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Original article

IMPEDANCE SPECTROMETRY AS A PROMISING METHOD TO ASSESS THE EFFECTS OF PARAMETRIC AND SHOCK-ACOUSTIC EFFECTS OF NON-LETHAL WEAPON SYSTEMS

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Abstract. *The aim of the study* is to adapt the method of impedance spectroscopy as applied to the assessment of possible effects of acoustic impact of various parameters.
Materials and research methods. The study was carried out using 70 rabbits (chinchilla) weighing 2.5-3 kg. Five experimental and control groups were formed based on a preliminary examination of the animals in order to cull individuals with altered acoustic stem evoked potential and other parameters. The experimental animals were exposed to five series of 160 acoustic pulses with low-frequency spectrum each.
Results of the study and their analysis. The study showed the promising prospects of using the method of impedansometry in experimental work to assess the impact of acoustic factors on the functional state of the body.
High sensitivity of the method was also proved, allowing to identify difference in the negative impact of acoustic factors of different parameters, which were not identified, in particular, in the analysis of the altered acoustic stem evoked potential.
The results of this work confirmed the need for further research on this phenomenon and for the search for methods of assessing the functional state at the organ and organism levels, correlating with impedance parameters.

Key words: *acoustic stem evoked potential, effects, impedance polarization, impedance spectrometry, intensity, lung biophysical parameters, non-lethal weapon systems, parametric emitter, parametric exposure, peak level, phase angle, probabilistic and temporal characteristics, shock-acoustic effect*

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Оригинальная статья

ИМПЕДАНСНАЯ СПЕКТРОМЕТРИЯ КАК ПЕРСПЕКТИВНЫЙ МЕТОД ОЦЕНКИ ЭФФЕКТОВ ПАРАМЕТРИЧЕСКОГО И УДАРНО-АКУСТИЧЕСКОГО ВОЗДЕЙСТВИЯ СИСТЕМ НЕЛЕТАЛЬНОГО ОРУЖИЯ

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Резюме. *Цель экспериментального исследования* – адаптация метода импедансной спектроскопии применительно к оценке возможных последствий акустического воздействия разных параметров.
Материалы и методы исследования. Исследование проводили на 70 кроликах (шиншилла) массой 2,5–3 кг. Формирование пяти экспериментальных и контрольной группы основывалось на предварительном обследовании животных с целью отбраковки особей с измененным акустическим стволовым вызванным потенциалом (АСВП) и другими показателями. Экспериментальные животные были подвергнуты воздействию пяти серий из 160 акустических импульсов с низкочастотным спектром в каждой серии.
Результаты исследования и их анализ. Исследование показало перспективность использования метода импедансометрии в экспериментальных работах для оценки влияния акустических факторов на функциональное состояние организма.
Показана также высокая чувствительность метода, позволяющего выявить разницу в негативном воздействии акустических факторов разных параметров, не выявленную, в частности, при анализе АСВП.
Результаты данной работы подтвердили необходимость проведения дальнейших исследований этого феномена и поиска методов оценки функционального состояния на органном и организменном уровнях, коррелирующих с параметрами импеданса.

Ключевые слова: *акустический стволовой вызванный потенциал, биофизические показатели легких, вероятностно-временны́е характеристики, импедансная спектрометрия, интенсивность, кролики, параметрический излучатель, параметрическое воздействие, пиковый уровень, поляризация импеданса, системы нелетального оружия, ударно-акустическое воздействие, фазовый угол, эффекты*
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Introduction

The variety of acoustic noise to which humans are exposed in a variety of situations is not limited to hearing impairment in the form of temporary or permanent hearing threshold reductions. Under moderate and very strong, but not destructive (above 120 dB) noise exposure, even at small rates, people may experience stress in different manifestations [1, 2].

Acoustic impacts of different intensity and different probability-time characteristics can cause not only violations of the auditory system up to rupture of tympanic membranes, but also pathological changes in the lungs and brain. Morphological manifestations of acoustic effects are usually associated with exposure to acoustic pulses with a peak level above 160-170 dB. However, (unlike a shock wave characterized by a direct supersonic impact and a throwing action leading to a secondary impact on the obstacles) acoustic pulses can also cause disorders in lungs and brain, from functional to pathological ones [3].

The main requirement for special means of acoustic influence is the possibility of psycho-emotional influence by blinding and stunting, simulating the danger of health damage and death, in order to form fear as a basic emotion. Such stress reaction is possible with the use of parametric acoustic and light emission means.

Currently, the development and implementation of non-lethal weapons require justification of their purposeful use, as well as the assessment of possible undesirable consequences, i.e., safety of use [4].

Thus, the assessment of justified risk of using complexly organized and extremely intense acoustic oscillations generated by pulse or parametric impact systems is an urgent task. It can be solved by experimental studies on two or three species of animals, which allows applying the technique of extrapolation of the obtained data on real objects.

Experimental study of the effects of acoustic pulses at a peak sound pressure level of 5-50 kPa revealed a number of features of acoustic effects on lungs, different from the impact of a shock wave.

The effectiveness and safety of the acoustic pulse cannot be evaluated by overpressure parameters. Because the biological effectiveness is composed of amplitude-frequency characteristics and time parameters of the pulse. At present, no regularities determining the nature and degree of changes in the functional state of lungs and brain have been revealed. This determines the need for experimental expert evaluation of each promising special means.

As a result, a method of quantitative assessment of the functional state of lungs was developed by a complex of indices, such as specific density of air lungs, collapsed lungs, ratio of air and collapsed lung densities, difference of air and collapsed lung volume [5, 6]. This complex allows to describe the clinical picture of lung lesions.

Changes in lungs are often combined with brain stem structures lesions even when acoustic impulses of different temporal characteristics and positive phase amplitude of only 10-20 kPa are applied. These changes have been revealed by acoustic stem evoked potentials registration method. This method is used in clinical practice, in particular, to assess the degree of brain lesions — lesions from medium severity to extremely severe lesions according to the classification of types of acoustic brainstem evoked potential disturbances [7, 8].

Chemical analysis of the brain stem elements of sheep with changes in acoustic stem evoked potentials of a severe degree showed an increase in the specific content of sodium by 27.9% on average and a decrease in the specific content of potassium by 28.0% (table).

The data presented in the table indicate swelling of the brain stem part, which was reflected in the character of acoustic stem evoked potentials.

In clinical practice, when analyzing acoustic stem evoked potentials, considerable attention is paid to the latency indices of the main peaks and inter-peak intervals. They characterize the presence of changes in the state of the central nervous system in various diseases, including hearing disorders [9].

The advantage of recording acoustic stem evoked potentials in the experiment before and after exposure is the possibility of individual analysis of changes in the amplitude values and latency and connection with the factor parameters.

The analysis of the chemical composition of the brain to a large extent serves as a supplement to the results of acoustic stem evoked potentials registration. However, it is a labor-intensive method, which makes it difficult to perform the necessary amount of analyses.

The above indicates the need to expand the methodological apparatus for assessing the biological effects of the acoustic effects of developed and existing special devices.

At present in biology and medicine for measuring the electrical properties of biological tissues the method of impedance spectroscopy is increasingly used [10-14]. This

Таблица /Table

Удельное содержание некоторых элементов в стволе мозга овец контрольной группы с изменениями АСВП тяжелой и крайне тяжелой степени после воздействия акустического импульса

Specific Content of Some Elements in the Brainstem of Sheep in the Control Group with Changes in Severe and Extremely Severe ASVP Degree after Exposure to an Acoustic Pulse

Элемент Element	Контроль Control	Опыт Experience
Na, мг/г (mg/g)	1,29±0,04	1,65±0,04
K, мг/г (mg/g)	3,65±0,05	2,85±0,11
Zn, мг/г (mg/g)× 10^{-2}	1,3±0,02	1,05±0,17
Fe, мг/г (mg/g)× 10^{-2}	1,58±0,05	1,4±0,04
Cu, мг/г (mg/g)× 10^{-3}	3,94±0,14	3,46±0,07
Mg, мг/г (mg/g)× 10^{-1}	1,19±0,02	1,29±0,03

method allows differentiation of tissues and recognition of pathological processes, primarily related to the condition of cell lipid membranes. In the region of -dispersion (0.1-100 kHz) the polarization of whole cells occurs as a result of ion diffusion. Currents enveloping cells through electrolyte solutions predominate there.

The normal state of lipid cell membranes is characterized by a sharp decrease in impedance when frequencies change from 0.1 to 100 kHz. Smoothing of the dispersion curve of impedance is indicative of negative changes in cell formation.

The aim of the study is to adapt the method of impedance spectroscopy as applied to the assessment of the possible effects of acoustic effects of different characteristics.

Research objectives:

- Adaptation of digital meter LRC AM-3125 to determine the electrical properties of biological tissues;

- Evaluating the sensitivity of the adapted methodological complex of registering electrical impedance under acoustic influences;

- determination of impedance parameters of the organs of rabbits of the control group after euthanasia;

- determination of brain impedance parameters in rabbits of 5 experimental groups which were exposed to acoustic influence of different parameters.

Materials and research methods. The investigation was carried out using 70 rabbits (chinchilla) weighing 2.5-3 kg. Formation of 5 experimental groups and the control group was based on a preliminary examination in order to cull individuals with altered acoustic stem evoked potentials and other indicators. Experimental animals were exposed to 5 series of 160 acoustic pulses with low-frequency spectrum. The peak levels of groups 1, 2, and 3 were 119, 125, and 112 dB, respectively, and groups 4 and 5 were 117 and 121 dB, respectively. In terms of the spectrum the 1st, 2nd and 3rd groups were identical, and differed from the 4th and 5th groups, which were similar to each other in the nature of the spectrum.

Before and after exposure, acoustic stem evoked potentials were recorded in rabbits of the control and experimental groups [12]. Euthanasia was performed by decapitation without crossing the trachea in accordance with the method of autopsy and macroscopic examination and measurement of lung biophysical indices [7].

Brain, blood and internal organs impendance sampling was carried out with a digital meter LRC AM-3125 adapted for biological research.

Digital meter Aktakom LRS AM-3125 is intended for measurement of inductance L, capacitance C, resistance R, total resistance Z, equivalent series resistance ESR, dissipation factor D, quality factor Q and phase angle in operation of radioelectronic equipment. The instrument provides measurements at working frequencies of 100 and 120 Hz; 1, 10 and 100 kHz. The basic relative error of measurements is -0,25%.

In the experiment, we used a standard measurement cable with Kelvin clips, which were connected to the

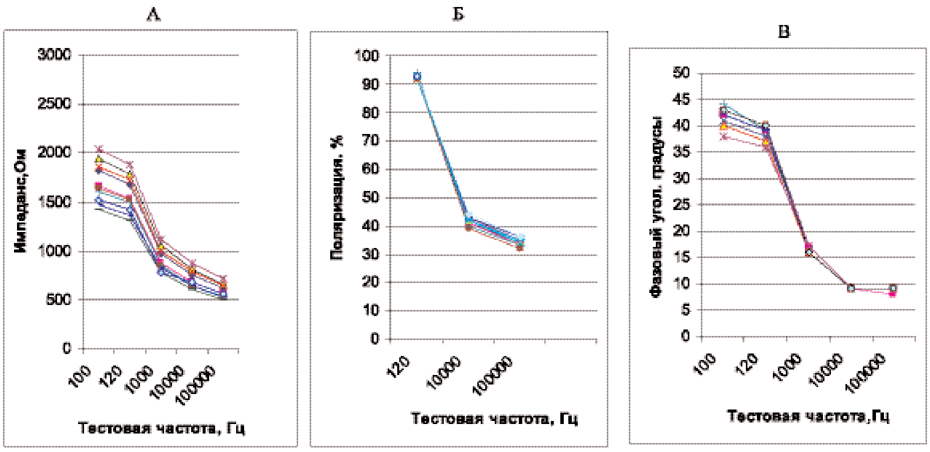

Рис.1. Импеданс головного мозга у кроликов контрольной группы
Fig. 1. Brain impedance of control group rabbits

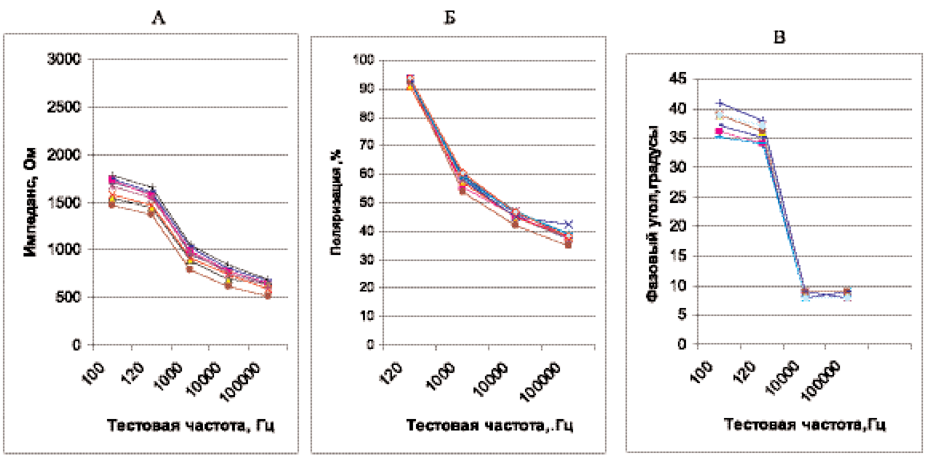

Рис.2. Импеданс головного мозга у кроликов 2-й группы
Fig. 2. Brain impedance of group 2 rabbits

contacts of the electrode holder, which were immersed in the biomaterial.

Injection needles 1 mm in diameter fixed in the holder and providing the same (10 mm) depth of immersion into the biomaterial at a distance of 10 mm were used as electrodes.

The measured initial parameters were: electric impedance dispersion and phase angle. Calculation of polarization in the group was performed.

Results of the study and their analysis. Digital meter LRC, designed to obtain the technical characteristics of radio equipment, is not equipped with electrodes suitable for measuring the electrical characteristics of biological tissues. In order to use impedansometry in a biological experiment we tested different options for installing electrodes in the measured organ. We settled on the holder providing the same immersion depth and the same distance between the electrodes. Functionality of the obtained measuring system was tested on plant objects (potato, aloe, apple) and on rat organs at different times after euthanasia. The obtained curves of impedance dispersion and phase angle and the dynamics of their transformation as a result of the natural process of tissue death showed the possibility of using this scheme for a biological experiment.

Comparative individual analysis of the parameters of acoustic stem evoked potentials of rabbits of experimental and control groups, registered before and at different times after exposure, did not reveal changes in the latency and inter-peak intervals of all major peaks, which could be associated with the influencing factor. Autopsy revealed no external macroscopic changes in the brain and internal organs, including the lungs. Biophysical indices of the lungs of the experimental animals did not differ from those recorded in the control groups.

Brain impedance of control and experimental animals was recorded between hemispheres in the vertex projection. Individual impedance dispersion curves of the brain of the control group show a difference of approximately 600 ohms at frequencies of 100-120 Hz and a smaller difference in the range 1-100 kHz (Fig. 1a). At the same time, impedance polarization in animals of this group is almost the same even at low frequencies (Fig. 1b) The difference in the value of the phase angle is only 5.6° only at 100 Hz (Fig. 1c).

Measurement of brain impedance of the animals of groups 1, 3 and 4 revealed no changes in electrical characteristics of brain tissue compared with the control and no difference in individual recorded and calculated parameters between the groups.

It seemed important to evaluate the impedance of rabbits of groups 2 and 5 subjected to acoustic influences with different frequency spectrum and peak sound pressure levels.

Comparison of the measurement results in the 2nd and control groups revealed a slight narrowing of the range of individual values and the absolute values of impedance at a frequency of 100-120 Hz (Fig. 2a, 2b, 2c). Polarization of impedance and phase angle did not differ from the control.

At the same time, in group 5 brain impedance dispersion of different rabbits differed significantly, which in turn affected the polarization curves at frequencies of 10-100kHz (Fig. 3a, 3b). The peak level of acoustic influence on rabbits of the 2nd group was higher by 4 dB than in the 5th group, but in the 2nd group no such negative processes in the brain of experimental animals as in the 5th group were detected.

The results of measurements of brain impedance parameters of the 5th group showed different acoustic sensitivity of the experimental animals. Thus, only 60% had serious deviations from the control of dispersion, polarization and phase angle (Fig. 3c). Correspondingly, in 40% of the animals no significant changes in impedansometry parameters were detected (Fig. 3d).

Thus, the study showed the prospects of using the method of impedansometry in experimental studies to assess the impact of acoustic factors on the functional state of the body.

High sensitivity of the method was shown, allowing to identify the difference in the negative impact of acoustic factors of different parameters, not detected, in particular, in the analysis of acoustic stem evoked potentials.

From the results of this work follows the need to expand studies of this phenomenon and the search for methods of assessing the functional state at the organismal and organ levels, correlating with impedance parameters.

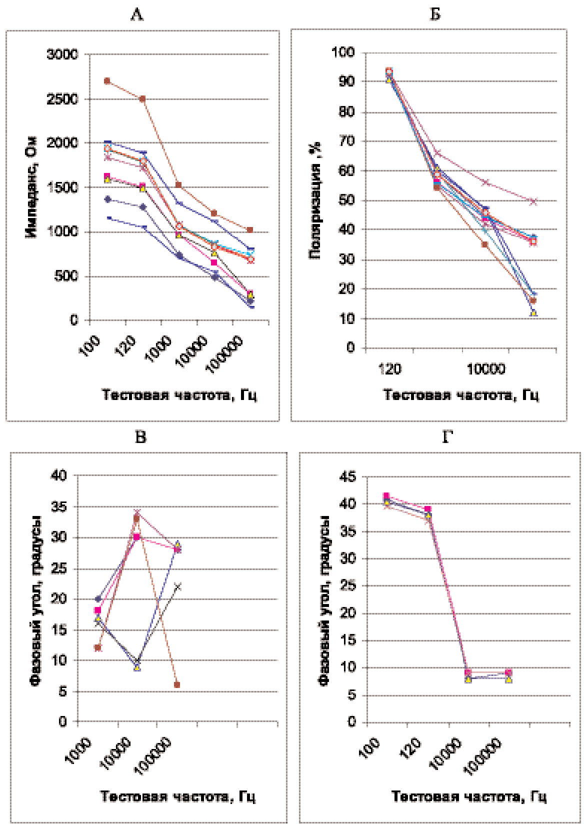

Рис.3. Импеданс головного мозга у кроликов 5-й группы
Fig. 3. Brain impedance of group 5 rabbits

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