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New perspective in cell communication: Potential role of ultra-weak photon emission

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ABSTRACT

Evolution has permitted a wide range of medium for communication between two living organism varying from information transfer via chemical, direct contact or through specialized receptors. Past decades have evidenced the existence of cell-to-cell communication in living system. Several studies have demonstrated the existence of one cell system influencing the other cells by means of electromagnetic radiations investigated by the stimulation of cell division, neutrophils activation, respiratory burst induction and alteration in the developmental stages, etc. The responses were evaluated by methods such as chemiluminescence, ultra-weak photon emission, generation of free oxygen radicals, and level of thiobarbituric acid-reactive substances (TBARS). The cellular communication is hypothesized to occur via several physical phenomenon's, however the current review attempts to provide thorough information and a detailed overview of experimental results on the cell-to-cell communication observed in different living system via ultra-weak photon emission to bring a better understanding and new perspective to the phenomenon.

1. Introduction

Organisms are known to emit spontaneous ultra-weak photons which are differentiated from the phenomenon of delayed luminescence as it is spontaneously emitted by living organism without any photoexcitation [1]. The intensity of ultra-weak photon emission is found to be in the order of 10^{-16}–10^{-18} W/cm^2 which is far behind the sensitivity of the human eye. The ultra-weak photon emission have been an research topic of limited groups for last few decades around the globe but still is deprived of extensive experimental results on the mechanism and understanding the significance of the phenomenon. Elementary biochemical reaction such as oxidation of biomolecules during the cellular metabolism is considered as a source of the ultra-weak photon emission [2–6]. It has also been proposed by Fritz-Albert Popp that DNA of an organism can also act as a source of ultra-weak photon emission and later its coherence properties was illustrated [7]. Different terminologies such as biophoton emission, biological chemiluminescence, low-level chemiluminescence or autoluminescence have been used by different authors during the span of time referring the same phenomenon [2,4,7–11]. There are also reports on the spectral distribution of ultra-weak photon emission from living system measured utilizing interference filters and edge filters. The study of spectral properties of ultra-weak photons from skin are found mainly at the red region of the spectrum revealing the role of singlet oxygen ($^1O_2$) dimol emission [12–14]. However, a shift has also been reported where maximum emission was observed at a wavelength of 500 nm [14]. Under UV stress, photon emission at 400–580 nm has also observed supporting the assumption that triplet carbonyls [$^3(R=O)^*$] is a main source of ultra-weak photon emission after the exposure of the human skin to UV radiation [15–19]. Thus, $^3(R=O)^*$ and $^1O_2$ are predicted as the main source of ultra-weak photon emission in non-photosynthetic samples. In chlorophyll-containing samples, the photons are known to be emitted mainly by chlorophyll and $^3(R=O)^*$. The ultra-weak photon emission has also been observed in the spectral range of 250–380 nm but there exist limited evidences on the photon emission in UV region [20]. Based on the results obtained by different authors, it can be concluded that the major part of

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ultra-weak photon emission is in the visible region of the spectrum but the contribution in the UV region cannot be completely ruled out.

Experimental result evidence the existence of cell-to-cell communication between cells utilizing a broad range of electromagnetic radiation [1,21–23]. It has been observed that the ultra-weak photon emitted from biological system can influence its neighboring population kept at close proximity. The research on cellular communication dates back to 1979, when the phenomenon of cellular communication via electromagnetic radiation was studied in the ultra-violet range of the spectrum [24,25]. The pioneer in the study for cellular communication, however, is A. Gurwitsch who worked with onion tips during 1925 and demonstrated that electromagnetic radiation emitted from living organism can accentuate cell division. Mirror cytopathic effect i.e., morphological changes in the neighboring population under the effect of virus infected tissue culture placed in close proximity was demonstrated in human and chick embryos fibroblasts where the infected tissue was considered to be the source of photons or specific signal and the non-infected as the detector [26]. However, there exist limited experimental data showing the phenomenon and are described in Sections 5 and Table 1.

2. Detection of ultra-weak photon emission and cell-to-cell communication

The intensity of ultra-weak photon emission which is claimed to be involved in cell-to-cell communication is 1000 times lower than the sensitivity of human eye and thus its detection and characterization is intricate [27,28]. During the last few decades, development and improvement in the detection techniques have made possible the detection of spontaneous ultra-weak photon emission distinguishing small changes which occur during any fluctuation from the normal state of an organism. Since a very small leakage of photons from an external source can influence the results of ultra-weak photon emission and cell-to-cell communication and it is a pre-requisite to standardize the experimental setup and instruments in order to avoid any error during the measurements. Different experimental setup utilized during the study of cellular interaction in varied living organism has been described in Fig. 1.

2.1. Detection and experimental setups of ultra-weak photon emission measurements

Since the intensity of ultra-weak photon emission is extremely weak, any small interference can lead to false signals and thus isolated dark room or chambers are a pre-requisite. The duration of dark adaptation can range from minutes to hours depending on the sample/subject to be measured. For instance, sample containing chlorophyll have to be dark adapted for period of hours in order to avoid long term delayed luminescence which is shorter in case of non- chlorophyll containing sample.

For the two-dimensional spatial and temporal imaging of ultra-weak photon emission, metal oxide semiconductor (MOS) charge coupled device (CCD) camera are most widely used [5,29,30]. For the CCD camera used for capturing ultra-weak photon emission, the CCD chip should be cooled either by using a liquid nitrogen cooling system, a peltier system or mechanical pumps (cryo-pumps) to decrease the thermal noise and enhance the signal-to-noise (S/N ratio) [31–33]. In the recent past, CCD cameras have been widely used for two-dimensional imaging of ultra-weak photon emission from the microbial, plant and animal both *in vivo* and *in vitro* [29,34–36]. The limitation which still persist is the spectral sensitivity of presently employed CCD camera which are currently only in the range of visible spectrum. Besides this, during the measurements, the parameters which are to be considered for image acquisition are : scan rate, gain, variable accumulation time and image formats. Different accumulation time and image format have to be used in order to enhance the image quality and the signal-to-noise (S/N) ratio. Software and hardware binning are also used to enhance the quality of the image.

Photomultiplier tubes have been used from last few decades for ultra-weak photon detection and are the major component of present day spectroscopic instruments. During the past 3 decades, the PMT's have been extensively used in the detection of ultra-weak photon emission by several authors [2,10,21]. A wide range of PMT's types has been used with a big difference in the background noise and thus comparisons of signal between different results are nearly impossible. It should be pointed here that PMT's can be precisely used to study the kinetic behavior of ultra-weak photon emission which however is not possible utilizing CCD.

2.2. Detection and experimental setup in cell-to-cell communication measurements

The studies with cell-to-cell communication via ultra-weak photon emission mainly followed the similar pattern of experimental setup where authors either used cuvettes, specially designed chambers or petri-dishes with different arrangements (Fig. 1). The selection of cuvettes however was variable with some particularly used quartz cuvettes while other used polystyrene or both. With experiments where petri-dishes were used, different sizes in order to keep different distances between the cell cultures were used. In case of fewer experiments, specialized constructed homemade setup were used [37,38]. These devices resembled the shape of a cylinder and was separated into equal compartments by glass window. The volume of culture in each compartment however was again variable ranging from 1 ml of culture [37] to 40 ml [38]. Besides this, experiment utilizing test-tubes kept at different distances has also been performed [37].

In experiments with petri-dishes, the surface of the dishes were used as chemical barrier, the cell populations allowed to interact were kept one above the other as shown in Fig. 1 (IIA) and Fig. 2 while in experiments utilizing cuvettes, the population were kept adjacent or inside of each other as shown in Fig. 1(I A and I B). In Fig. 2, petri-plates with different height were also used to estimate the distance to which information transfer can occur via ultra-weak photon emission. During most of the experiments, the author used different densities of cell culture to monitor the influence of one population on the other, a schematic representation of which is shown in Fig. 1(I and II). Other parameters such as cell mortality, polarization, neutrophil stimulation were also monitored by authors [39–41]. Besides the different setup used during the experiment, different materials such as polystyrene, glass and quartz were used in the experiments. The different material allowed variable wavelengths of light to pass through and thus helped author to understand the spectrum of ultra-weak photon emission involved in the cell-to-cell communication. Different experimental setup utilized during the study of cellular interaction in varied living organism has also been described in Fig. 1.

3. Generation of ultra-weak photon emission

The existence of spontaneous and delayed ultra-weak photon emission is widely accepted now a days with hundreds of experimental results from different living system ranging from microbes, plants and animals [42,43]. With the development of PMT's, photodiodes and CCD devices which are highly reliable and sensitive, the detection of ultra-weak photon emission has become possible. The early evidences on emission of ultra-weak photon was reported in green plants (*Phytolacca Americana* and *Trifolium repens*) and green