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Chapter 8
Electromagnetic cell communication and the barrier method

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Abstract: Cells emit electromagnetic signals. To focus on the understanding of the function of these signals, they need to be investigated by separating them from chemical signals. This is achieved with barriers disabling a transmission of chemical but not electromagnetic signals. Hence, the barrier method is described and examples of experiments are given that allow deducing a function of the signal (or not). Furthermore, confounding factors such as chemicals or room light are discussed. An approach towards non-invasive technologies is deduced from proposed experiments. Finally, it is concluded that the examples of electromagnetic cell signals that induce cell processes strongly support the basic hypothesis of an interaction between the fields and the molecules of the cell.

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1. Introduction

Communication demands a transfer of signals from a sender to a receiver. Since the receiver interprets the signal, the combination of both sender and receiver determines a function that is attributable to the signal. Hence, when we want to understand electromagnetic cell communication we have to know about the signal and the function it induces. Yet, when we measure electromagnetic waves released from cells with a technical device such as a photomultiplier, we will not know whether these waves induce functions in other cells. Similarly, when we find effects in cells (presumably signal-induced functions) that are separated with glass barriers from inducer cells, we do not know about the source of the signal within the cell. This problem has been known since the very beginning of the research on electromagnetic

cell communication. While a function could clearly be ascribed, namely induced cell division, the emitting source within the inducing cells leading to so-called *mitogenetic radiation* (Gurwitsch, 1923) was unknown. However, today we know that emissions from cells cover the whole spectrum from low energetic radio waves to high energetic UV-waves (Cifra et al., 2011). We also gained more understanding about the molecular sources of these broad range of electromagnetic frequencies (Cifra et al., 2011, van Wijk, 2001) with suggested sources for UV emission (Voeikov, 2011, Voeikov & Beloussov, 2007) not being commonly accepted. We are at the beginning of learning about structures perceiving and translating these signals into functions (Tsong, 1989) - an endeavour that needs the unified strength of both molecular and "electromagnetic" biologists, and may lead to the discovery of hitherto unknown photoreceptors, a process that has begun already (Briggs & Spudich, 2005, Idnurm & Crosson, 2009), probably including cell water itself (Chai et al., 2009, Pollack, 2012). Yet, independent from the signal sending and receiving sources, it is assumed that the visible range is a very efficient frequency window for electromagnetic cell communication. One reason is that the thermal electromagnetic noise which is omnipresent due to surrounding temperature (Planck's law) in those ranges commonly present on Earth has a low intensity in the visible and UV range, and so the signal-to-noise ratio can be high in that range. The other reason is that the energy content of photons in the visible range is high enough to trigger chemical reactions and, thus, can finally lead to chemical cascades and functions, respectively, as in photosynthesis or vision.

Apart from the uncertainty about the sending and receiving structures within cells (Trushin, 2004a), let alone the assessment of these structures while cells communicate, we simply state that cells, as complete units of life, function as both sender and receiver. As we focus here on functions, we will look mainly at the receiver. This is based on the assumption that the effects are induced by electromagnetic waves and hence, that they can be understood as functions. Furthermore, it follows the basic assumption (hypothesis) that cells are able to generate and perceive electromagnetic fields simultaneously.

2. Signal selective barriers

In order to test for effects due to presumed electromagnetic cell radiation in a biological system that produces metabolites potentially functioning as chemical signals, one has to isolate the electromagnetic from the chemical signals. Note, sound has been postulated as a physical signal, too, but mainly for bacteria and not as an omnipresent phenomenon (Reguera, 2011, Scholkmann et al., 2013); the researcher should bear in mind when performing experiments with barriers that sound can tresspass them.

As chemicals are an omnipresent confounding factor (Trushin, 2004a), one possibility is to control for them by using barriers that allow the transmission of electromagnetic waves but not of chemicals. Interestingly, in experiments on chemical cell-to-cell signalling, electromagnetic signals must be seen as a confounding factor, too. Therefore, in order to get a more complete vision of cell communication, we have to understand the simultaneous effects of chemical and electromagnetic signals. However, this is an endeavour that can only be undertaken when we start understanding more about the function of electromagnetic cell signals.

Barriers needed to isolate electromagnetic from chemical signals traditionally consist of quartz glass, allowing the transmission of long wave frequencies up to UV-C (Gurwitsch, 1923, Gurwitsch, 1926) with an equal absorption spectrum from microwaves to UV-C (Fels, 2009). Normal glass (but of purest quality) gives a similar spectrum except for cutting higher energy radiation such as UV-B and UV-C (Fels, 2009). In contrast, transmission spectra from any type of plastic material are very inhomogeneous (see spectra on websites for plastic cuvettes). Due to this, results from experiments with plastic barriers might produce a distorted reflection of the nature of the phenomenon. Hence, the use of pure SiO_2-based barriers is recommended because of its homogenous transmissibility of electromagnetic signals.

Two populations can be separated either vertically or horizontally depending on the biological material and the barriers used (Fig 1). With petri dishes one rather separates cultures horizontally (Rossi et al., 2011), while working with moving cells in cuvettes, these may be placed side-by-side (Fels, 2009). Some develop their own barrier-system (Farhadi et al., 2007). Interestingly, the literature describes so far only the separation of two populations of cells or tissues with barriers, while separating more than two populations, we could artificially create a situation that resembles embryonic development where different cell types need to be coordinated.

3. The fingerprint problem

Even though photon density within cells is assumed to be very high (the radiant flux is approximated to be in the range of 10^{-16}–10^{-7} W/cm^2) (Bokkon et al., 2010), we know that photon emission of cells is ultra-weak (Cifra et al., 2011). Yet, the first experiments on electromagnetic cell signalling were performed under *room-light conditions* where the amount of photons per cm^{2}sec exceeds the number of photons emitted by the communicating cells billion-fold.

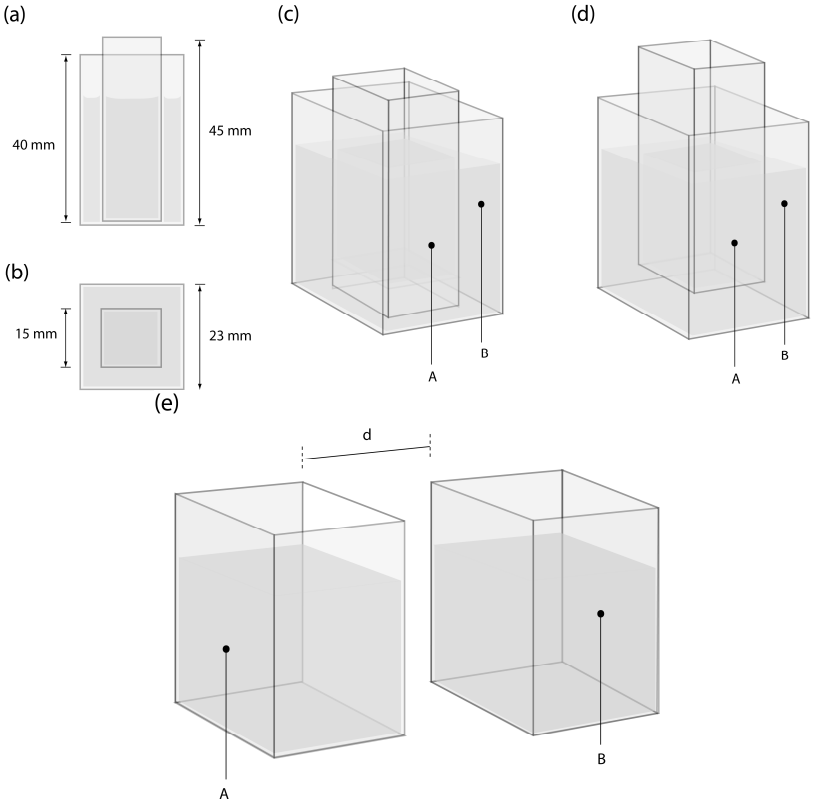

Figure 1. Cuvettes and their use. (a) Two cuvettes of different size and height with the smaller one standing in the bigger one; (b) from top and (a) from the side show dimensions of cuvettes as used in Fels (2009); in (c) we see the use of such an above-mentioned pair of cuvettes for a side-by-side separation with a maximum of exchange surface between an outer cell population (or tissue) B on an inner cell population (or tissue) A; in (d) the cuvettes are positioned in such a way as to have signal exchange in a vertical direction, too, *e.g.,* for testing effects among sinking biomaterial (yeast cells, or fish eggs); in (e) the contact surface between A and B is smaller than in (c) but this side-by-side positioning allows to test for distant effects or allows the use of several cuvettes standing in contact.

Recall that daylight consists of UV-A and -B while -C is filtered by the ozone layer (Letokhov & Dobryakov, 2003) and the whole range of visible photons (as well as lower energy waves). Since there are photoreceptors in organisms sensitive to photons from such natural or artificial (chaotic) light

sources we have to ask, how does a cell distinguishes between the few photons from a neighbour cell population and the tremendous number of photons from the sun (or light bulb)? This non-trivial problem (read Kucera & Cifra, 2013) has also led to the assumption that cell-photons are emitted from a non-chaotic source that gives the photons emitted by cells a physical fingerprint. Most prominent became the theory of coherently emitted photons (Popp, 2006, Popp & Yan, 2002). However, this theory on coherent cell radiation is controversially discussed (Budagovsky et al., 2007, Salari & Brouder, 2011), and we conclude that the fingerprint-problem is not yet solved.

With respect to the light-conditions when performing a barrier experiment, we note that regularly in the past but also in recent papers (Jaffe, 2005), authors often did not mention whether it was performed under darkness or room-light conditions: it is, therefore, not possible to list them desirably with regard to the results (Cifra et al., 2011). Yet, we can assume that early experiments were performed under conditions of room light because they were inspired by the pioneering experiment done by the Russian morphologist A.G. Gurwitsch (1874–1954), which he had performed under conditions of room-light: Gurwitsch assumed (even though not exclusively) that light dependent reactions were the sources of the emitted radiation (Gurwitsch, 1988, Voeikov & Beloussov, 2007).

In order to separate chemical from electromagnetic signals and simultaneously get out of the fingerprint problem it is suggested to separate cell populations under conditions of *total darkness*. Whatever the result will be, it will not depend on (nor be influenced by) room light - it will refer to the neighbouring cell population only. Such a *one-factorial design* is therefore a required condition when isolating electromagnetic waves from cells in order to understand the function they can induce.

To be more accurate, keeping two mutually exposed but chemically separated cell populations in a black box leads only to *quasi-total darkness* since it is dark for visible light but not with regard to the thermal radiation of the material surrounding the cells. Nonetheless, controls do exclude these infrared waves as cause for observed effects. The black box bears also an additional component. Some cells being part of a tissue (but also being, *e.g.*, a parasite) somewhere "in the depth" of a multi-cellular organism may indeed experience such *quasi-total darkness*. Yet, for single-cell free-living aquatic organisms such a condition, namely *quasi-total darkness* is generally not met in nature. Hence, when performing experiments under conditions of *quasi-total darkness* and finding cellular functions, we look at a between-cell relationship that may have resulted from natural selection regarding cells "from the depth" of multi-cellular organisms. For free-living single-cell organisms, however, these relational patterns may not have resulted from natural selection.

4. Multitude of effects

The discovery of *mitogenetic radiation* by A.G. Gurwitsch delivered the scientific community with strong evidence for a non-chemical causation of the most fundamental life process: cell division (Gurwitsch, 1923). Yet, at the beginning of the last century, hormones were already discovered and together with the integration of the key-lock principle tremendously supported the investigation of chemical signalling, despite the assumption of Gurwitsch (1923) that *mitogenetic radiation* is hierarchically seen "above" chemicals.

Gurwitsch and his group found evidence for cell radiation with up-regulating effects: In his famous *onion root experiments* (1923), which was repeated by many others (e.g., Reiter & Gabor, 1928), he found a significant increase in mitosis in the root meristem of the receiving root exactly there where that root was exposed to the tip of an inducer root. Gurwitsch, as a morphologist being interested in the appearance of form, was certainly encouraged to have found a non-molecular up-regulating factor. Even though the appearance of form demands also down-regulation (*e.g.*, when an organ or an organism has reached its final size, or when fingers appear in a developing embryo due to *apoptosis*), the Gurwitsch group did not test for down-regulation. They investigated the question of the cause of the signal and used general field theory to explain morphogenesis (Beloussov, 1997). Further, experiments across the species border (Reiter & Gabor, 1928) were performed testing for the generality of the phenomenon (for a review, see Cifra 2011).

With the development of photomultipliers (in the early 1950ies), measuring the emission of electromagnetic waves from biological material in the visible range (Colli et al., 1955, Strehler & Arnold, 1951) *mitogenetic radiation* lost its adjective *mitogenetic* and new terms appeared like *ultra-weak photon emission* (UPE) or *biophotons* (Niggli, 1992, Popp, 1988). For a while, machines became the detectors of this radiation and not life anymore: The *signal characteristics* became the focus and not their *biological significance (function)*. From the 1980's on, organisms were again taken as detectors for non-chemical signal transfer, unfortunately (and ironically) often not controlling for confounding effects from chemicals (Trushin, 2004b). Two interesting studies will illustrate that problem. One refers to the dependence of photon emission of the crustacean *Daphnia magna*, on its artificially increased density (Galle et al., 1991). There was an overall but non-linear increase in photon emission assessed: the minima and maxima indicated a density-dependent cause for maximal or minimal absorption of photons by the releasing crustaceans themselves. This supported the assumption of photon-based communication with (spatially) constructive and destructive interference (Galle et al., 1991, Popp & Klimek, 2007). However, the organisms

were all in the same cuvette and a density dependent release of chemicals may have confounded photon emission disabling a proper interpretation of the communication system. Similarly, in a study with malignant and healthy cells, the isolated malignant cells displayed an exponential increase in light induced (i.e. non-spontaneous) photon emission with increasing density, while the healthy cells displayed a decrease in (light induced) photon emission when measured at increasingly higher densities (Schamhart & van Wijk, 1987). This indicated, at a first look, again a photon-based communication with constructive and destructive interference (Popp & Klimek, 2007), but the differing densities may have correlated with differing releases of chemicals that contributed accordingly to the emission of photons. Hence, in order to distinguish between chemicals or photons organizing communication, both studies (Galle et al., 1991, Schamhart & van Wijk, 1987) would need a continuation with barriers in use. As such, we learn from both these experiments that density of cells or of crustaceans, respectively, correlate with photon emission, but we cannot deduce a function induced by the photons.

A wonderful experiment indicating communication between chemically isolated populations comes from the protozoan *Gonyaulax polyedra* (phylum: Dinoflagellata) showing the release of irregular bursts of photons of the same frequency (note that we talk here of bioluminescence) (Popp et al., 1994). The study demonstrated that these bursts were caused by a communication system between the cells working across glass barriers. When two populations were placed side-by-side in cuvettes with a photon shield between them, the bursts of each population were asynchronous in comparison with the other population. When the shield was removed, however, the bursts of the two populations became synchronized. Note that we are looking here at chemical reactions (leading to the bursts) that are induced by a signal that works across glass barriers. Even though the study does not reveal the function of synchronous light bursts, it shows the capability of a supra-cellular organisation based on an endogenous source most probably of electromagnetic nature.

Many other groups demonstrated inducing chemical reactions from one population to another population under the exclusion of chemical signals by using barriers. The group working with Shen provided evidence … *that a long-range optical coupling of biological significance between living cells exists* (Shen et al., 1994). In particular, the addition of *phorbol myristate acetate* to one population of neutrophils (i.e., cells) led in the other population to an increase in (i) photon emission, and (ii) the production of *superoxide radicals*. These effects were absent when the two cuvettes containing the populations were shielded from each other. Galantsev and his group provided similar results in a study on effects of different physiologically active substances from mouse mammary tissues on isolated mammary cells (Galantsev et al., 1993). They report that the induction of *acetylcholine* or

norepinephrine into the medium of one cell population resulted in protein synthesis in the other population from which the former was chemically but not optically separated (Galantsev et al., 1993). Farhadi's group added H_2O_2 to one group of intestinal epithelial cells and found a reduction in protein synthesis in neighbour cell cultures as compared to controls (Farhadi et al., 2007). Furthermore, they report cytoskeletal changes in structure and increases in nuclear extracts; some of the effects were obtained over a distance of 4 cm (Farhadi et al., 2007).

Very surprising results are reported from the Kaznacheyev group who worked with tissue cultures and various types of viruses deleterious to the tissue cultures (Kaznacheyev, 1982). They separated two cultures chemically from each other in a side-by-side arrangement allowing transmission of electromagnetic waves incubating one of the two cultures with a lethal pathogen. What they observed over many tissues and deleterious agents, in general, was that neighbour tissue cultures died as well. However, it is not clear whether we can speak of a function when the neighbour population is killed. Nonetheless, these experiments are famous and, hence, deserve to be mentioned. The question of the function is important, but being at the beginning of this research on electrodynamics in cell organisation every finding confirming that effects occur across barriers is important evidence for the phenomenon as such. For example, in a cross-species experiment on isolated human microvascular endothelial cells and mouse fibroblasts (Rossi et al., 2011), where it is not clear on how to understand the results in terms of function, there were pronounced effects: changes in morphology and growth rates of cells induced across barriers.

Coming back to morphogenesis where we have *cell migration* besides *cell division* and *differentiation* also, two studies give evidence that cell migration and positioning might also be under electromagnetic control. The first study refers to relative cell positioning of isolated (vertebrate cells) on either side of a glass slide (Albrecht-Buehler, 1992): after a first layer of isolated cells had adhered to one side of a glass slide in a non-organized (appearing) manner, a second layer of cells was placed at the opposed side of the slide and was seen to adhere in a position perpendicular to cells of the first layer. This positioning effect disappeared when the slides were shielded for electromagnetic waves. The second study dealt with the long unanswered question of how Zygotes of *Fucus sp.* know where the substrate is onto which they grow when germinating. It turned out, in an experiment where substrate (a seaweed) and Zygotes were separated by a chemical barrier, that a majority of Zygotes grew towards the substrate while growing in all directions when that barrier was shielding electromagnetic waves in the optical region of the spectrum (Jaffe, 2005).

Recent additional evidence for effects across glass barriers come from the Ciliate *Paramecium caudatum*, a freshwater unicellular organism in-

habiting ponds of the Eurasian plate. Being familiar with this organism (Fels & Kaltz, 2006, Fels et al., 2008) a study was started focusing on cell division. The results were promising. Cell populations could have enhancing as well as decreasing effects on cell division in neighbour populations, which depended on the separating material, either normal or quartz glass, indicating that other frequencies than those in the (strong) UV range contributed also to the effect. Further, energy consumption was influenced in either way depending on the number of neighbouring cells and the separating material (Fels, 2009). Interestingly, in the latter experiment, a short exposure to room light would blur effects, indicating that *Paramecium caudatum* has photoreceptors and is principally able to organize itself based on the detection of photons. In fact, effects on cilia movement due to light were described for *P. caudatum* (Okumura, 1963) or regarding meiosis and conjugation for *P. bursaria* (also when free from *Chlorella*, a photosynthetic symbiont) (Ehret, 1953). The general sensitivity to radiation in the genus *Paramecium* has been manifoldly described (but not with regard to cell division) (Wichtermann, 1986) while sensitivity to *ultra-weak* photon emission is rarely reported (Fels, 2009, Kozlov, 2000a).

Effects across barriers are described for quite different systems like plants, animals or single celled organisms. We may legitimately deduce that we are looking at a general property of life. Indeed, research with prokaryotes (non-nucleated cells, i.e. bacteria) (Nikolaev, 2000, Trushin, 2004a) confirms that these very primitive cells do also use endogenous electromagnetic signals for communication. This, however, cannot be surprising since prokaryotes have similar cell internal processes as eukaryotes (nucleated cells) and, further, are assumed to have led to the eukaryotes through a process called endosymbiosis (Margulis, 1981).

5. Environmental radiation and non-invasive cell research

Electromagnetic cell radiation (even though it may differ in field characteristics) is an environmental radiation like the one from the sun or an electronic device. A recent study, *e.g.*, shows that cells (*Paramecia caudatum)* responded with changes in growth and shape to the exposure of microwaves (900 MHz, 2 Watt) emitted by a switched-on cell phone (the treatment) (Cammaerts et al., 2011). Another study reports on cancer incidence that oscillates in accordance with rhythms of solar radiation (Juckett, 2009). The sensitivity of life to environmental radiation might also be expressed in ecological studies when experiments are repeated over time; the repetitions can contribute highly significantly to the variation in the data set (e.g., Fels, 2005). As the experimental set-up is standardised, the factor causing this *effect from repetition* is rather correlated with time than with space. It might therefore be that life fluctuates with a radiation source from the environ-

ment, probably – and this should be seen as a working hypothesis – fluctuations in a cosmophysical and/or heliogeophysical factor, *e.g.* cosmic radiation (Kozlov, 2000b, Trushin, 2004b). In another study it was reported that this *effect from repetition* was always found in controls but only in one of two mutually ("dark") exposed populations, namely in the population that was affected by its neighbour population (Fels, 2012). Due to its regular appearance this was interpreted as a pattern displaying a law-like property where one of the mutually exposed populations relates to the neighbour, the other to an *external factor*. Together they build a system and, hence, communicate (this is also presented in either of the figures 2a or 2b but serves there another purpose).

With reference to electromagnetic signalling between cells, one can imagine applying to any biological material different electromagnetic frequencies, looking for effects. Similarly, one may first analyse electromagnetic cell signals, reproduce them technically and apply them. An *indirect* method can also be imagined (Fig 2), where we apply a particular frequency in different amplitudes and see, first, whether one of two electromagnetically coupled populations will relate its growth rates or any other typical cell process to it and, second, whether this would influence the second population in its effects on that first population (compare this with Fels, 2012). In any case, the more we understand the signal quality with respect to the induced effect the closer we are to non-invasive healing technologies.

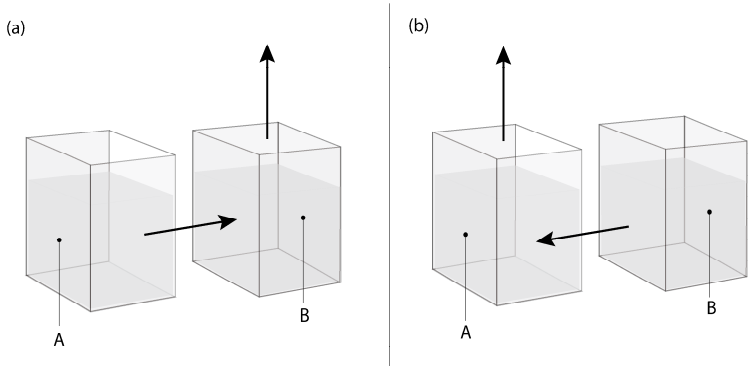

Figure 2. A hypothetical situation. On the left side (a) biological system B is sensitive to a particular frequency (f_1) and system A relates to B. On the right side (b) another frequency (f_2) is applied and the relations of the same cultures A and B have changed: A is sensitive to that particular frequency (f_2) and B relates to A.

6. Conclusions

The research in electromagnetic cell communication leaves us with many open questions. We still do not know (i) the extent to which chemical reactions occurring within cells can be induced electromagnetically, (ii) how more than two populations of cells or organisms act (in a barrier experiment) on or interact with each other, or (iii) to what extent cosmophysical factors contribute to life processes. But the barrier method is a useful tool to investigate electromagnetic cell signals that, in addition, are of high speed and low cost and are assumed to build unity among cells. Adding such physical understanding to cells does not compete with our chemical understanding of cell processes, it rather offers a *unified* understanding of the two (as in electromagnetobiology and photobiology). Such synergistic approach will inevitably lead to an enlarged understanding of life, namely that there is a chemical as well as an electromagnetic communication system at work in cells assumed to belong together (Beloussov, 2011). We recall just three studies supporting this. Oxidative processes induced by H_2O_2 leading to photon emission, therefore showing a connection between chemical and electromagnetic pathways (Farhadi et al., 2007). Alterations in protein content due to exposure to neighbouring cells (Galantsev et al., 1993, Shen et al., 1994) give at the same time evidence for regulatory effects on the gene level. We assume actually that the two systems, i.e. the chemical and the electromagnetic, belong together in such ways as they feedback on each other. Many experiments, including those on signal-induced cell division, strongly support the corresponding basic hypothesis that cells induce fields that feed back on cells.

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