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

Ankush Prasad [a], Claudio Rossi [b,c,*], Stefania Lamponi [b], Pavel Pospíšil [a], Alberto Foletti [d]

[a] Department of Biophysics, Centre of the Region Haná for Biotechnological and Agricultural Research, Faculty of Science, Palacký University, Šlechtitelů 11, 783 71 Olomouc, Czech Republic
[b] Department of Biotechnology, Chemistry and Pharmacy, University of Siena, Via A. Moro, 2-53100 Siena, Italy
[c] Centre for Colloid and Surface Science (CSGI), University of Florence, Via della, Lastruccia 3, Sesto Fiorentino, FI, Italy
[d] Laboratory of Applied Mathematics and Physics, Department of Innovative Technologies – DTI, University of Applied Sciences of Southern Switzerland-SUPSI, Manno, Switzerland

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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

* Corresponding author at: Department of Biotechnology, Chemistry and Pharmacy, University of Siena, Via A. Moro, 2-53100 Siena Italy. Tel.: +39 3381064621; fax: +39 0577234177.
E-mail address: claudio.rossi@unisi.it (C. Rossi).

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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

Table 1
Historical aspects on the experimental studies on cell-to-cell communication interaction via ultra-weak photon emission.

Authors & year	Organisms/Organelles	Experimental setup	Observations and results
Kaznacheev et al. (1980)	Tissue culture (human and chick embryonic fibroblast)	Quartz (280–320 nm) and glass slides (>440 nm) seperation with thickness of 0.2–2 mm	Mirror cytopathic effect (CPE) i.e. morphological changes was observed between two isolated cell culture induced by means of virus and mercuric chloride [26]
Batyanov (1984)	Mitochondria	Quartz cuvette	The change in the oxygen consumption was monitored and was postulated that UV radiation induced the activation of oxidative phosphorylation and destruction of mitochondria [56]
Galantsev et al. (1993)	Mammary explants of mice	Quartz glass wall seperation and non-transparent screens (homemade setup)	Changes in the intensity of chemiluminescence was observed in two mammary explant seperated by quartz. The induction of one explant treated with hormones influenced the other mammary explant [65]
Shen et al. (1994)	Neutrophils	Quartz cuvette seperation	Neutrophils from pig blood stimulated to undergo respiratory burst influenced the adjacent neutrophils seperated by quartz. A change in chemiluminescence and production of superoxide anion radical was found in the optically induced neutrophils [41]
Musumeci et al. (1999)	Yeast cells	Quartz cuvette seperation	Cell to cell interaction was demonstrated in temperature-sensitive mutant (*Saccharomyces cerevisiae*) [57]
Burlakov et al. (2000)	Loach (*Misgurnus fossilis*) embryo	Quartz cuvette, individual experiments wrapped in black paper and isolated from external electromagnetic field	The embryos of different ages were made to communicate optically by keeping them in close proximity. The observation indicated the deviation from normal pattern of growth [58]
Trushin (2003)	*E. coli* (*Escherichia coli*)	Homemade experimental setup with glass (Pyrex) seperation	*E. coli* was shown to be able to communicate via glass seperation and role of visible and infra-red light was presumed to be involved in the cellular interaction [22]
Jaffe (2005)	Brown algea, *Egregia menziesii* and *Fucus furcatus* together with *Zostera marina*	Petri-dishes	Luminescence generated from source plant, *Zostera marina* influenced the thallus growth. The growth of the thallus was towards the source of the luminescence [40]
Farhadi et al. (2007)	Epithelial cells	Homemade experimental setup with glass seperation	Epithelial cell culture treated with hydrogen peroxide (H_2O_2) was kept to non-treated cells. Total protein concentration, NFkB activation and structural changes were measured in treated cells and non-treated and were found altered as compared to control [37]
Zhang and Zhang (2007)	Osteoblast (rats)	Waveform generators	Pulsed electromagnetic field was applied to osteoblast which resulted in cell proliferation. The results also showed that proliferation of non-stimulated osteoblast increased when they were cultured together with previously stimulated osteoblasts [59]
Fels (2009)	Paramecium (*Paramecium caudatum*)	Glass and quartz seperation	Cellular communication are not necessarily based on molecule-receptor signaling and influence in both direction are possible [39]
Sun et al. (2010)	Spinal nerve (rats)	Visible to infrared light stimulations	One end of the spinal nerve was stimulated with light ranging from visible to infrared region of spectrum and biophotonic activity at the other end was measured. An enhanced biophotonic activity was recorded at the other end of the spinal nerve suggesting that biophoton generated at one end can travel along the neural fiber [60]
Rossi et al. (2011)	Mouse firoblast and human endothelial cells	Polystyrene petri-dishes	Cell proliferation rate and mortality was measured in mouse fibroblast and human endothelial cell placed in close proximity. A strong influence of one cultured on the other was recorded and thus electromagnetic radiation was presumed to be involved in the interaction [64]

algae (*Chlorella*, *Scenedesmus* and *Stichococcus*) recorded after several minutes of illumination which showed the spectral range similar to the action spectrum of photosynthesis [44].

In plants, the ultra-weak photon emission has also been recorded under different stress conditions such as fluctuation in temperature, chemical stress (salt stress), herbivore attack and pathogen infection [45–49]. It was also addressed that the ultra-weak photon emission can be used as a tool for investigating plant response under herbivore attack [50]. A spectral shift was observed under the pathogen effect and thus it was claimed to be a unique tool to monitor the physiological state of the plant [51]. In the study with corn leaves injured by *Helicoverpa Armigera,* the corn earworm, a relatively high intensity of ultra-weak photon emission was observed while ultra-weak photon emission in barley was shown to depend on the cell growth and respiration [10].

In addition to UPE measurement in plants, there are also evidences of the ultra-weak photon emission from animal cells and organism as a whole. In early 1990s, it was shown that sub-mitochondrial particles from bovine heart emit ultra-weak photon emission upon addition of exogenous organic hydroperoxide. The photon emission generated was considered to be contributed by $^1O_2$ formed during the oxidation of macromolecules [52]. The delayed and spontaneous ultra-weak photon emission has been extensively studied on the human hand in the last two decades. It has been shown that both palmar and dorsal side of the hands emits same number of photons which is not gender specific and the emission was recorded in the visible region of the spectrum [53]. In contrast, we recently demonstrated that the ultra-weak photon emission is dependent on the thickness of the skin. The result showed that photon emission from palmar side of the hand is almost twice than photons emission from the dorsal side of the human hand [4,34]. The reason for the variation in ultra-weak photon emission from dorsal and palmar side of the hand can be thickness to skin as pointed but at the same time the antioxidant capability of dorsal side of the hand can probably be a reason for it. The dorsal side of the hand might bear more antioxidant capability as compared to palmar side of the hand, for instance, the content of melanin which can act as antioxidant is higher in case of dorsal side of the hand and can suppress the level of ultra-weak photon emission. Nevertheless, a clear understanding is yet to be reached. The stress generated by UV radiation, exogenous application of reactive oxygen species (ROS), aerobic and anaerobic environment reflected by a high emission have also been studied on the human hand [4,34,53–55]. Besides this, photon emission from mice liver, fibroblasts and human skin, etc. has been shown to be related with the oxidation reaction of macromolecules [4,43]. The ultra-weak

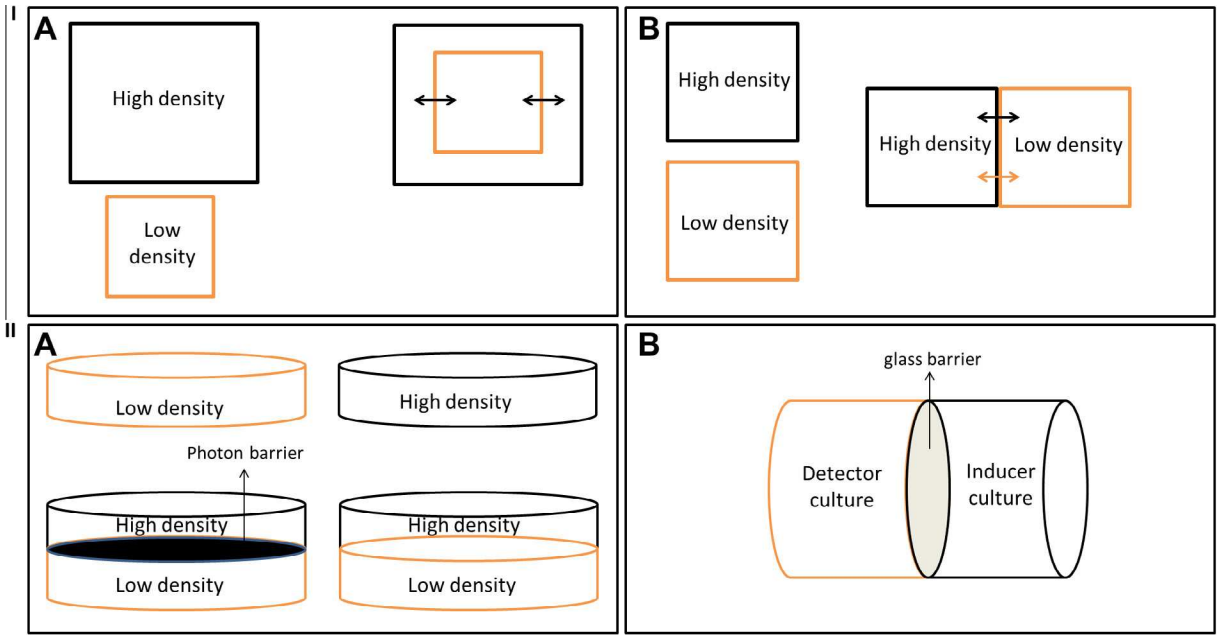

Fig. 1. Schematic illustration of experimental setup used by different authors for cell-to-cell communication experiments. (I and II) shows the different arrangements used during the measurements with cuvettes, petri-dishes and home-made setups. Besides cell density shown above, different parameters such as cell mortality, cell morphology, etc. were also monitored by different authors (summarized in Table 1).

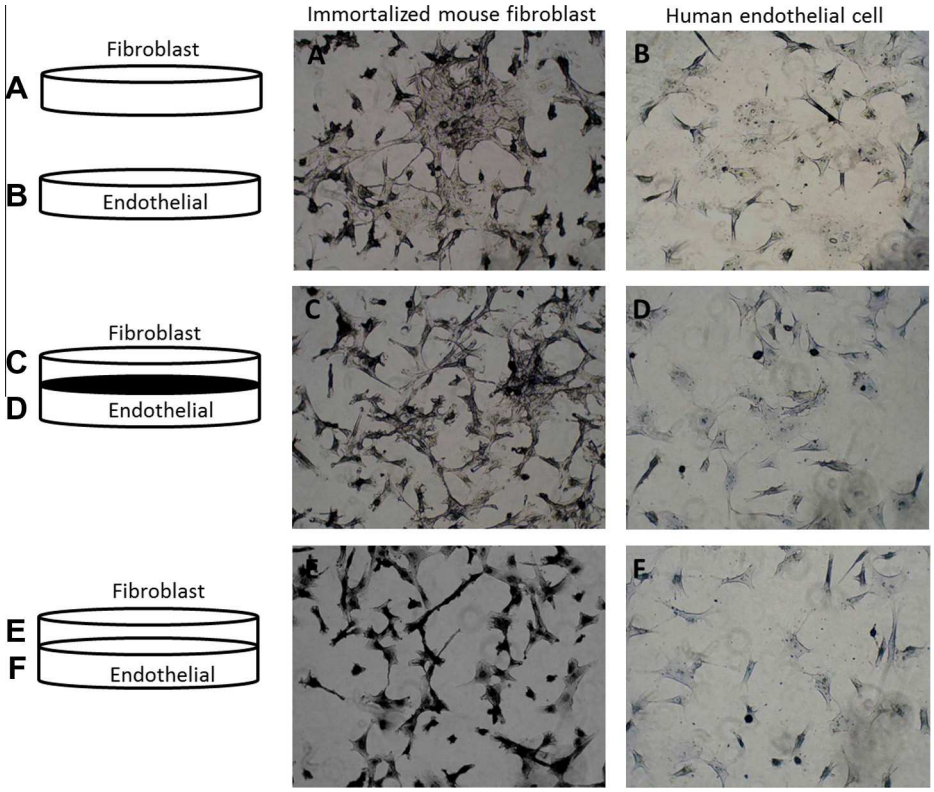

Fig. 2. Mouse immortalized fibroblast (NIH3T3) and human microvascular endothelial cells (HMVECad) were used for cell-to-cell communication in experimental arrangement shown (adopted with modification from [64]). A and B represents the controls where cells (NIH3T3 and HMVECad) were incubated in isolated condition kept apart from each other. In C and D, the cells (NIH3T3 and HMVECad) were kept in close contact however, seperated by a 100 μm black sheet of cellulose. In E and F, the cells were allowed to interact via optical contact (with no seperation). The images is adopted and reproduced with permission from John Wiley & Sons Ltd., Chichester, West Sussex, United Kingdom. PO19 8SQ.

photon emission has also been studied from yeast cell, *Saccharomyces cerevisiae* where a dependence of intensity of photon emission and density of the cells and the stage of the growth was observed.

Thus ultra-weak photon emission has been described in living systems starting from plants, microorganisms and more complex animal. The origin and mechanism of ultra-weak photon emission, however, is not completely clarified. There exist physical and

biochemical theories describing mechanism of ultra-weak photon emission. F.A. Popp has been one of the pioneers in the current research where he dealt with the physical aspects of the photon generation [7]. Biochemical theory on the other hand has gained more attention and has been studied by several authors in the recent past and has been discussed in the next chapter.

4. Biochemical theory on origin of ultra-weak photon emission

The oxidation of biomolecules such as lipids and proteins is regarded as the source of ultra-weak photon emission. Experimental evidence has been provided on the generation of ultra-weak photon emission via oxidative metabolic reactions. It has been shown that increasing concentration of hydrogen peroxide (H_2O_2) in bovine serum albumin solution lead to an increase in ultra-weak photon emission and protein carbonyls compounds. On experiments with particular amino acids, it was shown that ultra-weak photon emission signal was generated from the oxidation of Phe, Tyr, His and Cys and the ultra-weak photon emission signal were composed of two phases. It was reported that the first phase can be due to the combination reaction of reactive intermediates such as alkoxyl and peroxyl radical formed during the protein oxidation while the second phase was presumed to be from the degradation of protein hydroperoxides [17]. Besides this, the role of lipid peroxidation in ultra-weak photon emission has been described in details where addition of exogenous lipids (linoleic acid) to the algal cell culture has shown an increase in ultra-weak photon emission. The role of lipid peroxidation was confirmed by the treatment of inhibitors of lipoxygenase, the enzyme involved in the process. The exogenous application of catechol led to a decrease in the ultra-weak photon emission. Further, it has also been shown that scavenging of hydroxyl radical and removal of molecular oxygen led to a suppression of ultra-weak photon emission which directs to the conclusion that lipid peroxidation is involved in the generation of ultra-weak photon emission [5]. The production of $^3(R=O)^*$ and $^1O_2$ via the oxidative process are considered as the final emitters [3,5,6].

The ultra-weak photon emission from one cell/organism is known to carry information and influence cell/organism in close proximity. Currently there are several evidences on the role of ultra-weak photon emission in cell-to-cell communication which is also referred as optical communication, cellular interaction, non-chemical non-electrical intercellular signaling or bio-communication [37,39,43]. The intercellular communications between cells are generally considered to be mediated via messengers such as hormones, neurotransmitters, ions and antibodies. However, here we deal with the less focused as well as the controversial mode of communication between two different cell/cell culture chemically separated but optically coupled.

5. Experimental evidences on cell-to-cell communication via ultra-weak photon emission

The cell-to-cell communication experiments have been performed mainly on either unicellular organism or isolated cell organelles. In the study of cellular communication in mitochondria isolated from rat liver, it was reported the existence of cellular interaction/communication during quartz separation. The interaction was correlated with the fact that there was a significant decrease in oxygen consumption when mitochondria were kept together in close proximity as compared to isolated mitochondria [56].

In case of neutrophils isolated from pig blood, it was found that the chemically- separated but optically-coupled neutrophils can activate a neighboring population. It was demonstrated that neutrophils stimulated to undergo respiratory burst can bring about a change in the chemiluminescence and high generation of ROS which was measured using PMT and reduction of ferricytochrome c/spin trapping, respectively. The results provided evidence that interaction between the cells exists and also has biological significance [41].

Long range optical interaction between yeast cells was studied by Musumeci and co-workers [57]. Temperature-sensitive mutant of *S. cerevisiae* which only divide under the permissive temperature and thus can be strictly monitored was chosen in the experiments. A well and precisely controlled experiments showed evidence of optical coupling as stimulation factor for cell division in yeast cell [57].

As an embryo bears a rapid division rate, loach embryos were used in experiments by Burlakov and co-workers [58]. Embryos of different ages were placed in semi-closed quartz and the cuvettes were arranged above the other. The objective of the study was to check the cellular communication and the age of the embryo which give the maximum effect. The deviation in the normal development was observed in the interacting population of embryos and thus it was concluded that ultra-weak photon communication can occur within embryos and is involved in activation and suppression of development of the embryos [58].

There has always been the controversy regarding the range of electromagnetic radiation which is used by the cell for the cellular interaction. Trushin [38] with his experiments with *Escherichia Coli* employing chambers made of glass reported that the interaction is in the visible range of the spectrum rather than UV region as glass absorbed the UV radiations. He concluded that the interaction is likely to take place either in the visible or the near-infrared region [22].

Jaffe [40] have shown polarizing effect on *Fucus* eggs mediated by luminescent signal. The luminescent signal in the experiment was provided by intertidal marine plants. Signal transmission up to 10 mm was reported which was a very important conclusion in the regard of cell-to-cell communication [40]. Similarly, Farhadi and co-workers [37] utilized intestinal epithelial cells mechanically and chemically separated by use of glass barriers to determine the role of physical signals. The cells acting as inducers were treated with H_2O_2 while the receiver cells were kept untreated. Different cell cycle markers such as proteins, NFκB activation and structural change were utilized to follow its effect on neighboring population. The neighboring population showed correspondingly similar pattern of expression which led to the conclusion that H_2O_2 treatment in neighboring population of cells influenced the other cell put in close proximity. The term NCNE (non-chemical, non-electrical) signal was used for the phenomenon [37].

Electromagnetic fields can affect the proliferation of osteoblast. However, not only directly but also when proliferated osteoblast are kept together with normal osteoblast cells. The result obtained by Zhang and Zhang [59] led to the conclusion that communication persisted between stimulated and non-stimulated osteoblast cells. The authors confirmed by the use of copper net that the transmission of signal is not via general electromagnetic fields as proliferation still existed in this kind of experiments [59]. In the experiments with *Paramecium caudatum*, it has been demonstrated that population growth monitored by cell counting and feeding rate monitored via vacuole size depended on the number of cell in the neighboring population and the material through which the contact was established. It was concluded that cellular processes are not exclusively mediated by molecule receptor recognition but also there exists processes triggered by photons [39].

To investigate if ultra-weak photon emission can serve as neural communication signal, Sun and co-workers [60] monitored the external light stimulation on the biophotonic emission of spinal

motor nerve roots and sensory root nerve. One end of the nerve was illuminated with LED of the different wavelengths (infrared to white) and ultra-weak photon emission was monitored at the second end. It was found that light stimulation had significant increase in both cases. This led to the development of a new method called *in situ* biophoton autography which was after than applied successfully [60]. The interaction via near infrared was also shown between chemically-separated and optically-coupled cell culture by Albrecht-Buehler in live mammalian cells, fibroblast (3T3) and *Rhodospirillin rubnum* cells [61–63].

Recently, experiments to evaluate if two different cell populations influence each other when kept in close proximity utilizing fibroblast and endothelial cell were performed. The two cultures were separated by polystyrene petri dishes transparent in the spectral range from 400 to 800 nm. A strong influence of one over the other in morphology and proliferation rate which otherwise, when kept isolated had a normal growth pattern (Fig. 2, adopted with modification from Rossi et al. [64]) was observed [64]. Thus, these agree with the previous results of cellular communication by different authors as discussed [37,39,41,57,65]. Thus, this study attempted to better understand the phenomenon and add to the current understanding. Historical aspects on the experimental studies on cellular interaction via ultra-weak photon emission are summarized in Table 1.

6. Discussion

The cell-to-cell communication via ultra-weak photon emission can be important in the regulation of the metabolic processes and could be connected to the state of the organism and thus it is required to understand it more precisely. The research on cell-to-cell communication has been an intricate task and negative results are being obtained by researchers. Based on the results obtained till now and taking into consideration the negative results, it has to be mentioned that while working with intercellular communication, one should execute it with high precision, high statistical reliability and reproducibility. The reason for the negative results and failures during experiments which are evident from low number of results available in the context of the field of study can be because of choice of the cell culture or organism. The phases and the choice of the cell cycle may also play a pivotal role.

The problems which can be seen in cellular interaction experiments are the inconsistency in the experimental setup (similar setup but rather incomparable), the choice of organism and the parameters which are monitored. However, the former seems to be most important in order to compare between the results obtained by different authors. This can initially be reached by using one of the standard setup or by establishing a new setup for measurement which can be constructed by taking into account the distance between the communicating cells, inhibition of transfer of volatile compounds, proper growth condition during the measurement hours, etc. Farhadi's chamber [37] can be one of the possible options regarding the choice of setup. The proper design of the experiment is a critical factor in such kind of experiments. Since the current research on cell-to-cell communication is limited, it should be extensively investigated involving more complex organism. For an extensive and detailed study, early stage of a developing embryo can be a potential and promising model for the study.

Together with this, direct evidences of ultra-weak photon emission and cell-to-cell communication is justified in only few of the studies and in most of the cases, it is hypothesized with almost neglecting the effect of interference by other modes of communication. Experiments on cellular interaction have been studied in both isolated dark condition and in normal day-light but this phenomenon is still not sufficiently understood as to how the living cell distinguish between the two. The question which still exists is how the receiving cells recognize the photons emanated from the neighboring living cells and those from the environments. There exists almost no evidences and thus an open problem yet to be understood. Regarding the receptor for photon and associated mechanism, there are also limited evidences on existence of specialized cells for instance, pineal and retinal cells which are capable of detecting electromagnetic radiation [23]. Also, the response of receptors and its sensitivity under normal growth and during cellular interaction need to be understood. Thus, this can be also an interesting area of research to extent the knowledge in the context of cellular communication.

7. Abbreviations

PMT	photomultiplier tube
UV	ultraviolet
ROS	reactive oxygen species

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