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Mini Review

Circadian temperature rhythms of the healthy and damaged brain

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The study of circadian rhythms of changes in the performance of body systems allows us to evaluate the regulatory systems and is an important tool in diagnosing the severity of the course and prognosis of the outcomes of various diseases.

The most straightforward way to examine daily rhythms is to record the temperature in different parts of the heat center. It is well established that the body temperature is lower at night than during the day and the temperature of different organs of the heat center can differ significantly while exhibiting the same diurnal dynamics. Thermoheterogeneity, which is typical for the whole organism, is most evident in the brain. Studying the circadian dynamics of the brain temperature in normal conditions and in the case of injury is an important aspect in both fundamental and applied aspects.

The brain application of thermosensors indicated that in the case of hemorrhagic stroke and severe traumatic brain injury, the best results of the therapy and the best outcomes were in patients with a maintained circadian rhythm of brain temperature [1,2]. Invasive methods of temperature monitoring may be of limited use. Noninvasive microwave radiothermometry (RTM), based on electromagnetic radiation power registration of brain tissue, which allows determining the temperature at a depth of 5 cm - 7 cm from the skin surface, i.e., solely the temperature of the large hemisphere cortex, appears to be more convenient [3].

The application of RTM in 20 healthy people revealed a distinct circadian rhythm of changes in the frontal cortical temperature of the left and right hemispheres with maximum values at 12-16 p.m. (36.5 °C - 36.8 °C) and minimum values at 00 - 04 a.m. (35.7 °C - 36.4 °C) [4]. Daily changes in axial temperature had the same tendencies: at 12-16 p.m. - 36.4 °C - 36.7 °C, at 00-04 a.m. - 36.1 °C - 36.5 °C. The amplitude of variations in cortical temperature of the left and right hemispheres were reported as 1.1 °C - 1.4 °C and in body temperature as 0.4 °C - 0.7 °C. Correlation analysis revealed strong reliable positive correlations of changes in left and right hemispheres temperature during the day ($r = 0.899$). The correlations of changes in body temperature and frontal regions of the left and right hemispheres were medium ($r = 0.446$ and $r = 0.426$, respectively), demonstrating the relative independence of brain temperature regulation.

Stable diurnal rhythms of brain temperature are directly related to sleep. A decrease in the body and the brain temperature precedes falling asleep and contributes to the development of NREM sleep, during which several short periods, characterized as REM-phases with an increase in neuronal activity, can develop [5]. The brain temperature increases during the REM phase and temperature fluctuations that reach 1 - 1.5° promote neuronal recovery and synaptic plasticity with the expression of a number of genes, in particular c-fos, which encodes the synthesis of neuroprotective proteins [6].

Using RTM, we analyzed the daily dynamics of left and right frontal cortical temperature and axial temperature in patients with severe cerebral injuries (strokes, neurotrauma, and asphyxia) who developed a state of chronic impairment of consciousness (vegetative state) after coming out of coma [7]. In all patients, the diurnal rhythms of cortical and basal temperature changes were missing. The cortical temperature ranged from 35.8 to 36.8° and body temperature ranged from 35.9 to 36.9°. The correlation of temperature variations between the left and right frontal cortical areas was strong ($r = 0.717$), but the correlation between brain temperature and the axial temperature was absent ($r = 0.158$, $r = 0.206$).

In patients in a vegetative state, the presence of NREM sleep is possible, but the presence of REM phases has not been proven. Induction of selective craniocerebral hypothermia with a 2 - 2.5° decrease in the cortical temperature contributes to an increased level of consciousness in such patients, which may be due to the simulated brain temperature variations, typical for sleep phase change [8].

The study of brain temperature using MRS (magnetic resonance spectroscopy) in 40 healthy people showed the presence of diurnal rhythms as normal. In 100 patients after severe traumatic events, only 25% preserved the diurnal rhythm of the brain temperature fluctuations, and its absence increased the prognosis of lethal outcome in the intensive care unit by 21 times [9]. It has been suggested that it is the daily rhythm, rather than absolute temperature values, that is an accurate predictor of disease outcome. This study, in general, confirms the previous results about the prognostic informativity of the study of circadian rhythms of brain temperature in patients with cerebral lesions. Yet, it contains new information about the thermal balance of the brain and thermomeostasis of warm-blooded animals.

The authors found that the brain temperature of healthy individuals ranges from 36.1 °C - 40.9 °C (38.5 ± 0.4 °C) with an oral temperature of 36.0 ± 0.5 °C and the highest temperature was reported in the thalamus. These findings change traditional ideas about thermoregulation, based on the value of the central thermostat of the hypothalamus and the "set point" of thermosensitive neurons targeting 37 ± 0.1 °C. The above observation implies further research that could provide an answer to the mechanisms of body temperature regulation, taking into account significant variations in brain temperature.

Our short review of the literature on the results of studies on the diurnal dynamics of brain temperature in normal conditions and in the case of cerebral pathology aims to attract the attention of specialists to the problems of central mechanisms of thermoregulation, their role in the pathogenesis of brain injuries, taking into account circadian rhythms, as well as to noninvasive methods of brain temperature registration.

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