Microwave Radiation as Interface to the Brain Functional State

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Keywords: Brain, Microwave Radiation, Interface, Absorption Coefficient, Thermodynamic Temperature Permittivity, Brightness Temperature, Fluctuations, Wavelet Analysis, Frequency Range, Metabolic and Humoral Processes.

Abstract: The paper deals with investigations of spectral characteristics of fluctuations of brain microwave radiation changes in metabolism production in the brain tissue. In the frequency band from 0.02 Hz to 0.013 Hz, these fluctuations mainly show liquid circulation of products in the intercellular and intracellular spaces of brain tissue. In the frequency band below 0.013 Hz, these fluctuations show thermodynamic changes in tissues. This conclusion is related to radiation in the frequency band from 650 to 850 MHz and is based on the results of anaysis of the phenomenological models of brain tissue radiation and thermodynamic processes in it, and, also, on the experimental data received by means of the measuring radiophysical system.

1 INTRODUCTION

The brain is the most complicated biological structure, in which functioning the interconnected dynamic systems participate (Haken, 2006). Those are: neural networks, glia, brain covers, and system of liquor and blood circulation. Investigations of a brain, behavior, and cognitive activity have a large number of peculiarities. The brain plays a special role in the organization of life sustenance of human being. Its tissues possess high intensity of metabolic processes, have no internal stocks neither oxidable substrate, nor an oxidizer and, consequently, demand intensive and very reliable blood circulation. Therefore, it is necessary to search for models adequately reflecting features of regulation mechanisms of processes in brain tissue and to work out apparatus complexes for functional researches of brain including the investigation of a homeostasis function in its tissues.

It is known that metabolism processes in brain tissues are accompanied by fluctuations of thermodynamic temperature and variations of the liquid circulation (Godik and Gulyaev, 1991). The same parameters define characteristics of the brain microwave radiation. Note that the brain brightness temperature $T_{br}(t)$ depends on two parameters: absorption coefficient $\chi(t)$ of medium and its thermodynamic temperature $T(t)$

$$T_{br}(t) = \frac{k}{2\pi\lambda^2}\chi(t)T(t), \tag{1}$$

where k is the Boltshman constant, λ is the wavelength of radiation.

It is important to search for such conditions when the brightness temperature Tbr(t) of brain can be mainly defined by one of these parameters. The problem can be solved by researching the phenomenological models of microwave radiation of brain tissues and thermodynamic processes in them.

In our investigations, methods of phenomenological simulation of these processes and physiological verification of their features were applied to verification of the experimental data received by means of contact microwave radiothermography. For formating certain physiological factors in an investigated organism, the loading tests for their stimulation were used.

2 MODELS OF BRAIN PROCESSES

According to equation (1), the brightness temperature T_{br} depends on two values χ and T. However, search of such conditions is of interest when the brightness temperature T_{br} of the brain can

Kublanov V..
Microwave Radiation as Interface to the Brain Functional State.
DOI: 10.5220/0004371703180322
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (MHGInterf-2013), pages 318-322
ISBN: 978-989-8565-34-1

be mainly defined by one of them. Such search is based on investigation of phenomenological models of microwave radiation of brain tissues and thermodynamic processes in them.

The results of the phenomenological modelling of the microwave radiation and thermodynamic processes on brain tissue revealed the following facts.

It shows that fluctuations of own microwave radiation of a brain in the band of frequencies from 650 to 850 MHz are mainly defined by changes of an absorption coefficient of white and grey substances of a brain. On the one hand, it is so since the basic contribution to radiation is brought by partial radiations of deep structures of a brain (grey and white substances). Moreover, it is because in these layers on depth more than 15 mm, a thermoneutral zone is formed, in which changes of thermodynamic temperature can be neglected.

The estimations received by modelling characterize quasistatic processes in a brain and allow us to obtain recept of the changes domain of the absorption coefficient χ and the thermodynamic temperature T in its tissues, but not time dynamics of these changes.

There are few data about the changes of thermodynamic temperature in brain tissues under the functional-loading tests received by direct methods of measurement. So, according to contact measurements, for thermoneutral zones of a brain of the human, the thermodynamic temperature can change not more, than (0.05 – 0.06) ^{0}C, and their period makes tens minutes (Ivanov, 1990). At the same time, it is shown that under functional-loading testes change of a blood flow happens rather quickly within several seconds. But temperature changes of a cerebral tissue are significantly slow, they depend on the rate of transfer of heat defined by a blood flow thermal conduction α_i.

According to (Yablonskiy et al., 2000), any temperature inhomogenities in the brain have a characteristic length Δ depending on the blood flow that are described as follows:

$$\Delta = \frac{\alpha_i}{\alpha_b \cdot p_b \cdot F}, \qquad (2)$$

where p_b is the blood density, α_b and α_i are the specific heat capacity of tissues of a brain and blood, accordingly.

Typically, Δ is approximately of several millimeters. For large animals that have head diameter of several centimeters or higher (this includes adult humans with the head diameter of ~ 15 cm; neonates with the head diameter of ~ 6 cm; most primates, etc.), the temperature distribution near the brain surface can be treated as a one-dimensional problem with temperature depending only on the distance from the brain surface.

The temperature relaxation time constant is described:

$$\tau = \frac{c_{\text{tissue}}}{\rho_b \cdot c_b \cdot rCBF}, \qquad (3)$$

where c_{tissue} is the heat capacity of the tissue, $rCBF$ is the local cerebral blood flow.

For the human and higher animals, this constant of time makes some tens seconds. These data were proved to be true by the experimental results: temperature reaction to visual stimulation by analogy «on-off» is formed in (50 – 80) sec (McElligott and Melzack, 1967). The similar result has been received in experiment on laboratory rats, in which the maximum of the temperature response was reached in 60 sec after including the stimulation (Trubel, 2006).

Results of indirect estimation of the temperature response in brain tissues at glucose test are presented in (Guyton, 2010): skin rise in temperature in a projection of one of veins in the head (v. retromandibularus) is observed in (150 – 200) sec.

In the obtained experimental data (Ivanov, 1990), the time constant of thermodynamic changes in a brain coincides with theoretical estimations, that is, it is at least not less than (50 – 80) sec. Therefore, it is possible to suppose that the spectrum of fluctuations of the brain own microwave radiation (defined by thermodynamic processes in its tissues) is in range of frequencies below 0.013 Hz.

3 EXPERIMENTAL RESEARCHES

During experimental researches of own radiation, a complex of works was performed. Metabolic or hydrodynamic processes in brain tissues were mainly activated by means of special functional-loading tests.

In the first case for research of the contribution of thermodynamic temperature in changes of the own microwave radiation, the provocative influence by a glucose is chosen. Remind that metabolic processes of a human body entirely depend on a metabolism of a glucose, which is the basic power resources of a human body, and some organs and tissues (the brain, erythrocytes) use exclusively it as power raw materials. So, the change of a metabolism in organism tissues is accompanied by the change of their local temperature.

In the second case the passive antiorthostatic load was applied. The main objective of these researches is formation in the experimental model of influence of weightlessness on a human brain. Thus, the head inclination angle relatively the feet was minus 15^0. In antiorthostatic position, a blood redistribution in vessels of the top half of the body or shift of a hydrostatic vector of liquid motion on vascular spaces are caused by moving «gravitation indifferent point» of the body towards a brain. Thus, the condition of long counteraction to the antigravitational vascular mechanisms is created in system of cerebral circulation. This state is formed by erect walking of a human that leads to raised filling the brain with blood and to shift filter-absorptive equilibriums in capillaries towards augmentation of degree of hydration of intercellular spaces, i.e., to formation of physiological brain edema.

Researches were implemented with use of the measuring radiophysical system (Kublanov, 2009) on a group of 46 healthy volunteers with age from 18 to 25 years.

The general view of the measuring radiophysical system is given on Fig. 1.

Figure 1: General view of the measuring radiophysical system.

Except monitoring the brain own microwave radiation by measuring, the radiophysical system allows one to record simultaneously the heart rate variability and to assess changes in the autonomic nervous system in the real time mode. The choice of this system is stipulated by the fact that the autonomic nervous system is a part of nervous system and coordinates activity of the systems participating in conservation of dynamic balance of vital signs, regulating a metabolism, excitability, and automatism of an internal and the central nervous system. Cooperating with the somatic nervous system and endocrine system, it provides maintenance of constancy of a homeostasis and adaptation in varying environmental conditions. But in this paper, these topics are not discussed.

During experiments, the patient was inside screened cabins of the measuring radiophysical system. Procedure of measurements included two stages: functional rest and loading test. Time intervals of staying the patient in each of these stages were chosen long enough to exclude influence of transient processes onto results of the research.

In analysis of dynamic parameters of time-and-frequency characteristics of signals of the brain microwave radiation, wavelet analysis was applied. Analysis was implemented in the following three frequency bands: (0.1 – 0.05) Hz, (0.02-0.013) and less 0.013 Hz.

3.1 The Glucose Test

During experiments, the following regimes got out: patient was in condition of functional rest within 300 sec. After that through gastrointestinal tract, the fixed dose of an aqueous solution of glucose was entered from calculation 0.2 gr glucose per 1 kg of mass of the patient body. After the receiving the glucose the time interval of observation was more than 1500 sec.

In Figure 2, graphs of the target microwave radiation signals from the measuring radiophysical system MRTHR are shown during the test with the glucose.

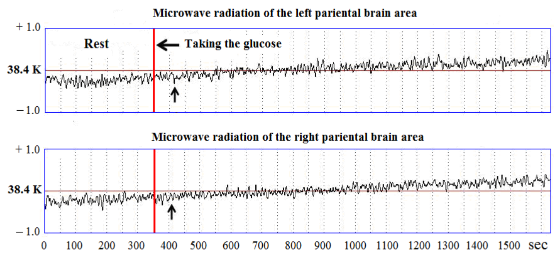

Figure 2: Signals on an exit of the measuring radiophysical system during the test with the glucose of healthy patient X. (the instant of taking the glucose is marked by a horizontal arrow, and the beginning of reaction of radiation is marked by a vertical arrow).

In Table 1, values of the mean intensities of the microwave radiation fluctuations in four frequency bands in various phases of functional research are given.

Table 1: Values of the mean intensities of the microwave radiation fluctuations in various phases of functional research.

Intensity of microwave radiation, K					
Functional status / [time], sec	Area	Frequency bands, Hz			
		[0.10, 0.05]	[0.05, 0.02]	[0.02, 0.013]	Below 0.013
Rest / [0, 300]	Left	0,16	0.00	0,14	0,03
	Right	0,18	0.00	0,18	0,12
Glucose load / [300,1600]	Left	0,21	0.00	0,19	**0,46**
	Right	0,15	0.00	0,15	**0,43**

Taking the glucose, the trend of the brain own microwave radiation is formed by (20 – 50) sec. The largest changes of intensity are observed in the band of frequencies below 0.013 Hz.

In Table 2, the values of these fluctuations are in bold.

3.2 The Antiorthostatic Test

In these experiments three functional conditions of the patient were formed: functional rest, an antiorthostatic load and clinostatic load. The patient was in each of these conditions within 300 sec.

In Figure 3, the target signals of microwave radiation of the measuring radiophysical system MRTHR are presented during the functional researches with an antiorthostatic load of the healthy patient G.

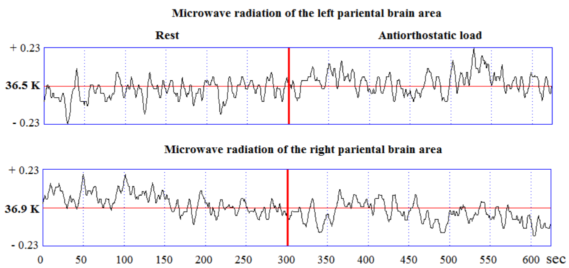

Figure 3: Signals on an exit of the measuring radiophysical system during functional researches with an antiorthostatic load of the healthy patient G.

In Table 2, values of the mean intensities of the microwave radiation fluctuations in four frequency bands in various phases of functional research are given.

Table 2: Values of the mean intensities of the microwave radiation fluctuations in various phases of functional research.

Intensity of microwave radiation, K					
Functional status / [time], sec	Area	Frequency bands, Hz			
		[0.10, 0.05]	[0.05, 0.02]	[0.02, 0.013]	Below 0.013
Rest / [0, 300]	Left	0.14	0.00	0.14	0.06
	Right	0.09	0.00	0.18	0.1
Antiorthostatic load / [300, 600]	Left	0.14	0.00	**0.25**	0.00
	Right	0.14	0.00	**0.27**	0.01

After passage from the condition of the functional rest into the condition defined by an antiorthostatic load, the trend of the microwave radiation is formed during (5 – 10) sec. The largest changes of microwave radiation are observed in frequency bands from 0.02 to 0.013 Hz. This corresponds to range (50 – 80) sec of fluctuation period of microwave radiation.

In Table 3, the values of these fluctuations are in bold.

4 CONCLUSIONS

Results of theoretical and experimental researches of the brain own microwave radiation in a band of frequencies from 650 to 850 MHz show that its fluctuations of the microwave radiation are objective reflexion of the physiological changes in brain tissues. Spectrum of these fluctuations in the frequency range from 0.02 to 0.013 Hz mainly reflects changes of dielectric permeability in tissues in depth more than 10 mm and is a consequence of the humoral processes. In the field of frequencies below 0.013 Hz, intensity of fluctuations of brain microwave radiation is defined by thermodynamic changes in its tissues that is stipulated by metabolic processes. These conclusions confirm legitimacy of the hypothesis offered by us before about the mechanism of transport of a liquid in intercellular and intracellular spaces of a nervous tissue.

Note, also, that in our researches the radiophysical system was applied. This is non-invasive, diagnostic, and meets the concept of development of the modern public health.

This allows us to regard described approach as a method for observation of functional changes in the brain at early stages of formation of various pathologies.

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