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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 fibers. Mitochondria themselves could generate biophotons, and their morphology and intracellular distribution could form a network to coordinate activities through electrical coupling [62–64]; while microtubules may play an important role in information processing, suiting nerve signal transmission, coding, processing and storage [65]. In addition, according to Jibu's theory, light can be transmitted in microtubules without heat noise and weakening [66], that is to say, filamentous mitochondria and microtubules can be used as neuronal "optic fibers" [67], and the biophotons can be transmitted in these "optic fiber" networks.

Empirical researches have shown that the propagation of biophotons in the brain depends on the trend of nerve fibers [68]. The previous studies of our group have confirmed that the external light-induced biophotons could transmit along the sensory and motor nerve fibers, which could be blocked by an anesthetic (procaine) or the application of metabolic inhibitors (deoxyglucose together with sodium azide) [11].

In our recent study, by observing the projection fibers of corpus callosum originating from cortical neurons, and the neural circuits of the hippocampus in mice, it has been proved that glutamate-induced biophoton emission mainly comes from the cut profiles of axons, suggesting that biophotonic activities can be transmitted along the axonal fibers of neural circuits. Such a biophotonic transmission can be significantly blocked by the hyperphosphorylation of microtubule-associated protein tau, linking it to the microtubule system [13]. As to the mechanism of biophotonic transmission, whether it is completed by protein–protein biophotonic interactions [11], or through the electromagnetic radiation in the cavity of microtubule, or a combination of both, still needs to investigated further.

Based on the findings mentioned above, we propose that the biophotons in neural cells may consist of two components, called background biophotons and signal biophotons (or active biophotons), respectively [11]. Background biophotons are generated by the metabolic activity in neural cells and may play a role in maintaining the "pre-action" state of the molecules that are responsible for biophotonic transmission; while signal biophotons can transmit along dendrites and axons in neural circuits, and may carry neural information, being a basis of neural communication.

3.3. Biophotons in visual perception

Traditional theory holds that the external light signal is transformed to neural electrical signal by the retina, and then enters into the central nervous system through the optic nerve and produce visual perception. However, some new studies have found that neural electrical signals *per se* do not explain some of special visual phenomena, such as phosphenes, negative afterimage and retinal discrete dark noise. The recent theoretical and experimental studies have demonstrated that light-induced biophotons or spontaneous biophotons may provide explanations for these visual phenomena [69,70]. The endogenous oxidative metabolism in eyes, which can be influenced by external factors such as ionizing radiation (cosmic particle rays) and space travel [71], could produce biophotons, which then activate the rhodopsins in retinal photoreceptor cells and result in a certain sense of light [71,72]. The existence of induced biophotons in all parts of rat eyes was verified by a recent experiment [70].

Bókkon proposed that biophotons may be involved in the whole process of visual perception and representation. The external visible light signals are transformed into neural electrical signals by the retina, and then transmitted to the primary visual cortex (V1 area). The electrical signals are converted into biophotonic signals in V1 region synchronized via a radical reaction with mitochondrial cytochrome oxidase (CO), and then the biophotonic signals are transmitted and processed at a higher level of neural circuits, thus form visual perception, visual image and even visual awareness [73–75]. Experimental studies have demonstrated significant increases in biophotonic energies along the right side of human brain (where visual information is mainly processed) but not the left when subjects imagined white light in a dark environment [12,76]. However, Bókkon's theory does not consider biophotons as a relative independent medium to complete the transmission and processing of nerve signals. Our recent study has provided evidence that either bioelectrical or chemical transmission may only provide a basis for the initiation and maintenance of biophotonic activities and transmission in neural circuits [13], raising the possibility that biophotons may serve as a relative independent medium of nerve signals.

3.4. Biophotons and neural coding

There are both material basis and experimental evidences that suggest that biophotons could mediate signal transmission in neural circuits. Similar to the real-life fiber–optic communications, biophotons may encode neural signals through intensity and frequency [77]. On the one hand, the change of physiological state of the organisms or the stress response to external stimuli will lead to the intensity change of biophotons activities; on the other hand, according to the coherent radiation theory, the frequency of biophotons generated by nucleic acid synthesis is coherent, which is different to that generated by other metabolic and physiological activities, raising the possibility that the different spectral biophotons generated by the neural cells may have different information functions.

The nervous system also has material basis to complete neural information coding via biophotons. Among a variety of biological amines, these that have the strongest fluorescence characteristics are selected by evolution as the neurotransmitters, such as 5-serotonin, dopamine and norepinephrine. Due to the special characteristics of fluorescence, they may be involved in the neural information coding, transmission and processing, in particular the biophotonic transmission in synapses. In addition, there are other natural light-sensitive biological molecules in neurons, such as porphyrin ring, pyridine ring, lipid chromophore group and aromatic amino acid, and the mitochondrial electron transport chain also contains several chromophores. Light-sensitive molecules can absorb biophotons and pass the energy to other molecules through resonance energy transfer, leading to the conformational changes and triggering or modulating complex cellular signal processing [74].

Compared with the electrical and chemical signals, biophotons, as the carrier of information coding, transmission and processing, have some distinct advantages: fast delivery, large amount of information and low energy consumption. Human brain only accounts for about 2% of body weight but consumes 20% of the body's energy, having reached the limit of physical ability, and these advantages may have important physiological significance. We propose that the red-shifted biophotons may be a key characteristic in human brain for having higher intelligence than other animals since low-energy spectral biophotons may be transmitted and conducted more efficiently in neural circuits.

3.5. Biophotons, quantum brain and consciousness

In traditional idea, the mechanisms of brain function should obey the bioelectrical and biochemical reaction rules, but based on such a consideration, we cannot understand the advanced features and mental activity of human brain, especially the generation of consciousness. Since several similarities are existed between neural information processing and quantum process, such as integrity, coherence and probabilistic [78,79], there are some tries to study the working mechanism of the brain from the view of quantum mechanics [80–82].

According to Penrose–Hameroff hypothesis, microtubule proteins in the nervous system may have quantum computing functions, and the change of macro coherence state of microtubule proteins may be the mechanism for the generation of consciousness [83,84]. Rahnama et al. carried out a theoretical analysis of the interaction between mitochondrial biophotons and cellular microtubule system based on quantum mechanics, and they suggested that biophotons may influence the depolymerization and restructuring of microtubule, which mediates the relationship between biophotons and EEG in the cerebral cortex [85]. In addition, Dotta et al. found that if one participant see a flashing lights in a dark room, the biophotonic emission of the head of another participant in another dark room will increase correspondingly, while the heads are in the same condition of external magnetic field, indicating that under special condition, the change of biophotonic emission may reflect the information exchange of quantum type (macroscopic quantum entanglement) between the subjects [86–88].

However, the theory of quantum information processing of brain always faces a fundamental problem, which is in the spatial scales of biological macromolecules or above, a lot of special quantum properties will not appear. For example, the quantum superposition and the quantum coherence are the essential features of quantum information processing, but the maintenance of these properties needs harsh conditions of ultra-low temperature and undisturbed by outside. Due to the high temperature of 37 °C and the interaction of materials in the human brain, it is hard to keep these quantum properties [89]. Human brain may be not a pure "quantum computer", but this is not to say that the quantum properties of the material is not involved in nerve information coding and processing since quantum mechanics itself has many problems to be elucidated too.

4. The remained questions for biophoton research in relation to brain functions

Although research advances in biophotons allow for the reconsideration of the traditional views on the signal transmission and processing in the brain, however, many questions remain to be answered. For example, what is the origin of signal biophotons? In fact, in addition to free radical linked production of biophotons, we have recently provided evidence that the biophotonic activities and transmission in neural circuits may originate from possible further mechanism [13]. How do biophotons play a role in neuronal communication and information processing? What is the mechanism of biophotonic transmission in neural circuits? It includes not only its transmission along axons and dendrites, but also across the synapses; how do we construct novel models for neural information coding, storage and processing according to biophotonic activities and transmission? The answers to these questions should help to explain the fundamental mechanisms of neural communications, and the functions of nervous system, such as vision, learning and memory, cognition and consciousness, and the mechanisms of human neurological and psychiatric diseases.

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