The code of light: do neurons generate light to communicate and repair?

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A great challenge in neuroscience has been to understand how neurons communicate. The neuroanatomists of the 19th Century could see neurons stretching processes to contact other neurons, but could not see the detail of the contact. Even when membranes are highly active, with their activity being electrical and their communication being either chemical, electrical or gaseous.

Although first proposed about a century ago, another form of communication between neurons has been attracting attention in recent times. This form of communication involves light; that neurons, indeed all living cells, can generate light and may use this to send messages to each other. This phenomenon has been termed ultra-weak photon emission. There are two striking features of biophotons. First, they are emitted with a rather broad range of wavelengths from ultraviolent light to red and near infrared range (i.e., 200–950 nm). Such a broad range opens the possibility that particular wavelengths within that range are associated with different cellular reactions and different states of homeostasis (Dotta et al., 2014; Tang and Dai, 2014). Second, this self-generated light from neurons is not bright, not something that is detectable by the naked eye, nor even a relatively sensitive radiometer, but only with an ultra-sensitive light detection device, such as a photomultiplier or with a very specific histochemical stain (Zangari et al., 2021). It has been estimated that the number of biophotons generated by a cell can vary anywhere between 2–200 photons/s/cm² (Tang and Dai, 2014; Salari et al., 2015). This level of emission appears to occur steadily, but the level is increased or decreased by an external stimulus. For example, a set of pathways that are preferentially (but not exclusively) along the axons of large numbers of neurons may have evolved to use biophotons as a means of communication (Tang and Dai, 2014). In addition to this flow along extracellular pathways, intrinsic activity associated with dopamine, serotonin or noradrenaline, appears most closely linked with biophoton emission and fluorescence (Tang and Dai, 2014; Mothersill et al., 2019). In addition to this flow along structural pathways, there appears to be some penetration of biophotons across the extracellular matrix, which may not clear what distances are involved here, but it is tempting to speculate that there is a biophoton code of communication between neurons that is not restricted by a set pathway or synaptic connectivity, one that may involve many neurons across, for example, an entire cerebral lobe. This mode of communication would be near-instantaneous and would require little energy, since it may use the collateral emission of light by major metabolic pathways (Tang and Dai, 2014).

Why do neurons generate light and should it be surprising? Surprising always arises from expectations and neuroscientists have had to expect the obvious. The brain is the most metabolically active organ of the body at rest. Though it forms –2% of total body weight, the brain requires ten-fold that share of the cardiac output to keep functioning. And what the brain needs from all that blood is glucose and oxygen to fuel energy production. All our tissues generally require metabolism to be active and the blood that brings their nutrients spreads that heat throughout the body. Hence, there should be no surprise that the same metabolic processes of mitochondria that produce the energy currency of neurons (i.e., adenosine triphosphate) and some collateral heat, may also generate light, in the form of biophotons.
An issue worthy of some comment is whether external environmental light can influence the biophoton network between neurons (Grass et al., 2004; Tang and Dai, 2014). Nearly all neurons, particularly those of the central nervous system, are encased in bone (cranium and vertebral column) and thick connective tissue coverings (meninges). They work, for the most part, in near total-darkness. In these regions, communication by biophotons may be little influenced by external light. But there are some notable exceptions. The neurons of the retina, as well as peripheral sensory neurons innervating the skin are exposed continually to light and these neurons, unlike those that work in the dark, could have their biophoton network compromised. There is evidence however, that the communication by biophotons still operates within these light-exposed neurons. It appears that these, perhaps all, neurons may have developed a means of incorporating any external light exposure as part of their working biophotonic system of communication and repair (Wang et al., 2011; Tang and Dai, 2014). Indeed, most previous work on biophotons has been on non-neuronal cells and most of these cells – whether from plant or animal – are exposed to external light continually (Grass et al., 2004; Tang and Dai, 2014; Salari et al., 2015; Mothersill et al., 2019; Van Wik et al., 2020). Hence, it is likely that any given living cell can operate a biophoton network with or without external light exposure.

In this context, many of the beneficial effects on cell function and survival provided by photobiomodulation, the application of red to near infrared light (λ = 600–1000 nm) on body tissues, may depend on the biophoton network (Liebert et al., 2014). Photobiomodulation, when applied to a living cell, stimulates mitochondrial activity and improves function and survival (Hamblin, 2016), just as biophotons of similar wavelengths would do, albeit at much lower intensities, after being emitted from either the same or bystander cells. This feature would explain, at least in part, the findings that neurons located so deep within the near total-dickness of the brain, are receptive to light and benefit from photobiomodulation. That is because they themselves use light - at very low intensity - to communicate and maintain homeostasis and photobiomodulation has its effects by engaging this network (Liebert et al., 2014).

In conclusion, there is a still-growing body of evidence that neurons self-generate light across a range of wavelengths, from ultraviolet to red and near infrared; and that this light, referred to as biophotons, has during evolution become a means of communication between neurons, informing each other on their different states of activity and homeostasis. Biophotons may also be used for repair when the neuron is damaged or in distress, either for itself or for others. We suggest that the beneficial effects of photobiomodulation pivot on engaging this biophoton communication and repair network. Although there is so much that remains unclear of how and why biophotons are produced, as well as their precise functional significance, the therapeutic implications of de-coding the biophoton communication and repair network are enormous. Technically, the development of an ultrasensitive biophoton detection device that identifies mitochondrial pathology in distressed and/or damaged neurons of the living human brain and then guides therapeutic intervention (e.g., targeted photobiomodulation) would be a goal worthy of much endeavor and exploration.

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