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Biophoton signal transmission and processing in the brain

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ABSTRACT

The transmission and processing of neural information in the nervous system plays a key role in neural functions. It is well accepted that neural communication is mediated by bioelectricity and chemical molecules via the processes called bioelectrical and chemical transmission, respectively. Indeed, the traditional theories seem to give valuable explanations for the basic functions of the nervous system, but difficult to construct general accepted concepts or principles to provide reasonable explanations of higher brain functions and mental activities, such as perception, learning and memory, emotion and consciousness. Therefore, many unanswered questions and debates over the neural encoding and mechanisms of neuronal networks remain. Cell to cell communication by biophotons, also called ultra-weak photon emissions, has been demonstrated in several plants, bacteria and certain animal cells. Recently, both experimental evidence and theoretical speculation have suggested that biophotons may play a potential role in neural signal transmission and processing, contributing to the understanding of the high functions of nervous system. In this paper, we review the relevant experimental findings and discuss the possible underlying mechanisms of biophoton signal transmission and processing in the nervous system.

1. The debates over the brain mechanisms

Human beings have higher intelligence than other animals to learn and transform this world. The reason why human beings have such a capability is mainly because we have evolved a superior brain. The brain is the foundation of human's intelligence and spiritual activities, and is thought to be the most complex material in the universe. In about 1.3 kg brain tissue, there are 10^2 billion neurons and 10^3 billion glial cells, and each neuron would connect with thousands of other neurons [1]. It is such a super-scale neural network system that generates human intelligence and consciousness. Although we have done our best to understand the mechanism of the brain, however, our knowledge is still poor.

It is now believed that the brain is a distributed parallel information processing system [2], in which the information is encoded and transmitted in the form of neural bioelectricity and chemical molecules [3,4]. Each neuron is both a basic signal transmission unit and a signal processing unit. However, the encoding and processing of any information is not dependent on an individual neuron but a group of neurons [5,6], which is in a nonlinear network mechanism since the particular connection architecture of the neural network presents the dynamics of a complex network [7].

Indeed we have partly understood the physiological mechanism of information coding, transmission and processing in the nervous system, and the classical theory of bioelectrical and chemical transmission could explain the low-level functions of the nervous system, such as sensory, motor and reflection, however, the wide array of experimental observations regarding bioelectrical and chemical transmission have made it difficult to construct general accepted concepts or principles to provide reasonable explanations of higher neural functions, such as perception, motor control, learning and memory, emotion and consciousness. Therefore, many unanswered questions and debates over the neural encoding and mechanisms of neuronal networks remain [8–10]. For instance, the number of spikes fired by neurons that originate from bioelectrical and chemical transmission have been considered to be the primary mechanism for the encoding of neural information (rate coding); however, the fire rate is not fully correlated to neural functions, and it is even very sparse or silent for most of the neurons in the hippocampus, neocortex and cerebellum under the appropriate behavioral conditions [9,10]. In addition, the transfer speed of action potential in one neuron is limited to less than 120 m/s, and would be slower when traveling across a chemical synapse. Can this kind of speed afford the advanced features of human brain, especially the rapid changes of the conscious state? Therefore, to understand the physical and chemical changes generated by the neurons that ultimately form the human subjective feelings and awareness activities are still the biggest challenge in neuroscience.

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The existence of the above issues, on the one hand, may be because we have not really understood the signal transmission and processing mechanisms of neural network, especially the complex system of human neural network; on the other hand, whether there exist other forms of neural information coding and processing mechanisms, which are completely different from the traditional theories and concepts. Among these studies, biophotons, also called ultra-weak photon emissions (UPE), have attracted the attention as a possible medium of the transmission and processing of neural information [11–13]. In this paper, we review some advances in this research field.

2. Biophotons in relation to life activities

Bioluminescent phenomenon has been well known for long time, such as the fireflies which could emit light themselves, but this is only a small portion of bioluminescence. Now we know, almost all life, including microorganisms, plants, animals and human beings, can spontaneously radiate extremely weak photon beam in the normal or pathological conditions. Such a phenomenon is known as biophotons [14–16], which is closely related to the physiological and pathological states of the organisms [17,18]. From the points of physics, as the spectral distribution of biophotons covers, at least, the range from 200 to 800 nm with no obvious characteristic peaks [19], they are the electromagnetic waves, which are emitted by the excited atom's outer electrons when they return to the ground state. The radiation intensity of biophotons is extremely weak, only 10^2–10^3 photons/(cm^2 s) [14], with the characteristics of the Poisson coherent field [20–22], however, the current biophoton detection techniques are mainly to measure the radiation intensity from the outside of cells [23], therefore, the biophoton intensity may be considerably higher inside cells [24]. This suggestion has recently been proven that the extensive biophotonic activities were found at the cut ends of axons of cortical projection neurons slices after the application of gultamate in mouse sagittal brain [13].

2.1. The history of biophoton research

In the 1920s, Gurwitsch first reported the biophoton phenomenon [25], but due to the technical limitations, the existence of this extremely weak biophotons cannot be verified directly. In 1955, Colli first detected the biophotons of plants by using new invented photomultiplier tubes [26]. Between the 1960s and 1970s, scientists began to explore the generation mechanism of biophotons, and thought it was related to the mitochondrial respiration, lipid oxidation and other metabolic activities [27,28]. After the 1980s, two hypotheses have been gradually raised, which are metabolic hypothesis and coherent radiation hypothesis, respectively. Cadenas proposed metabolic hypothesis systematically and thought a variety of reactive oxygen species (ROS) substance would be produced in different metabolic activities, especially the aerobic metabolism (mitochondrial respiration), which has been proven by different experiments [29–34]. When these high-energy molecules or radicals return to the ground state, they will release photons outward.

Increasing experimental evidence have demonstrated that free radicals, reactive species and their derivatives act as fundamental regulated cellular signals in biological systems, and because their production is not random, but rather a precise process, suggesting that the biophoton production can also be a regulated process, and therefore biophotons may serve as cellular signals [35–39]. Popp found that DNA is one source of biophotons, and proposed biophoton coherent radiation hypothesis on this basis, and he also believed that there would be a coherent electromagnetic field inside the cells, which could be the base of cell communication [20–22].

2.2. Biophotons as a non-invasive indicator

Since the change of the level of organism oxidative stress is one of the characteristics in many physiological and pathological reactions, and biophotons can reflect it sensitively, therefore, biophotons are used widely as a non-invasive indicator of physiological state, such as the monitoring of the response of plants for flooding stress and fungal infection, the diagnosis of cancer and so on [40–43]. Meanwhile, based on the impact of biophotons on the physiological state of organism, a number of effective treatment methods and technologies have been developed, not only the sunbathing therapy [44,45]. Biophoton research can also provide biophysical theory and experimental support to traditional Chinese medicine theory of meridian and collateral or "qi" [46–48].

2.3. Biophotons mediate cell–cell communication

The first report of biophotonic finding in the 1920s demonstrated that the root tip of the mitosis onion could produce ultraviolet ray, which can promote the adjacent root tip cells of onion to divide, indicating that the biophotons have the function of information communication [25]. Further studies have provided more evidence for biophotons in mediating cell–cell communication in several microbes, plants and animals. For instance, the germinating fertilized egg of fucus may identify biophotons through the following matrix [49], and paramecium could emit biophotons to influence the feeding and division of adjacent paramecium [50]. There is nonlinear effect on biophotons radiation among the organisms in Popp's experiments of Gonyaulax and female Daphnia [51]. There exists cell–cell communication (cellular "vision") among young hamster kidney cells [52], which is mediated by red light or near-infrared light. Such a phenomenon is found in pig neutrophilic granulocytes [53] and in cultured intestinal epithelial cells (Caco-2 cells) [54]. In addition, visible light radiation has positive effect on the development of cultured neural cells [55,56].

3. Biophotonic transmission and processing in the nervous system

3.1. Biophotons in relation to neural electrical and chemical activities

Due to the intense metabolic activity, the nervous system can emit biophotons continuously, and the electrical activities may affect biophotonic emission. Pulse current stimulation [57] or depolarization caused by the high-potassium medium can enhance biophotonic activities in neurons, while the removal of extracellular Ca^{2+} or the addition of tetrodotoxin (TTX) can weaken biophotonic activities [58]. In recent experiments, we show that the long-lasting application of glutamate to mouse brain slices produces a gradual and significant increase of biophotonic activities. The initiation and/or maintenance of biophotonic activities by glutamate can be obviously blocked by oxygen and glucose deprivation, together with the application of a cytochrome c oxidase inhibitor (sodium azide), but only partly by an action potential inhibitor (TTX), an anesthetic (procaine), or the removal of intracellular and extracellular Ca^{2+} [13]. In addition, *in vivo* studies of brain biophotonic activities have found to be related to electroencephalography (EEG) [59–61].

3.2. Biophotonic transmission in neural circuits

If the biophotons can mediate the transmission and processing of nerve signals, they should be able to be transmitted along the nerve fibers. Theoretical speculation is that biophotonic transmission may be related to mitochondria and microtubules in the nerve