9}$$

To find the dependence $\boldsymbol{F_q(s)}$ we change the time scale s with the fixed indicator $\boldsymbol{q}$ and represent it in binary logarithmic coordinates.

If the studied series corresponds to a similar number ($s \to 0$), then the scaling relationship is fulfilled

$$F_q(s) \sim s^{h(q)}, \tag{10}$$

where $\boldsymbol{h(q)}$ is a generalized index of Herst [35]. For stationary time series h (2) = H is the known index of the degree of Hearst, which with one side does not depend on $\boldsymbol{q}$, and with the other variance is the same for all segments. In the positive/negative value q, $\boldsymbol{h(q)}$ indicates the scaling behavior of segments with large/small fluctuations [35].

For small values of s, $\boldsymbol{h(q)}$ we determine the linear regression [36].

$$F_q(s) = h(q)\cdot \ln(s) \tag{11}$$

The standard representation of the scaling properties of the temporal series assumes a transition from the indicator Hearst $\boldsymbol{h(q)}$ to the mass indicator $\boldsymbol{\tau(q)}$ and the spectral function f (α), the size of Rennie, which are in [37].

Mass index is calculated by the formula:

$$\tau(q) = qh(q) - 1 \tag{12}$$

The spectral function has a connection with the mass indicator and the indicator Hearst:

$$\alpha(q) = \frac{d\tau(q)}{dq} = h(q) + q\frac{dh}{dq}$$

$$f(\alpha) = 1 + q(\alpha)[\alpha - h(q(\alpha))] \tag{13}$$

where $\boldsymbol{\alpha}$ is an indicator of Gelder, which estimates the probability of the occurrence of the element of fractal multiplicity in the ν-th fragment.

The size of Rennie is determined by the equilibrium of spectral function and (12)

$$D_q = \frac{qh(q) - 1}{q - 1}, \tag{14}$$

Apparently the equation is not fulfilled when q = 1. For this value according to the rules of Lopital (14), we use the dependence:

$$D(1) = h(1) + \left.\frac{\partial h}{\partial q}\right|_{q=1} \tag{15}$$

5.2 Discussion of results

With the purpose of demonstration of the possibility of using this method for quantitative assessment of asymmetry of the patient's muscle. Conduct testing of the expressed method on EMG signals. Calculation is carried out separately for each multiplicity.

The experiments used muscle signals: Quadriceps femoris muscle - rectus femoris, Quadriceps femoris muscle - vastus lateralis, Quadriceps femoris muscle - vastus medialis, Gastrocnemius muscle - lateral part, Gastrocnemius muscle - medial part, and biceps femoris muscle.

In accordance with the above-mentioned algorithm for the computational experiment, medical records were used of the quadriceps femoris muscle-vastus lateralis, obtained with a 16-channel electromyograph ME6000 in lateral and right medial and medial lobes.

Signals are marked $\mathbf{x}_l(k)$ - for the separation of the left part, $\mathbf{x}_r(k)$ - for the separation of the right part. Each signal was broken down into 5 segments ($N_s = 5$). In the time series in both directions $\mathbf{x}_l(k)$ s = 83 and in $\mathbf{x}_r(k)$ s = 83.

Dependence $F_q(s)$ for differential values $q = \overline{1,9}$ obtained after accounting trend in formulas (6) and (7) – **Figure 10**. When the values $q < 0$ and $q > 4$ are so different that it is possible to say that they are repeated (**Figure 10**) and with these values they lose their significance. It is found and in the values of the indicator Renée calculated using (12) (**Figure 11**).

The results of the indicator Hersta are shown in **Figure 12**. At $q > 2$ values it is possible to observe well-marked value of the indicator, which gives an opportunity to use it as an information indicator. Between the values of $h(q)$ is determined by the relationship $h^L_{(q)} > h^R_{(q)}$ and this is observed at positive values of q.

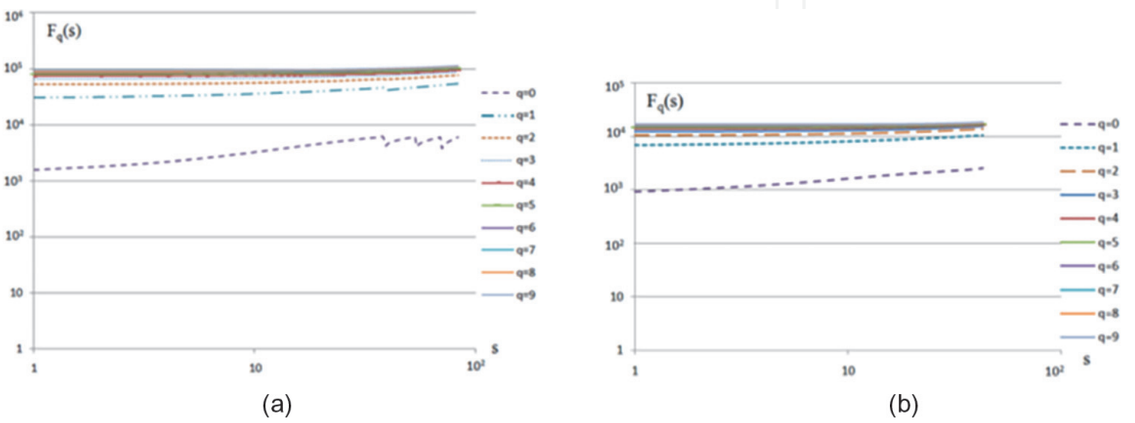


Figure 10.
The dependence of the variance of the quadriceps femoris muscle-vastus lateralis on the size of the segment s ((a) - s = 83; (b) - s = 43) at different values of the deformation parameter q (q = 1–9).

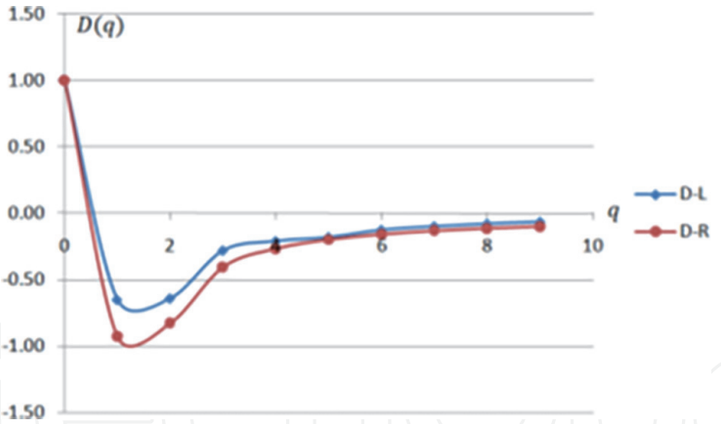


Figure 11.
Rennie's graphics for the right and left parts.

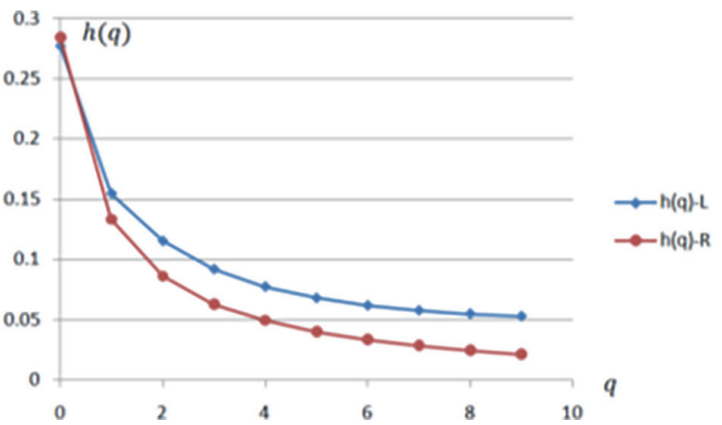


Figure 12.
Herst's indicator graphics are for the left and right parts.

Defining $D_q^{(L)}$ *and* $D_q^{(R)}$ parameter D_q obtained from the left and right parts of the Quadriceps femoris muscle-vastus lateralis muscle of the patient. From **Figure 12** easily determines the relationship

$$D_q^{(L)} > D_q^{(R)}$$

This inequality is fulfilled for $0 < q < 4$, and for other values we get repetitive values (it can be seen from the graphs), which lose their diagnostic value

$$D_q^{(L)} = D_q^{(R)}$$

The numerical value of the spectral function f (α) is shown in **Figure 13**.

As in the graphs of the indicator Hersta (**Figure 12**) here is also found good correlation in the values $q > 2$. With the increase of the value of q in the signals of the left part of the mouse, the value of f(α) is increased in comparison with the value of the right part

$$f_q^{(L)} > f_q^{(R)}$$

5.3 The conclusion

The results show that the proposed method of acceptance and for the analysis of the detection of asymmetry of human extremities. It is possible to consider that the

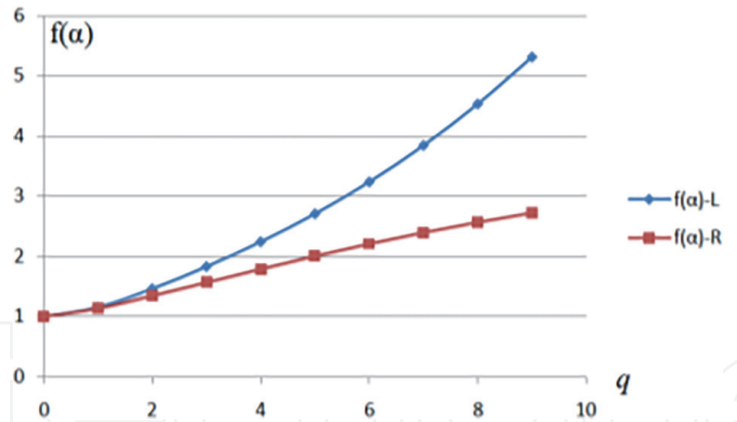


Figure 13.
Graphs of the spectral function f(α) for the right and left parts.

magnitudes that are used as the main characteristics of multifractals are informative signs that can be used to detect violations of the asymmetry of the ends. The results obtained show that in order to reveal the asymmetry of the finite points it is necessary to use the indicator Hearst and the value of the spectral function, as the informational range is wider than that of the indicator Reny.

6. Use of correlation analysis to assess the level of asymmetry in muscles

Electromyography is the only objective and informative method of studying the leading diseases of the nervous system, the functional state of the peripheral nervous system. Electromyography allows not only to determine the nature of the disease and its topical diagnosis, but also to objectively monitor the effectiveness of treatment and predict the time and stages of the recovery process [38].

Although symmetry is considered ideal in the body, this is not the case. In other words, the muscle mass of a healthy person's limbs has a slightly different mass and strength compared to the opposite side. One method of determining asymmetry is the analysis of EMG signals received by surface electrodes [25, 39].

The application of various methods to the processing of EMG signals, including mathematical, statistical, and complex, can be found in numerous literature sources [16, 29, 40–42]. It should be noted that despite the widespread use of complex mathematical processing methods in recent decades to increase the accuracy of calculations and reliability of diagnostic results, the development of processing devices based on the application of such methods is weak in terms of processing algorithms and constructive implementation. In this regard, the application of classical processing methods does not lose its relevance.

Correlation functions characterize the stable statistical characteristics of EMG. Some of these features have a functional or phenomenological value in the interpretation of EMG, but some of them open up new interesting ways in the neurophysiological analysis of the neuromotor apparatus.

In [43], the authors used a correlation analysis method to recognize the movement of the limbs. The obtained measurement results are compared with the EMG placed in the database and the signals are classified. The method of mutual correlation was used in [44] to analyze the process of renewal of the unit of movement of the nervous-muscular system. [45] examined the correlation between the age of patients with Packerson's disease and the frequency of tremor.

The maximum value of the correlation function (correlation coefficient) characterizes the relationship of processes over time, their degree of class.

Interference EMF is the result of a large number of potentials located in the separation area. However, then it is impossible to separate the action potentials of individual units of action. The dispersion of loads over time passing through motoneurons is not so great. Therefore, the statistical determination of the phase relationship of the two interfering EMGs allows to reveal the relationship of the action potentials of the two groups of units of motion over time (if these two EMGs reflect the loads of different HV). Based on this, cross-correlation analysis has opened up great opportunities in the study of synchronization of motoneuron charges.

6.1 Problem solving methods and approbation

In the mutually correlated analysis of EMG, the integral of the derivatives of two different functions is found. If they are not completely dependent and the phase ratios are random, the mutual correlation function will be equal to o for any τ. If the processes are related and the phases of any of the two curves at τ often overlap, then the mutual correlation function τ will be positive at the considered value.

In order for the value of the correlation function not to depend on the change in EMG or amplification of the electromyograph, it is normalized, ie it is expressed as part of the average power of both processes [46]:

$$R_{norm}(\tau) = \frac{\frac{1}{T}\int_0^T f_1(t) f_2(t+\tau)dt}{\sqrt{\frac{1}{T}\int_0^T f_1^2(t)dt}\sqrt{\frac{1}{T}\int_0^T f_2^2(t)dt}} \tag{16}$$

As a result of normalization, the correlation value is relative (it indicates the share of class electrical events in total electrical activity).

It is not advisable to use the correlation analysis method to measure the duration of the waves, as this quantity can be obtained by a simple instrument or by visual means.

The maximum of the mutual correlation function is accompanied not only by the value of $\tau = 0$, but also by a slip.

This shift indicates that there is a connection between the two EMFs. But one of them is late compared to the other. The average value of this delay is characterized by the value of the landslide, ie it is possible to speculate on which EMG delay is based on its direction. A small displacement may be due to a difference in the path of excitation from one electrode to another. Therefore, significant landslides greater than 3–4 ms are considered.

If we imagine the human body divided into two parts from the center, it is not difficult to see that most organs are symmetrical and consist of right and left parts: limbs (hands, feet), cerebral hemispheres, lungs, kidneys, and so on. Even the only visible organs in the general system consist of two symmetrically divided parts, such as the heart (right and left atrium, right and left ventricle), and so on.

Some pathological changes, working conditions, habits, and some sports form asymmetries that can cause serious complications in the body. This leads to the pathology of the part that consumes more energy after a certain period.

Various methods and tools are used in clinics and hospitals to identify such deficiencies. **Figure 14** shows the measurement results recorded using the ME6000-EMQ - 12-channel electromyograph.

In this example, 12 measurements are made without separation, and the results reflect the muscle strength in the form of a graph or figure. In this device, muscle

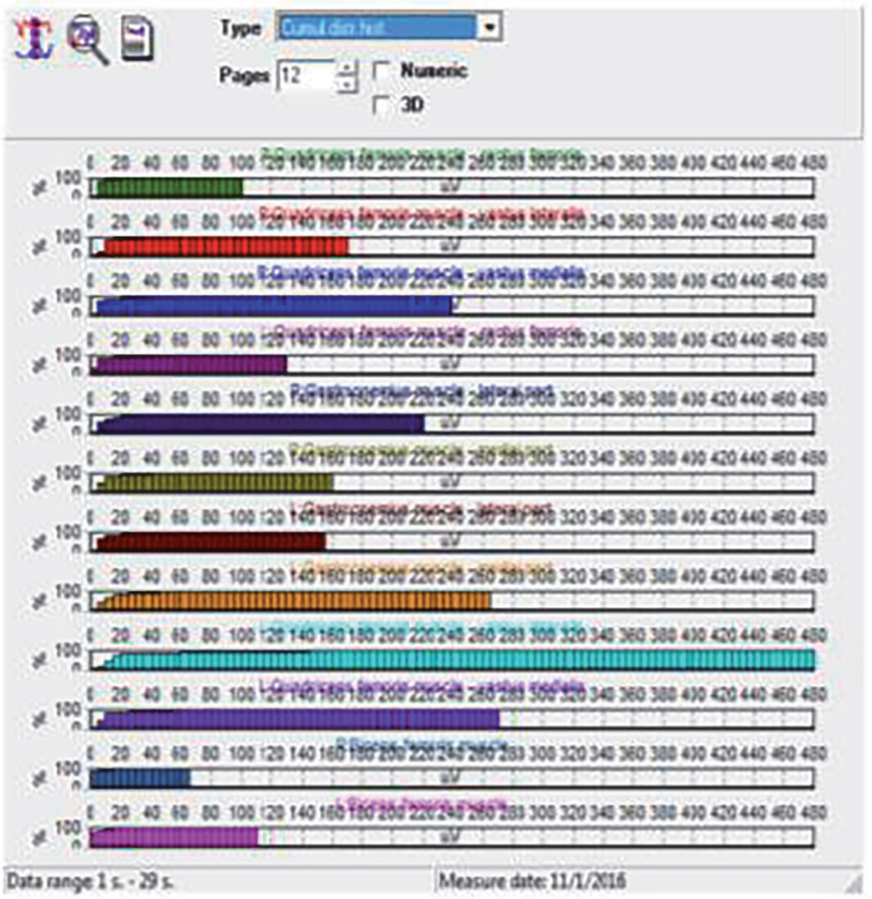


Figure 14.
Measurement result recorded using ME6000-EMQ device.

strength is recorded on a scale equal to 480 μV. The measurement time is 30 seconds. Here, the value is taken as the result of an indicator equal to the maximum amplitude. That is, for example, **Figure 1** shows the maximum value of muscle strength in the quadriceps femoris muscle - vastus lateralis, and this muscle is considered to have undergone asymmetry. However, it is not possible to see the level of asymmetry in other muscles here.

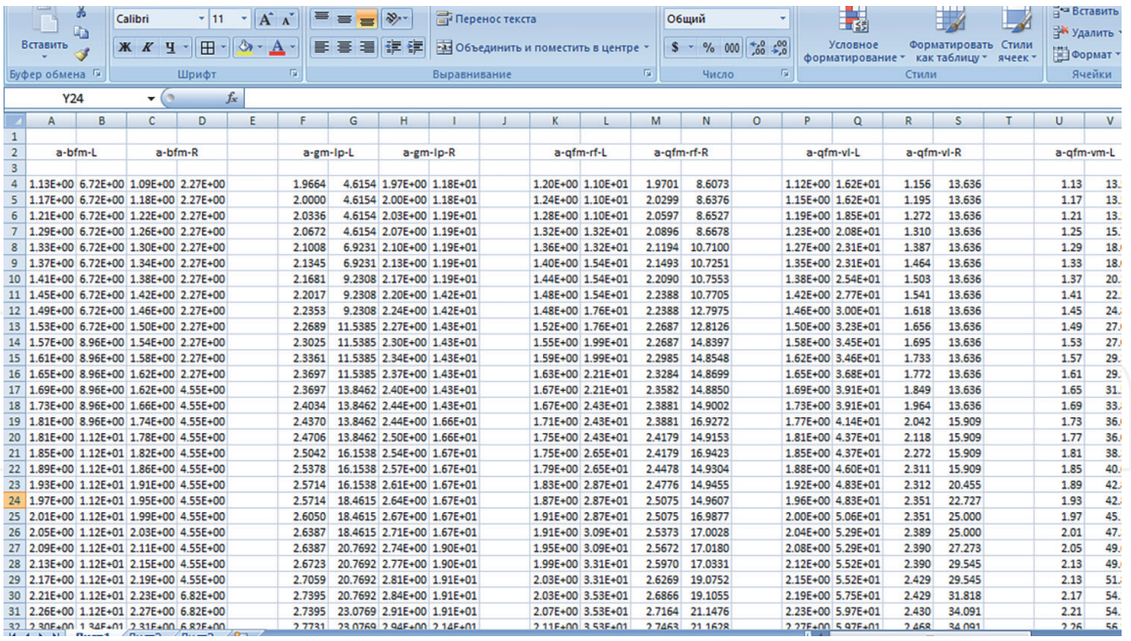
The muscles being measured are the main muscles that control the movement of the lower extremities. Muscles used in experiment are the same, and are given in **Table 1**.

The measurement results are collected in the form of a file with.dbf, .xls, .m, or any other possible extensions for further processing. An example is **Figure 15**. Here L and R show the left and right parts as the corresponding muscle.

The appropriate sequence of operations is then performed to calculate the correlation function or correlation coefficient of the corresponding pair of signals.

Computer modeling of calculations was performed in the Excel software package. The results of the calculated correlation coefficient are shown in **Table 8**, and the histogram of the results for muscles is shown in **Figure 3**.

As can be seen from the table, the results obtained (correlation coefficients) are the value of the correlation dependence of the muscle pair on each other (right or left) and not on the environment. This result does not show the difference between a muscle in one area and another, but the relationship between a pair of muscles over time. On the other hand, this approach allows us to determine how weak or strong the degree of class failure in the muscles is, and thus which muscle mass is more prone to asymmetry. These can be seen more clearly visually in **Figure 16**.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1																						
2	a-bfm-L		a-bfm-R			a-gm-lp-L		a-gm-lp-R			a-qfm-rf-L		a-qfm-rf-R			a-qfm-vl-L		a-qfm-vl-R			a-qfm-vm-L	
3																						
4	1.13E+00	6.72E+00	1.09E+00	2.27E+00		1.9664	4.6154	1.97E+00	1.18E+01		1.20E+00	1.10E+01	1.9701	8.6073		1.12E+00	1.62E+01	1.156	13.636		1.13	13.
5	1.17E+00	6.72E+00	1.18E+00	2.27E+00		2.0000	4.6154	2.00E+00	1.18E+01		1.24E+00	1.10E+01	2.0299	8.6376		1.15E+00	1.62E+01	1.195	13.636		1.17	13.
6	1.21E+00	6.72E+00	1.22E+00	2.27E+00		2.0336	4.6154	2.03E+00	1.19E+01		1.28E+00	1.10E+01	2.0597	8.6527		1.19E+00	1.85E+01	1.272	13.636		1.21	13.
7	1.29E+00	6.72E+00	1.26E+00	2.27E+00		2.0672	4.6154	2.07E+00	1.19E+01		1.32E+00	1.32E+01	2.0896	8.6678		1.23E+00	2.08E+01	1.310	13.636		1.25	15.
8	1.33E+00	6.72E+00	1.30E+00	2.27E+00		2.1008	6.9231	2.10E+00	1.19E+01		1.36E+00	1.32E+01	2.1194	10.7100		1.27E+00	2.31E+01	1.387	13.636		1.29	18.
9	1.37E+00	6.72E+00	1.34E+00	2.27E+00		2.1345	6.9231	2.13E+00	1.19E+01		1.40E+00	1.54E+01	2.1493	10.7251		1.35E+00	2.31E+01	1.464	13.636		1.33	18.
10	1.41E+00	6.72E+00	1.38E+00	2.27E+00		2.1681	9.2308	2.17E+00	1.19E+01		1.44E+00	1.54E+01	2.2090	10.7553		1.38E+00	2.54E+01	1.503	13.636		1.37	20.
11	1.45E+00	6.72E+00	1.42E+00	2.27E+00		2.2017	9.2308	2.20E+00	1.42E+01		1.48E+00	1.54E+01	2.2388	10.7705		1.42E+00	2.77E+01	1.541	13.636		1.41	22.
12	1.49E+00	6.72E+00	1.46E+00	2.27E+00		2.2353	9.2308	2.24E+00	1.42E+01		1.48E+00	1.76E+01	2.2388	12.7975		1.46E+00	3.00E+01	1.618	13.636		1.45	24.
13	1.53E+00	6.72E+00	1.50E+00	2.27E+00		2.2689	11.5385	2.27E+00	1.43E+01		1.52E+00	1.76E+01	2.2687	12.8126		1.50E+00	3.23E+01	1.656	13.636		1.49	27.
14	1.57E+00	8.96E+00	1.54E+00	2.27E+00		2.3025	11.5385	2.30E+00	1.43E+01		1.55E+00	1.99E+01	2.2687	14.8397		1.58E+00	3.45E+01	1.695	13.636		1.53	27.
15	1.61E+00	8.96E+00	1.58E+00	2.27E+00		2.3361	11.5385	2.34E+00	1.43E+01		1.59E+00	1.99E+01	2.2985	14.8548		1.62E+00	3.46E+01	1.733	13.636		1.57	29.
16	1.65E+00	8.96E+00	1.62E+00	2.27E+00		2.3697	11.5385	2.37E+00	1.43E+01		1.63E+00	2.21E+01	2.3284	14.8699		1.65E+00	3.68E+01	1.772	13.636		1.61	29.
17	1.69E+00	8.96E+00	1.62E+00	4.55E+00		2.3697	13.8462	2.40E+00	1.43E+01		1.67E+00	2.21E+01	2.3582	14.8850		1.69E+00	3.91E+01	1.849	13.636		1.65	31.
18	1.73E+00	8.96E+00	1.66E+00	4.55E+00		2.4034	13.8462	2.44E+00	1.43E+01		1.67E+00	2.43E+01	2.3881	14.9002		1.73E+00	3.91E+01	1.964	13.636		1.69	33.
19	1.81E+00	8.96E+00	1.74E+00	4.55E+00		2.4370	13.8462	2.44E+00	1.66E+01		1.71E+00	2.43E+01	2.3881	16.9272		1.77E+00	4.14E+01	2.042	15.909		1.73	36.
20	1.81E+00	1.12E+01	1.78E+00	4.55E+00		2.4706	13.8462	2.50E+00	1.66E+01		1.75E+00	2.43E+01	2.4179	14.9153		1.81E+00	4.37E+01	2.118	15.909		1.77	36.
21	1.85E+00	1.12E+01	1.82E+00	4.55E+00		2.5042	16.1538	2.54E+00	1.67E+01		1.75E+00	2.65E+01	2.4179	16.9423		1.85E+00	4.37E+01	2.272	15.909		1.81	38.
22	1.89E+00	1.12E+01	1.86E+00	4.55E+00		2.5378	16.1538	2.57E+00	1.67E+01		1.79E+00	2.65E+01	2.4478	14.9304		1.88E+00	4.60E+01	2.311	15.909		1.85	40.
23	1.93E+00	1.12E+01	1.91E+00	4.55E+00		2.5714	16.1538	2.61E+00	1.67E+01		1.83E+00	2.87E+01	2.4776	14.9455		1.92E+00	4.83E+01	2.312	20.455		1.89	42.
24	1.97E+00	1.12E+01	1.95E+00	4.55E+00		2.5714	18.4615	2.64E+00	1.67E+01		1.87E+00	2.87E+01	2.5075	14.9607		1.96E+00	4.83E+01	2.351	22.727		1.93	42.
25	2.01E+00	1.12E+01	1.99E+00	4.55E+00		2.6050	18.4615	2.67E+00	1.67E+01		1.91E+00	2.87E+01	2.5075	16.9877		2.00E+00	5.06E+01	2.351	25.000		1.97	45.
26	2.05E+00	1.12E+01	2.03E+00	4.55E+00		2.6387	18.4615	2.71E+00	1.67E+01		1.91E+00	3.09E+01	2.5373	17.0028		2.04E+00	5.29E+01	2.389	25.000		2.01	47.
27	2.09E+00	1.12E+01	2.11E+00	4.55E+00		2.6387	20.7692	2.74E+00	1.90E+01		1.95E+00	3.09E+01	2.5672	17.0180		2.08E+00	5.29E+01	2.390	27.273		2.05	49.
28	2.13E+00	1.12E+01	2.15E+00	4.55E+00		2.6723	20.7692	2.77E+00	1.90E+01		1.99E+00	3.31E+01	2.5970	17.0331		2.12E+00	5.52E+01	2.390	29.545		2.13	49.
29	2.17E+00	1.12E+01	2.19E+00	4.55E+00		2.7059	20.7692	2.81E+00	1.91E+01		2.03E+00	3.31E+01	2.6269	19.0752		2.15E+00	5.52E+01	2.429	29.545		2.13	51.
30	2.21E+00	1.12E+01	2.23E+00	6.82E+00		2.7395	20.7692	2.84E+00	1.91E+01		2.03E+00	3.53E+01	2.6866	19.1055		2.19E+00	5.75E+01	2.429	31.818		2.17	54.
31	2.26E+00	1.12E+01	2.27E+00	6.82E+00		2.7395	23.0769	2.91E+00	1.91E+01		2.07E+00	3.53E+01	2.7164	21.1476		2.23E+00	5.97E+01	2.430	34.091		2.21	54.
32	2.30E+00	1.36E+01	2.31E+00	6.82E+00		2.7731	23.0769	2.94E+00	2.14E+01		2.11E+00	3.53E+01	2.7463	21.1628		2.27E+00	5.97E+01	2.468	34.091		2.26	56.

Figure 15.
Measurement results from 12 muscles (sets Xn and Yn).

##	Abbreviation	Correlation coefficient
1	a-bfm	0.769
2	a-gm-lp	0.878
3	a-qfm-rf	0.952
4	a-qfm-vl	0.553
5	a-qfm-vm	0.995
6	a-gm-mp	0.774

Table 8.
Results of the calculated correlation coefficient.

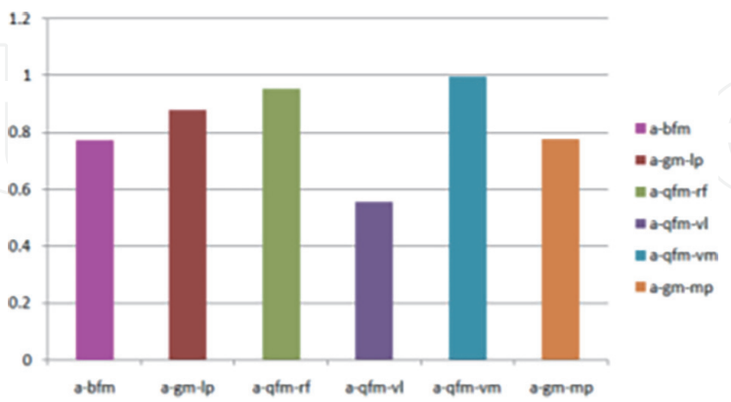


Figure 16.
Histograms of muscle-dependent values of correlation coefficients.

6.2 Application of the obtained results

Figure 17 shows a comparative interpretation of the results obtained from the measurement of muscle strength and the correlation analysis of the measurement results using the available apparatus of the EMG signals.

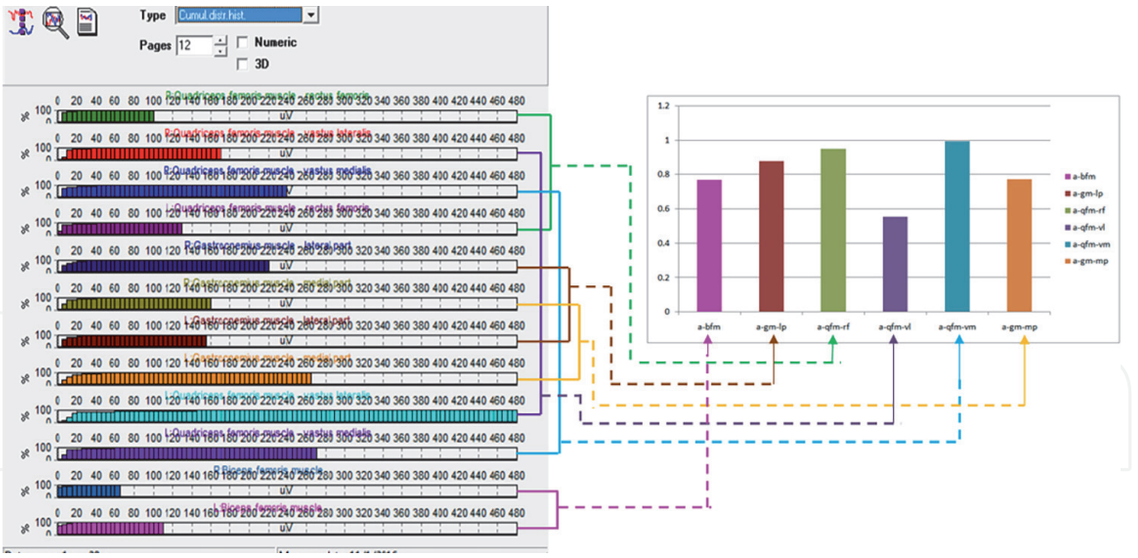


Figure 17.
Comparison of the results obtained from the measurement of muscle strength and the correlation analysis of the measurement results of the EMG signals using the existing apparatus.

As can be seen from the figure, in the first case, the measurement results are presented separately for each muscle in the form of histograms or graphs. However, sometimes the results obtained from the right or left side of the same muscle are inconsistent, making this comparison difficult. On the other hand, because the diagnosis is based on the maximum value, it is difficult to observe and compare the tendency to asymmetry in other muscles. This is also reflected in the comparison of different measurement results.

The results obtained by calculating the correlation coefficient are not only simpler in terms of visual observation, but also easier to compare. It can be easily deduced from the graph that the biceps femoris muscle and the gastrocnemius muscle are already prone to asymmetry in the medial part muscles (**Figure 17**), and this is important information in determining subsequent treatment procedures.

6.3 The result

A correlation analysis method has been proposed that allows the determination of this asymmetry on the basis of EMG signals and the judgment of its level in different measurements. For this purpose, 12 signal results from three main muscle types covering the lower extremity were used, and the asymmetry was determined by calculating the correlation coefficient of the samples. This allows to easily compare the results from a visual point of view, as well as to determine the level of asymmetry in other muscles.

7. Conclusion

Muscles are one of the main constituents of the human body and are complex and numerous. In this regard, complementary methods are needed in the diagnosis of neuromuscular diseases and the choice of treatment methods.

The results of the study show that assessment of the degree of asymmetry of muscle strength allows an expert doctor to accurately assess the differences in the biopotentials of the studied muscles of the limbs. The segmental method also gives informative values about the composition and differences between individual body

segments. The multifractal nature of human allows use of the quantities used as key features of multifractals as an informative sign that can be used to detect a violation of the asymmetry of the limbs. The isokinetic test results help to assess asymmetry in measuring muscle strength, relying on the randomness of the dynamic processes of the biological system, which again contains informative parameters. Research and practical calculations show that these methods can be used to assess asymmetry and are used as a complementary tool in making diagnostic decisions.

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