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Articles

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Distant Non-chemical Communication in Various Biological Systems

Abstract. *Communication is a natural ability of all living systems. It is very likely that various types of communication were evolved during evolution. While the communication by means of chemicals, direct contact or via organs of sense is under intensive study for a long time, alternative ways of interaction are still considered debatable. This review covers the topic of physically mediated communication in various biological systems.*

Key words. Communication, biological systems, electromagnetic fields, light emission, information transfer.

1. INTRODUCTION

Most of the current literature, for example, on intercellular communication focuses on research of receptor-based cellular interactions and chemical signaling, including the cell-cell and cell-matrix interactions (Hohenester *et al.* [1999]), molecular mechanisms of cellular responses to cytokines and chemotactic factors

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(Syed *et al.* [1998]; Aritomi *et al.* [1999]), cell recognition (Garcia *et al.* [1999]), structure and function of cell surface receptors and interacting molecules (Felion and Popel [2004]), recognition events in cell trafficking and immune-based cellular interactions (Maenaka and Jones [1999]), and the influence of the composition and molecular organization of the extracellular matrix or plasma membrane on cell recognition events (Bosman and Stamenkovic [2003]). Relatively few articles delve into the study of non-chemical and non-contact communication. There is, however, an increasing evidence for widespread importance of physically mediated relationships for some cellular events, including cell division and adhesion (Nikolaev [1992], [2000]), growth and light emission (Trushin [2003]), cellular differentiation (Popp *et al.* [1992]), orientation in the environment and cell motility (Albrecht-Buehler [1991], [1992a], [1995]).

In this paper I will review some of the data accumulating within the mode of relationships between various biological systems, the current working models and hypotheses being proposed as explanations for phenomena of light-mediated interactions of cells, tissues and the whole organisms. The coverage of this paper is not restricted to publications that appeared only recently for the reason that the historical aspect of this subject has not been reviewed previously. But first of all, I would like to throw light upon the history of the research.

2. HISTORICAL ACCOUNT

Studies of the Period 1920-1940. A famous Russian embryologist and histologist Alexander Gurvitch was the first to study the role of light in living processes, particularly in communication between cells. His thoughts on the role of light were confirmed in experiments with onion roots in the 1920s (Gurvitch [1926]). The essence of his experiments was as follows. Two quartz capillaries with onion roots were disposed athwart so that apex of one root (inducer) was in front of meristemal tissue of another bulb root (detector). Relative position of inducer and de-

tector roots was controlled by a horizontal microscope. The author and his colleagues performed over 200 experiments and found that actively dividing cells of the inducer stimulated 35-40%-increment of mitoses in meristemal tissue of the detector. When the inducer and detector roots were separated by an UV-opaque glass plate, the effect was absent. Therefore, Gurvitch suggested that the functioning factor was an ultra-weak UV light that accompanies mitoses (Gurvitch [1926]). The author called this ultra-weak UV light mitogenetic radiation (MR).

Not only plant detectors but also bacterial (Rahn [1936]; Ioffe and Billing [1935]), yeast (Bukatina [1938]) and animal (frog cornea: Ponomareva [1936]; sympathetic nerve of cat: Brines and Galperin [1934]; blood: Mironov and Kristovaya [1935]) detectors were used in the detection of MR. Moreover, interaction between some staphylococcus species and fertilized ovules of sea-urchin was investigated (Magrou [1932]). Simultaneously, physical detection of MR proved that it is UV light in the range of 190-320 nm (Grebe *et al.* [1937]; Barth and Glasser [1939]; Fillipov [1937]).

By the 1940s, some general properties of MR were revealed. First, MR was confirmed to represent ultra-weak UV light. The sources of MR are actively dividing cells (microorganisms, embryos, culture tissues, regenerating organs; blood, neural, brain and muscular tissues). Second, Gurvitch found that MR sharply increases due to action of some factors (rapid freezing, narcosis, centrifugation, and continuous and alternating electric current). This phenomenon is referred to as degradation radiation (Gurvitch [1944]). The author and his colleagues suggested that all living systems are able to emit this type of energy (experiments were done on yeast cells (Billing [1938]), onion and haricot roots, mucous tunic of pyloric part of stomach, kidney of mouse, liver of alive rabbit (Gurvitch [1944]), and human blood (Klenitsky [1934]). Gurvitch showed that degradation radiation is highly specific. Each tissue or organ within an organism possesses a unique type of light emission. Spectral distribution of degradation radiation of tissues or organs depends on the type of acting factor (Gurvitch [1944]).

Third, it was found that cancerous growth possesses an in-

creased intensity of MR, while blood of tumor patients shows complete disappearance of MR (Bogdanovich and Lozaris [1935]; Gurvitch [1944]). From blood of these patients, a special high-molecular peptide (with enol bonds within it) could be isolated that caused loss of MR. Gurvitch called it as "cancer quencher". The authors found that the "cancer quencher" appears in human blood before the manifestation of cancer after introduction of carcinogens (approximately by sixth week, while cancer mark after 6 months (Gurvitch [1944]). In 1930s-1940s, this phenomenon was successfully used in diagnostics of cancerous sickness.

Unfortunately, the period of 1940s-1950s was marked by interruption in research. The international climate of this period (World War II and post-war economic dislocation) did not allow conducting the studies intensively. Moreover, an August session of 1948 of VASHNIL in Moscow was the reason for destruction of several lines of biological investigations, including the Gurvitch's school. The interest in the problem has been rekindled only in the beginning of 1960s.

Studies of the Period 1960-1980. In the 60s–80s, Kaznacheev's group conducted a series of impressive experiments (Kaznacheev and Mikhailova [1985]). Different animal and human cultures (primary tissue of human embryo, fibroblasts of chicken embryo, kidney of cattle embryo) were grown on a quartz or UV-opaque glass plate (thickness about 0.2-2 mm), which were soldered to the bottom of a spherical flask. After monolayer formation, the above spheric flask, which contained any animal or human culture (inducer) treated with different damaging agent (FPV, adenovirus, Coxsackie virus, mercuric chloride, UV radiation) was attached to an another identical spheric flask containing a monolayer of intact (non-treated) culture (detector). The monolayers of treated and non-treated cultures had an optical contact between them through quartz or UV-opaque plate. So, the attached spheric flasks with treated and non-treated cultures were bound with revolving rotor transversely to his axis. The rotor with attached flasks was placed into blackout thermostat and rotated with 25-rpm speed (Kaznacheev and Mikhailova [1985]).

After a certain period of time, cells of inducer and detector

cultures were fixed and stained with specific dye. The results of distant interaction between inducer and detector culture were analyzed morphologically and the percentage of dead cells was evaluated (Kaznacheev and Mikhailova [1985]).

Usually, in intact (non-treated) cultures serving as biodetectors, normally proliferating cells also started to die upon several hours of optical contact with the afflicted inducer culture (Kaznacheev and Mikhailova [1985]). The effects depended on the type of damaging agent, which was used for treatment of inducer culture. The damaging agents were of biological, chemical and physical nature. All the specific cases are discussed below.

Experiments with Coxsackie A-13 virus. Coxsackie virus belongs to the *Picornaviridae* family. The RNA-containing viruses have icosahedral form (up to 40 nm in diameter) without capsule. Coxsackie virus is able to propagate within the primary culture of human tissues and organs of human and monkey embryos as well as within the cultures of renal and amniotic human tissues. Infection with Coxsackie virus results in pyknosis of nuclei, disappearance of nucleolus, appearance of RNA-containing eosinophilic masses in the center of the infected cells (Caddle [2003]). The primary culture of human embryo tissue infected with Coxsackie virus was grown with non-infected detector culture for 4-5 days. At 24-36 h after infection, alterations in the monolayer and large cells with basophilic cytoplasm appeared in the inducer culture. The number of dividing cells was significantly reduced. Later, basophilic cells were pyknosised and damaged. In detector (non-treated with Coxsackie virus) cultures, the same forms of degeneration were observed in 74% of all the cases (the experiments were performed in 180 replicates). However, the degeneration events were observed later on 12-13 h in comparison with inducer culture. It is also necessary to note that, after the experiment was finished, the Coxsackie virus could not be isolated from the detector culture during thrice-repeated passage of the culture liquid (Kaznacheev and Mikhailova [1985]).

Experiments with FPV virus. FPV (the virus of classical plague in birds) belongs to Orthomyxoviridae family. It is 90-120 nm spheric virus with capsule. FPV propagates within 10-11 day

chicken embryos and causes death (Murphy *et al.* [1995]). The experimental design was the same as the Coxsackie virus experiments (Kaznacheev and Mikhailova [1985]). Infected with FPV inducer culture of chicken embryo's fibroblasts was grown simultaneously with intact (detector) culture for 2 days. At that time, a large quantity of cells was rounded and included in botryoidal formations in the inducer culture. Then cells corrugated and nuclei were pyknosised. In 74-78% cases (experiments were performed in 118 replicates), in detector culture the same alterations in cellular morphology were determined. After the experiment was finished, the authors also tried to isolate FPV virus from detector culture. After thrice-repeated passage of culture liquid, FPV was not observed in the detector culture (Kaznacheev and Mikhailova [1985]).

Experiments with adenovirus. Adenoviruses (*Adenoviridae* family) are 70-90 nm capsule-free icosahedral virions. This virus propagates within nuclei and causes respiratory disease in humans and animals (Mackie [2003]). In these experiments, inducer culture of monkey kidney tissue was infected with adenovirus (type 5) and grown simultaneously with intact detector culture during 2-3 days. In infected inducer culture, cells became inflated, stacked into assembly, and then destroyed. The analogous alterations were determined in 72% of cells of detector intact culture (experiments were done in 170 replicates) (Kaznacheev and Mikhailova [1985]).

Experiments with mercuric chloride. Mercuric chloride inhibits respiratory enzymes' activity and alters the biochemical function of thiamine and some amino acids (Woggon *et al.* [1984]). Culture cells of human and chicken embryos were treated with mercuric chloride (4-5 μg per ml of nutrient medium). After 2 days of incubation, the vacuolar degeneration and karyopyknosis were observed in inducer and detector (about 78% of cases) cultures (Kaznacheev and Mikhailova [1985]).

Experiments with UV radiation. Damaging and mutagenic properties of UV radiation are well established (Miller [1985]). Irradiated with lethal dose of UV light inducer culture of human embryo's fibroblasts was cultivated with intact detector culture during 2 days. After that cells were fixed by methyl alcohol and stained with hematoxylin-eosin. In the inducer culture, there was nuclear

material condensation into compact hyperchromic body, followed by cell destruction. In the detector culture, the same alterations were observed in 78% (experiments were performed in 500 replicates) (Kaznacheev and Mikhailova [1985]).

The effects described above were announced as the discovery of distant intercellular interactions in the system of two cultures (or "mirror cytopathic effect") (Kaznacheev and Mikhailova [1985]).

Properties of distant intercellular interactions. Experiments in which the damaged detector culture was grown with new-grown intact culture were also performed. In this scheme, the transfer of cytomorphological abnormalities occurred but at a lower level. By third passage, the efficiency of such a transfer was decreased up to 20-30% (Kaznacheev and Mikhailova [1985]).

In order to know whether cells are able to perceive signals from non-homologous culture, special experiments were done in which the inducer and detector culture belonged to different cellular types. These results are summarized in the Table 1. As one can see from Table 1, there is a strong specificity in manifestation of the effect. The "mirror cytopathic effect" is maximal when the inducer and detector culture belong to the same species; it is lower when the closely related cultures serve as inducer and detector. The effect is absent when the inducer and detector cultures are of different origin (Kaznacheev and Mikhailova [1985]).

Investigations that have been performed during more than two decades clearly showed that manifestation of "mirror cytopathic effect" strongly depended on the heliogeomagnetic situation: solar activity, geomagnetic disturbances and geographic latitude. So, in different years or even months the cell interactions could be pronounced to a different extent.

Kaznacheev and co-workers have used an electromagnetic concept for the interpretation of the observed phenomenon. It is the author's opinion that mechanism of distant intercellular interactions is associated with generation of ultraviolet and/or near infrared radiation by the cells (Kaznacheev and Mikhailova [1985]). This conclusion was not speculative. In order to determine the most probable area of the spectrum that is capable for the effects observed, a series of special experiments were done. Different materials were placed between inducer and detector cultures, and the

manifestation of "mirror cytopathic effect" was analysed. The materials were: a) polyethylene film with fine-dispersed soot stuff (thickness of 0.1 mm), and b) copper net (the distance between the centers of the squares were 140, 180, 200, 240, 280, 400 and 440 micrometers). The given experiments clearly showed that the most appropriate candidates for the information signals might be ultraviolet and infrared radiation with the exception of sub-millimeter, millimeter and radio waves. Kaznacheev and co-workers also supposed (though did not confirm experimentally) that such radiation should be highly coherent.

Table 1
Manifestation of distant interaction in the systems of non-homologous cultures, %
(cited from Kaznacheev and Mikhailova [1985])

Type of inducer culture	Type of detector culture								
	HEF	Hep-2	HeLa	SVG	REPE	F1	RH	HEE	MK
HEF	73	0	0	0	0	?	?	?	0
Hep-2	?	70	30	0	0	0	14	?	20
HeLa	0	23	70	0	0	?	6	?	?
SVG	?	0	?	63	?	0	?	?	?
REPE	?	4	?	?	81	?	14	?	33
F1	?	0	0	0	?	70	?	?	?
RH	0	16	6	12	?	?	75	0	?
HEE	?	?	?	?	?	?	0	0	60
MK	0	40	?	33	?	?	?	?	76

Abbreviations and designations. HEF – human embryo's fibroblasts; Hep-2 – transplantable line of human larynx's carcinoma; HeLa – transplantable line of cervical tumor; SVG – transplantable line of simian venereal glands; REPE – renal epithelium of pig's embryo; F1 -transplantable line of amnion envelope's epithelium; RH – transplantable line of human kidney; HEE – transplantable line of human embryo's eye; MK – transplantable line of monkey kidney; ? – data are not known.

The existence of a field (non-chemical) communication channel was also shown by Kirkin (Kirkin [1981]). The scheme of his ex-

periment is presented in Fig. 1. Kirkin found that the growth rate of detector culture depended on the presence or absence of the inducer culture and its concentration. In condition of presence of inducer culture, the growth rate of detector was enhanced. However, the difference between the detector and control culture was observed only after 3 days of incubation. In general, after 4-6 days of growth, there was a twofold or threefold increase of cell's number in detector culture in comparison with control culture. When cells in the inducer culture were fixed with methanol, the stimulating effect was decreased significantly. After 5 days of incubation, a screening of radioactive chemicals in 35 mm Petri dish was performed, and negligibly small amounts of it were detected (^{22}Na – 0.002%, ^{3}H-thymidine – 0.0015%, ^{3}H-leucine – 0.006%, ^{51}Cr was not registered) (Kirkin [1981]). Therefore, the author

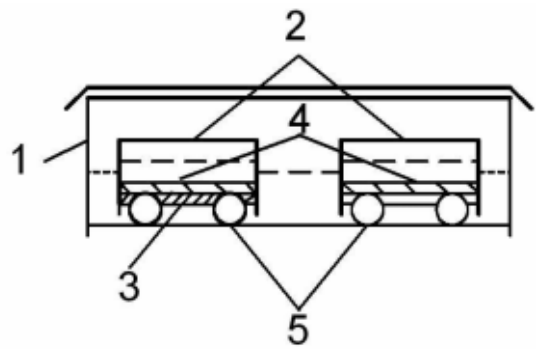

Fig. 1 – Kirkin's experiment with rat sarcoma Cells [1981]. 1 ml of high-density inducer Culture (3) was placed on the bottom's external surface of 35-mm inverted Petri dishes (2). These dishes (2) were located into external 100-mm Petri dishes (1) and incubated in thermostat during 24 h. Then growth medium was eliminated, 35 mm Petri dishes (2) were inverted and placed onto a special 0.5-mm-thick spheric spacers (5) in the 100 mm Petri dish, which Contained a growth medium. Low-density detector Culture (4) was grown on the 35-mm dishes. In order to isolate the inducer and detector Culture Chemically, lids of 35 mm Petri dishes were glued to its foundation by glue of wax and paraffin (ratio 1:1). Lids of each 35-mm Petri dish had 1.5-mm holes for cell inoculation by syringe. After Cell inoculation, the holes were Closed by wax-paraffin glue. Radioactive Chemicals such as $^{51}Cr(Na_2{}^{51}CrO_4)$, ^{22}Na, ^{3}H-thymidine and ^{3}H-leucine were applied for Control of Chemical diffusion between the inducer and detector Culture. Incubation of Cells was Conducted in thermostat with 5% Carbonic acid. Number of detector Cells was analyzed with the use of inverted-stage microscope [Kirkin [1981].

claimed that chemical compounds could not be responsible for the stimulation effect. Although Kirkin concluded that physical fields were responsible for the effects observed, he did not specify it.

In 1984, Mostovnikov and Khokhlov reported that they found the optical interaction between diploid cells of musculocutaneous tissue from human embryo (Mostovnikov and Khokhlov [1984]). Special devices were used for the purpose of cell cultivation. The right-angled glass flasks had a window at one of the side that has been glued with glass plate (thickness of 0.1 mm). Cover glasses (18x18 mm) with monolayer of cells were placed afloat in the area of the window above (inducer culture). In other cases, cover glasses cellular monolayers were placed at angle of 30-40° to horizontal plane of the window (detector culture). Cells of inducer culture were treated with fast neutrons, laser radiation (helium-neon laser, helium-cadmium laser and monopulse ruby laser), colchicine and dimethyl sulphate. After 3-10 minutes of inducer treatment, the inducer and detector flasks were attached and cultured during 5 hours in the thermostat. After that, cells were fixed and analyzed. It was found that treatment with fast neutrons and laser radiation resulted in significant increase of chromosomal aberrations among both inducer and detector (non-treated) cultures (Mostovnikov and Khokhlov [1984]).

In addition, the transfer of alterations in mitotic activity was observed (Mostovnikov and Khokhlov [1984]). Suppression of mitotic activity in inducer culture was caused by treatment with monopulse ruby laser radiation (dose of 8 Joule per square centimeter). The stimulation of cell division was caused by irradiation with helium-neon laser and helium-cadmium laser (power density of 2 Watt per square centimeter). Initially, cells were irradiated with helium-cadmium laser, and then with helium-neon laser. For both of the lasers, the time of irradiation was 10 min (Mostovnikov and Khokhlov [1984]). The results of the experiment are shown in the Table 2.

In order to confirm the electromagnetic nature of informational signals, the experimental design was changed. Namely, radiation from inducer culture was directed to aluminum mirror and its reflection was felt by detector culture (Mostovnikov and Khokhlov [1984]). When the mirror was eliminated, the effect of interaction

was absent too. The authors performed over 500 experiments and claimed that light in the range of 500-700 nm was used for communication of the cultures. As regards the stimulation of mitotic activity, Mostovnikov and Khokhlov suggested that 250-500 nm light was responsible for the effects.

Table 2
The alteration in mitotic activity in optically interacting inducer and detector cultures (cited from Mostovnikov and Khokhlov [1984])

	Control (vs 1)	Irradiation (1) with monopulse ruby laser		Control (vs 2)	Irradiation (2) with helium-neon and helium-cadmium laser	
		inducer	detector		inducer	detector
Total number of analysed cells	16730	11520	13120	12770	11630	10310
Number of dividing cells	400	184	202	213	312	270
Mitotic activity (vs control, %)	100	67±6	45±5	100	160±10	157±10

In the late 1970s, a distinguished research on communication between insects (*Heterotermes indicola*, Rhinotermitidae family of termites) by means of electromagnetic fields has been done (Becker [1979]). Approximately 500 individuals of worker or older larvae were kept in right-angled polystyrene boxes (3.5x5.5x9.5, cm) with vermiculite in order to maintain an essential humidity. Pine sapwood treated with basidiomycete fungus served as a food. The length and the direction of gallery building were analyzed by the author.

Becker found that the gallery-building activity of termites largely depends on the location of containers. For example, the author watched that termites preferred to build gallery mostly at outside edges of containers when it were located oppositely (two rows of 5 containers). Analogous results were obtained when 16

containers with insects were positioned in 4 rows: despite of equal conditions, the gallery-building activity was suppressed in the 4 central containers; termites built galleries predominantly at the outer edges of 12 exterior ones. However, the effect of gallery-building suppression was absent when groups of termites with high gallery-building activity at the beginning of the experiment were placed in the 4 central containers. Then, the author excluded the various factors that could influence the results. For example, the use of polyurethane foam allowed to decline the possibility for vibrational explanation of the results in both series of the experiments (with 10 and 16 containers): galleries were again built at the outer edges of the containers (or were not build in the 4 central boxes when the experiment was done with 16 containers).

The most interesting results were observed when Becker used a different plugging materials between termites. Namely, the distribution of gallery-building activity was random (even in the central containers) when 5-mm thick aluminum plates were placed between containers. Therefore, the author concluded that communication between termites might be mediated by electromagnetic fields produced by themselves. Becker also found that the effect of communication depends on the number of individuals within the containers and on the distance between them. Namely, the effect was absent when the containers with 500 and 250 individuals were moved away more than 6 and 4 cm, respectively.

It was also shown that the communication does occur during interspecific interaction. Viz, the same results (suppression of gallery-building activity at the interior edges of two rows of the containers) were observed when *H. indicola* interacted with *Coptotermes formosanus*, *C. niger* Snyder, *Reticulitermes flavipes* Kollar, R. *lucifugus*, *R. santonensis* Feytaud, R. *speratus*, *R. tibialis*, *R. virginicus* (Rhinotermitidae species), *Microcerotermes crassus* and *Nasutitermes nigriceps* (Termitidae species), *Zootermopsis angusticollis* (Termopsidae species), *Neotermes jouteli* (Kalotermitidae species) as well as with *Mastotermes darwiniensis* (Mastotermitidae species). Thus, this type of communication occurred between all the families of Isoptera class.

3. PRESENT-DAY INVESTIGATIONS

Since results of the modern research can be found easily using library and Internet resources, these studies will not be presented in great details.

Communication in yeast. Light-mediated communication has been shown recently in ascomycetes by Italian and Bulgarian scientists. In 1991, Grasso and co-workers published a paper dedicated to alterations in growth due to optical contact between *Saccharomyces cerevisiae* cells (Grasso *et al.* [1991]). For self-irradiation, agar disks with cells were cut and put opposite each other at a distance of 6 mm for 30 s at a room temperature. In order to avoid the non-uniformity of the cultures, 15-mm disks with cells used for self-irradiation experiments and for controls were taken from the same Petri dish. After self-irradiation, 104 sample-control couples (with 1000 cells within each of them) were analysed microscopically, and the number of gemmae was calculated.

The authors found that there was 15% (on average) increase in gemmae's quantity in self-irradiated cells in comparison with the control samples. Although the self-irradiated samples were not separated chemically, Grasso and co-workers rejected the possibility that the effect might be mediated by metabolite exchange. The authors claimed that the chemical communication should occur more significantly within each self-irradiated or control sample during the incubation time since all the samples possessed an equal size and chemical content. Instead, self-irradiation, which was limited within the same sample due to light absorption, became more significant when the cultures were located in front of each other, as authors argued.

Finally, Grasso and collaborators reported that their attempts to state the spectral distribution of yeast radiation were unsuccessful, though by that time Quickenden and Que-Hee has informed of light emission from *S. cerevisiae* cells (Quickenden and Que-Hee [1976]).

It is also important to note that analogous experiments were performed with liquid yeast culture (Musumeci *et al.* [1999]). Musumeci and co-workers observed that actively growing yeast culture stimulated growth of lag-phase culture of the same species

(Musumeci *et al.* [1999]). Analogous results were observed in my experiments with *E. coli* cells (unpublished data).

Communication in plant objects. Plants were also involved in the study of optical communication phenomenon (Budagovskii *et al.* [2001]). The aim of the experiment was to study the optical communication between irradiated and non-irradiated pollen grains of cherry (*Cerasus pensylvanica* L. and plum (*Prunus domestica* L.). The male gametophyte of these orchard crops was irradiated with helium-neon laser (0.5-24 min, power density 12 W/m^2). Pollen grain germination was used as an indicator both of the biological effectiveness of the laser exposure and optical interaction. Cover glasses with nutrient medium (15% sucrose, 0.8% agar and 0.001% boric acid) were used for germination of pollen grains. Germination was detected as it was described by Pausheva (Pausheva [1974]).

In order to reject the hypothesis about chemical communication between pollen grains under study, inducer, detector and control were located into common gaseous environment (Budagovskii *et al.* [2001]). With this aim, an airproof box with slots for 64 specimens and channels for free gas exchange between them was made. Inducers and detectors were placed at a distance of 3 mm face (pollen) to face; the controls were also placed in pairs. The backside of each cover glass was covered with aluminum foil. Budagovskii and collaborators found that the maximal effect of detector (as well as in inducer) stimulation was observed after 30-s irradiation. In this situation, it should be marked that detector and control differed significantly in germination level when they were screened by aluminum foil. In this experiment, Budagovskii and co-workers demonstrated unambiguously that the communication was mediated by physical rather than chemical mechanism (Budagovskii *et al.* [2001]).

Communication between animal cells, tissues and the whole organisms. In the early 1990s, Guenter Albrecht-Buehler, a biophysicist at Northwestern University Medical School in Chicago, discovered that some cells can respond to 800-1000-nm light signals (Albrecht-Buehler [1991]). Very soon after that, the author found that mammalian cells also can detect and respond to light signals from the same cells (Albrecht-Buehler [1992a]). Experi-

ments were done with BHK cells (baby hamster kidney cells, a well-established fibroblastic cell line). BHK cells were grown on one side of soda-lime glass plates with various thickness (2.5-160 mm). A lump of BHK cells was inoculated onto one side of glass plates. Two days later, the glass plates these with the cells were turned upside down, and 1- to 3-day-old BHK cells were drifted on another side of these glass plates. Therefore, one side of glass plate contained a sparse culture of BHK cells while the other a confluent (dense) one (the author called them as "s-face" and "c-face", respectively). Glass plates with cells were located in Petri dishes and incubated for 7 h, then fixed with formaldehyde, stained with Coomassie blue, and analyzed using bright-field microscopy (Albrecht-Buehler [1992a]).

Albrecht-Buehler found that long axes of 76±4% of BHK cells on s-face were situated at angles of ≥ 45° to those on the c-face of the glass plate. The author suggested that a special type of communication between cells of s-face and c-face resulted in this cell orientation. When the author used more thick glass plates, the number of traversing cells reduced pro rata to glass thickness. Namely, the use of 6-8- and 30-40-μm-thick glass plates resulted in 69±3% and 59±3% of traversing cells, respectively. Increase of glass plate thickness up to 160 μm resulted in decrease of traversing cell's quantity to the level of stochastic variations (49±4%) (Albrecht-Buehler [1992a]).

In order to determine whether the effect was mediated by light signal transmission, Albrecht-Buehler used special materials that covered the glass plate (Albrecht-Buehler [1992a]). Particularly, the 6-8-μm-thick glass plates were coated with 100-150-Å-thick Ni-Cr layer, which reduced optical transmission up to 0.4-10% in the range of 400-900 nm. Before cell inoculation onto s-face, the glass plate used was covered with this thin metal layer. In this case, the percentage of traversing cells was about 40%. These results clearly indicated that the nature of communication signals is rather electromagnetic. To define the communication wavelengths, the author used silicone whose light transmission increased in the 400-900-nm range (especially in the red and infrared region). In this case, the number of traversing cells was almost the same as without the silicone layer. Therefore, Albrecht-Buehler proposed that

the light signals, which are responsible for cell orientation, are probable to belong to red-to-infrared region (Albrecht-Buehler [1992a]). Considering the alternative explanations for the effect observed, Albrecht-Buehler rejected another factors that might be responsible for aforementioned orientation of BHK cells on s-face of the glass plate. Chemical and electrical signals, sound waves, magnetostatic fields, stress lines, and local bending of the glass plate were declined emphatically as signal carriers. The reasons for such a refusal are greatly discussed in the paper of Albrecht-Buehler (Albrecht-Buehler [1992a]).

Thus, the author suggested that such a kind cellular "vision" might be used for orientation in the environment or intercellular communication. Since tissue cells are able to emit and detect infrared light, there must be a specific light emitters and detectors within the cells, as the author proposed. However, the possible mechanisms will be discussed in a special chapter below.

In 1995, it was reported about communication via light among the *Lampyridae Pekennisis* beetles, which were captured in Beijing Hunting Park, China (Chang *et al.* [1995]). Males and females of these beetles were located into two identical cylindrical glass containers with a shutter between them. So, males and females could see each other. Light emission in the range of 200-800 nm was measured from the insects after 32-72 h being catched. The authors found that the light emission patterns were different in males and females: shapes of flashing pulses from males were more regular and the width of the peaks was lower. In contrast, flashing pulses from females were more irregular. Chang and co-workers also calculated correlation coefficient and cross correlation of photon emission from males and females of the beetles. The authors found that the correlation coefficient for light emission was higher when males and females were able to interact via shutter between the chambers used. Another characteristic feature of light emission from these insects was observed by the authors. Namely, delayed luminescence from illuminated with white, red or blue light, displayed non-exponential shape. Obtained hyperbolic curve of this delayed luminescence confirmed that light emission from the organisms was coherent. Chang and co-workers suggested that communication via light between beetles is not a simple exchange of

light flashes but rather is based on the interference pattern of light from these insects (Chang *et al.* [1995]).

The experiments on optical communication were also performed with the use of higher organisms. For example, Burlakov and co-workers (Burlakov *et al.* [1999a], [1999b], [2000]; Doronina *et al.* [2002]; Beloussov *et al.* [2002]; Beloussov [2003]) investigated optical interactions between embryos of a loach, *Misgurnus fossilis*, at different stages of development.

The scheme of Burlakov's experiment is presented in Fig. 2. The authors observed 92-94% mortality in early embryos (10-15 min after fertilization) after their 24-h optical interaction with embryos at the stage of early blastula. In the same time, there were no significant alterations in development of early blastula embryos (Burlakov *et al.* [1999a]).

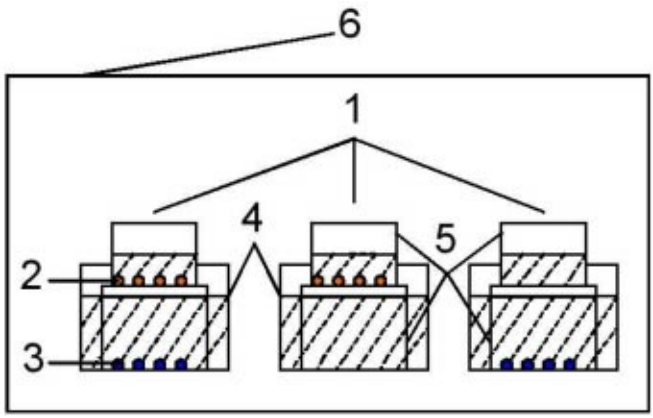

Fig. 2 – Experiments of Burlakov *et al.* [1999a]. To obtain embryos, loach females were treated with choriogonadotropin, as it was described previously [Kostomarova 1975]. Age-specific embryos were obtained owing to delay in fertilization of fish spawn from the same individuals. Loach embryos of different stages (2 and 3) were positioned in quartz or ordinary glass cuvettes (1). Each cuvette contained 80-100 embryos. Cuvettes were placed into glass Petri dishes with water (4). Control samples (5) contained embryos of one stage of development and were enveloped with black paper. In order to prevent external light action , all the cuvettes were put into metal sheath (6). After optical interaction, embryos were analyzed microscopically. Experiments were done in 8-10 replicates (Burlakov *et al.* [1999a]).

In 1999, the same authors reported about optical contact between loach embryos that were obtained from spawn of high and low piscicultural quality (the efficacy of fertilization was 90-98% and 10-15%, respectively) (Burlakov *et al.* [1999b]). Burlakov and co-workers observed an increased rate of development, increased synchronism of cell-division, decreased level of mortality (38-45% in comparison with 78-85% control level) in group of embryos obtained from spawn of low piscicultural quality. So, spawn of high piscicultural quality influenced positively the spawn of low piscicultural quality.

In 2000, Burlakov and co-workers performed more detailed research on optical interaction between embryos of different age (Burlakov *et al.* [2000]). Different-age embryos (stage 0, 1, 2, 5, 6, 8, 9, 10, 14, 20, 30, 33) were involved in this study. Overall, older embryos negatively influenced the younger ones. Optical contact of similar-age embryos resulted in synchronization and growth acceleration of interacting embryos. However, in the case of interaction between stage 2-4 and stage 6 (and the subsequent stages) embryos, the effect was opposite. 2-4 stage embryos developed without any serious aberrations, while in older embryos there was significant increase in mortality (sometimes up to 100%) (Burlakov *et al.* [2000]).

During these experiments not only general mortality but also developmental aperiodicities were analysed. Simultaneous growth of stage 0-1 and stage 8 embryos resulted in appearance (in older group) of embryos with encephalic end bifurcation of axled complex (in 8% cases). These anomalous embryos formed subsequently two-headed pre-larvae with developed encephalic structures and independent hearts. However, appearance of "two-headed" embryos was observed also in stage 1 embryos when yellow filter was positioned between interacting embryos. In stage 8 embryos, such abnormalities were not detected but single individuals with 3-6 heads were observed. Burlakov and co-workers found such type of developmental aberration for the first time. When interference infrared filters were used between stage 0-1 and stage eight embryos, there was 8-10% of embryos without tail and body segments in older group. After interaction between stage 5 (morula) and stage 9 (epithelial blastula), in older group there

were embryos with underdevelopment of encephalic segments, wide spreading of body segment along the yolk and anticipatory formation of circular somites in caudal part. Utilization of yellow filter between morula and epithelial blastula resulted in appearance of headless embryo in older group, which had two tails. Finally, after interaction between stage 6 (early blastula) and stage 10 (the beginning of emboly) embryos with dismemberment of axled structures in body segments were detected in older group (Burlakov *et al.* [2000]).

It should be noted that all the abnormal embryos were sufficiently viable during pre-larval period, but within all of them extremely slow yolk resorption was observed. There was also intensive water plenty in pericardial cavity that caused death (Burlakov *et al.* [2000]).

Concerning the biological role of light emission from embryos, Burkalov and co-workers suggested that optical interactions are able to cause the alteration, which are identical either to ectopic activation of gene-regulator (Kazanskaya *et al.* [1997]) expression, or to elimination of competent material due to prohibition of competence acquiring.

Similar results were obtained by Doronina and co-workers (Doronina *et al.* [2002]). They suggested that light emission that mediates the interaction observed provides an informative role only when the competent systems to this radiation in the receiving system do exist.

As regards the possible biological data carrier, a few notes should be made. All the authors (Burlakov *et al.* [1999a], [1999b], Doronina *et al.* [2002]) mentioned that placement of 3-mm thick UV-opaque glass plate or black paper between the interacting embryos resulted in elimination of the effect. Therefore, the authors suggested that UV light served as informational medium.

Moreover, Beloussov and co-workers experimentally shown that unfertilized and fertilized eggs, embryos, larvae and eggs envelopes of loach *Misgurnus fossilis* do emit ultraweak light emission in the range of 200-800 nm (Beloussov *et al.* [2002]). Ovules, 50-100 embryos and larvae were located into quartz cuvettes. It was found that intensity and frequency of signals from biological objects under study depended on stage of development. One year later, a

comparative investigation of light emission patterns was carried out with loach embryos and rat fibroblasts (Beloussov [2003]). Biophotonic patterns of optical interactions between fish eggs and embryos were also under study (Beloussov *et al.* [2003]).

Communication between biological objects of different origin. In 1994, Kuzin and co-workers reported about discovery of so-called secondary biogenic radiation (SBR) (Kuzin and Surkenova [1994]). According to theory of excitation in biological polymers (Dicke [1954]; Popp *et al.* [1992]), Kuzin and co-workers suggested that after excitation of cellular polymers (proteins or nucleic acids) with γ-rays, the latter will form polaritons, which are able to emit the secondary coherent radiation. Their theoretical prediction was confirmed in experiments with radish seeds. Namely, one part of the seeds (inducer) was irradiated with γ-rays in recommended dose (Berezina [1964]), and another part was intact (detector). Developmental index (DI) was used for evaluation of the interaction effect; it was determined as Σ/N, where Σ is the sum of the lengths of all seedlings, N is the number of seeds under study.

The authors observed an increased DI (147-165% in comparison with control) in detector seeds when they were located in front of the irradiated inducer (Kuzin and Surkenova [1994]).

It was also found that SBR is able to revive old seeds with low germinating capacity (Kuzin *et al.* [1995]). In experiment with seven-year-old seeds of Barley, Kuzin and co-workers showed that germinating capacity increased twofold due to interaction with g-irradiated radish seeds. Similar results were obtained in experiments with lilac sprouts (Kuzin *et al.* [1995]).

In order to show the universality of SBR, experiments were performed also with native, g-irradiated and coagulated albumen, protein-rich tissues (freshly cut wool of dog and cat, legless bodies of cockroach), human blood and human body (Kuzin *et al.* [1996]; Kuzin *et al.* [1997]; Kuzin and Surkenova [1999]). Let us consider these experiments systematically.

Kuzin and co-workers found that both the g-irradiated and native albumen were able to increase the DI in detector radish seeds (140 and 175% for irradiated and native protein, respectively). However, coagulated albumen did not cause DI increase in detector. In the experiments with animal wool and insect bodies,

analogous results were obtained: native and γ-irradiated wool and cockroach bodies increased DI in detector radish seeds while the heated wool and lifeless cockroach did not do the same (Kuzin *et al.* [1996]).

Influence of inducer γ-irradiated human blood resulted in 171% DI increase in detector radish (Kuzin *et al.* [1997]). Two main findings were discovered in this experiment: first, only fresh blood was able to generate SBR, and, second, the effect was absent when detector seed were placed opposite the lustreless walls of cuvette with blood (Kuzin *et al.* [1997]). Since previously it was shown that lustreless quartz significantly absorbed coherent light (Perina [1974]), Kuzin and co-workers suggested that SBR is highly coherent.

The influence of human body on the growth of wheat seeds with low germinating capacity was also investigated (Kuzin and Surkenova [1999]). There was a significant increase (effect varied from 164 to 487%) in DI of the seeds when it were placed on the human breast or were squeezed in the left and right palms (Kuzin and Surkenova [1999]).

Analyzing the properties of SBR, a few remarks should be done. First, SBR is inherent in all organisms, including microorganisms, plants and animals. Second, the greatest stimulating activity of SBR is observed in organisms with reduced viability. Third, there is no dose-dependent action of SBR after γ-irradiation of inducer organisms. Experiments with albumen clearly proved such a property of SBR (Kuzin *et al.* [1996]). Moreover, it was demonstrated that non-irradiated with γ-rays biological objects are able to emit SBR but with lesser intensity (Kuzin *et al.* [1996]; Kuzin and Surkenova [1999]). Very likely that SBR represents UV light: in all the aforementioned experiments, the effect was absent when inducer and detector were separated by UV-opaque glass. The detailed scheme of SBR formation is presented in Kuzin's monograph (Kuzin [2002]).

4. DISCUSSION

First of all, I would like to note that the following remarks are

not for the sake of sharp criticism but rather for giving some advice in order to prevent any experimental shortcomings in the future.

Let's begin with statistics. The early studies do not tell us anything about statistical treatment of data. Therefore, in this paragraph only postwar and modern investigations will be considered. As one can see, except for research of Musumeci and co-workers, there were not satisfactory explanations why one or another criterion was used. For example, Kaznacheev and Mikhailova used chi-square test (Kaznacheev and Mikhailova [1985]), Burlakov and co-workers [2000] used *t*-test for evaluation of the data. But they did not define in their papers whether the testing of normality was done. In Albrecht-Buehler's paper of 1992a it is written: "two methods were used for statistical treatment of the results. One method evaluated each preparation individually and determined the average and standard deviation of the data of repeated experiments. The second method evaluated the cumulative counts for the different experimental conditions". But, however, what criteria were used? In the paper of Budagovskii and co-authors [2001] the following phrase is presented: "Statistical analysis of the results showed that...". Although confidence intervals are shown, there are no mentions what type of criterion was used. The same situation is observed in the papers of Kuzin and collaborators. In the papers of Kirkin, Mostovnikov and Khokhlov, Becker, Chang *et al.* there are not any indications concerning statistical treatment of data presented. As for further research in this controversial field of biology, one must keep in mind that more attention should be given to statistical treatment of experimental data. For example, the introduction of "double-blind" scheme would be of help.

It should be also noted that experimental design of the above-mentioned studies did not allow to determine the exact nature of signal carrier. For example, there were no stringent controls for diffusion of signalling volatiles. In this connection, the use of radioactive substances (as it was done by Kirkin in his research of 1981) would be helpful for elimination of chemical's transfer possibility during the experiments. Moreover, in the paper of Becker [1979] it is stated that lids of the containers with insects contained special holes for ventilation. And although the effect of communi-

cation was absent during use of a special shielding, it is possible that microdoses of insect pheromones were conducive to manifestation of macroeffects observed. The analogous critical remarks might be done with respect to experiments of Grasso *et al.* [1991], Kuzin *et al.* ([1994], [1995], and [1999]), Chang *et al.* [1995], and Burlakov *et al.* ([1999a], [1999b], and [2000]). If radioactive control of volatiles transfer is not accessible, the alternative way out from this situation may be placement of interacting objects and control samples in uniform atmosphere conditions as it was done by Budagovskii *et al.* [2001].

Furthermore, shielding experiments that has been done by some researchers may be very useful in determination of the precise mode of the communication signal. For example, experiments of Kaznacheev and Mikhailova performed with different materials clearly demonstrated that UV and infrared light were the most probable signal carriers [1985]. The utilization of aluminum mirrors helped to confirm the light nature of the signals in the experiments of Mostovnikov and Khokhlov [1984]. The analogous technical approach has been undertaken in the experiments of Becker [1979] and Chang *et al.* [1995] where the electromagnetic mechanism was postulated. In these cases, the absence of the effect during screening with different materials between interacting organisms might corroborate the light nature of the signals. However, there are scientific data that different organisms may communicate also via sonic waves. For example, in the discussion part of Matsuhashi *et al.* paper of 1998 it was stated that sonic signalling occurs in *S. cerevisiae*, bean seedlings (*Vigna mungo*) and fish embryos (*Medaca*) (Matsuhashi *et al.* [1998]). For example, in the experiments of Kirkin [1981], Kuzin *et al.* ([1994], [1995], and [1999], Budagovski *et al.* [2001], Musumeci *et al.* [1999] where a special shielding was not done, it is possible that sonic signals were also involved in communication.

To concretize the exact nature of the signal, there are two ways: first, it is necessary to consider the physical properties of materials that were used; and, second, there is a need to use special ultra sensitive instruments for registration of light or sonic production. According to the first suggestion, it should be noted that only Albrecht-Buehler [1992a] made a detailed description of physical

properties of materials dividing the culture under study. Unfortunately, in another experiment the same analysis was not undertaken. In some experiments (Kaznacheev and Mikhailova [1985], Kuzin *et al.* [1994], [1995], and [1999], Burlakov *et al.* [1999a], [1999b], [2000], Doronina *et al.* [2002]), it was stated that quartz barrier allowed the effect in contrast to UV-opaque glass. But, for example, fused silica and crystalline quartz that differ in content of inorganic elements vary also in transmittance range (150 nm-3000 nm for fused silica, and 200 nm-2000 nm for crystalline quartz) (Holloway [1973]). Since the exact kind of quartz barriers used was not specified, it is really unclear what precise wavelength (UV C, UV B or UV A) was responsible for the effects observed. In some cases when quartz cuvettes were used (Musumeci *et al.* [1999]), visible light might be also took part in the communication events. In this connection, the use of various colour filters might be very useful in concrete definition of signal carrier frequency (some attempts in this direction were made by Burlakov and co-workers: they used yellow filter and polarizer between interacting embryos) (Burlakov *et al.* [2000]). And, a second way as I said before is the direct light emission measurement in the broad band of wavelengths. Unfortunately, except for experiments of Beloussov *et al.* ([2002], [2003]) this was not done. Probably, the reason for it is the expensiveness of equipment for light emission measurements.

It is important to note that not only a frequency distribution but also other features of information carriers should be taken into consideration. For example, the central question today is the coherence of radiation emitted by living organisms. Historical background comes from theoretical works of Dicke [1954] and Frohlich ([1968], [1975], and [1977]). The essence of their theory is in the following. Biological molecules with large dipole charges are able to vibrate at various frequencies but those whose frequencies are similar may start to resonate and build up to either a collective electromechanical oscillation (phonons or sound waves) or a collective electromagnetic oscillation (photons). According to Frohlich's predictions, these oscillations may extend over the long distances (much more than cellular size) within the organism and probably outside the organism (Frohlich [1968], [1975]).

Now, there is a good reason to believe that this radiation is really coherent. Namely, many works of Popp and co-workers show that light emission from living organisms (Popp called it as "biophoton emission") decays in a hyperbolic way, in contrast to the exponential decay of non-coherent light (Popp [1986]; Popp *et al.* [1992], [1994], [2002], [2003]). Other experimental data also confirm the coherence of the light emitted by living organisms (Kuzin *et al.* [1997]; Ho *et al.* [1992], Dekorsy *et al.* [1995]). Some theoretical considerations on the coherence of biophoton emission are also given in the works of Zhang and Popp [1994], Brizhik *et al.* [2000], Ho [1993], Ho *et al.* [1994].

Concerning the source of the light emitted by organisms, it also should be noted that no agreement has been achieved in the area of interpretation of its origin. According to the generally accepted point of view, the light emission is due to heterogeneous, localized phenomena in various compartments of the cell with different sources of emission from unrelated processes (Cadenas [1984]). However, the competing standpoint maintains that cellular DNA is as a high energy, electronically excited molecular complex that emits light from UV to infrared (Nagl and Popp [1983]; Chwirot [1986]). However that may be in reality, the current opinion is that light emission is able to regulate various important processes (Van Wijk and Schamhart [1988]; Multi-author review [1988]; Bajpai [1999]) and can provide us some valuable information on the status of a biological system (Kobayashi and Inaba [2000]; Kobayashi *et al.* [2001]; Kobayashi [2003]) as well as can be used for diagnostics (Takeda *et al.* [1998]; Cohen and Popp [2003]). However, the discussion of light generation is not the goal of this review.

The molecular mechanisms of light absorption are greatly discussed by Karu [1999]. There is a lot of another literature, which is dedicated to mechanisms of influence of electromagnetic fields of a broad frequency spectrum on the living organisms (Colacicco and Pilla [1984]; Grattarola *et al.* [1985]; Barnes [1992]; Pilla and Markov [1994]; Engstrom and Fitzsimmons [1999]; Sidorenko [2001]). However, the aforementioned papers do not go into problems on mechanisms of participation of electromagnetic fields in communication. In this connection, Albrecht-Buehler's stand-

point seems to be interest. For example, the author proved that mitochondria may be able the sources of light within the cells (Albrecht-Buehler [2000]) and that light detector system is situated in centrosome (Albrecht-Buehler [1994]). The last statement was confirmed in the experiments on cell center irradiation (Albrecht-Buehler [1994]). Namely, the author found that 3T3 cells are unable to detect nearby infrared sources when they are irradiated with the same light. The next step was to identify the more exact location of light-sensitive organelle. As everybody knows, three microbodies (nucleus, Golgi-apparatus and centrosome) are situated in the center of cell. Albrecht-Buehler found that enucleated cells (treated with cytochalasin B and then centrifugated) were still able to react to distant IR light sources (Albrecht-Buehler [1994]). Analogous results were obtained when Golgi-apparatus was inhibited with monensin (Albrecht-Buehler [1994]). Therefore, Albrecht-Buehler concluded that centrosome (with pairs of centrioles) was responsible for light detection (Albrecht-Buehler [1994]). Considering previously the geometric properties of centrioles (Albrecht-Buehler [1981], [1985], [1992b]), the author concluded that they are the best candidates for cellular "eye" (Albrecht-Buehler [1994]). The next bright idea of Albrecht-Buehler was that heme-containing mitochondria are the most suitable candidates for light production. Being excited with UV light (*in vitro*) or due to specific action of enzymes, mitochondria they then were able to emit in red-infrared region (Albrecht-Buehler [2000]). This phenomenon called as RELIEF (Reversible Excitation Light-Induced Enhancement of Fluorescence) was shown to reside in 3T3 and CV1 cells as well as HeLa cells and BHK cells (however, in cells from non-placental animals it was not found) (Albrecht-Buehler [2000]).

Another aspect of physically-mediated communication should also be studied. Namely, it is a well-known fact that a variety of processes are dependent on the geophysical activity. A great many of examples are summarized by Chizhevskii (Chizhevskii and Shishina [1969]; Chizhevskii [1995] and Uglev [1991]). In this connection it is interesting to investigate how this type of interaction depends on these factors. In order to answer this question it is necessary: (1) to study the phenomenon of communication for a

long time, and (2) to perform these studies in the different geographical locations. Only one work (Kaznacheev and Mikhailova [1985] satisfies these conditions. Namely, Kaznacheev and Mikhailova performed their experiments during a long period of time (1966-1976) in different geographic coordinates (Novosibirsk, Norilsk, Moscow, and Simferopol). They found that there is a seasonal dependence in the manifestation of "mirror cytopathic effect". Namely, decennial analysis revealed that the effect was increasing from January to August, and decreasing from August to December (from December to January the effect was totally absent). In synchronous experiments performed in Novosibirsk and Norilsk, it was shown that during arctic day (May-July) there was no difference in the manifestation of "mirror cytopathic effect" whereas there was a 10-20% decrease in the display of effect in Norilsk during arctic night. Moreover, cell cultures in Norilsk were more resistant to action of mercuric chloride than in Novosibirsk. There were no differences when the same experiments were done in Novosibirsk and Moscow. Cellular culture (transplantable line of human kidney) grew more intensively in Simferopol in comparison with Novosibirsk. However, the manifestation of "mirror cytopathic effect" was at the same level in these cities.

Thus, the studies of Kaznacheev and Mikhailova clearly demonstrated that the effect of non-chemical and non-mechanical interaction might be dependent on the cosmo-geophysical factors. In this connection, the investigation of this type of communication, for example, in various continents would be of great interest.

5. CONCLUSION

Many of the above-mentioned experimental data provides strong evidence that bio-systems do communicate via electromagnetic signals. With the exception of direct evidence for this possibility, the indirect ones also corroborate that there is more complex system of interaction between living organisms than previously thought. It is unclear, for example, how neurons interact with each other within the brain: if this interaction occurs only via

synapse contacts, then the real weight of brain must be more greater than in reality. Next, millions of cells die every second in higher organisms and all of them must be replaced immediately. Therefore, it is reasonable to expect that the process of cell regeneration must be quick and precise. It is incomprehensible, for example, how some gregarious fishes change their motion simultaneously. The most probable answer to these questions is that there is an electromagnetic link between cells, tissues and organisms. Indeed, electromagnetic signalling is the most suitable kind of communication in various media, including the atmosphere, water or living tissues.

At present, it is important to determine what can be said about the parameters of electromagnetic fields involved in the communication. In the near future, frequency, intensity and character of pulse modulation should be studied for various biological systems. These data must be processed in terms of bioinformatics. Namely, the concept of "informational capacity" should be introduced into practice. In this connection it is interesting to note that as early as 1964, Kaznacheev and co-workers proposed that "informational capacity" of near-UV light is about $5 \cdot 10^9$ bit per second (Kaznacheev *et al.* [1964]). So, much work must be done before universal theory of communication between living organisms can be created.

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COMUNICAZIONE NON-CHIMICA A DISTANZA IN VARI SISTEMI BIOLOGICI

Riassunto

La comunicazione è una proprietà fondamentale dei sistemi viventi. È molto probabile che nel corso dell'evoluzione si siano sviluppati diversi tipi di comunicazione. Mentre la comunicazione basata sui recettori e sulla segnalazione chimica è da lungo tempo sotto studio, modalità alternative di interazione cellulare sono ancora oggetto di discussione. In questo articolo vengono passati in rassegna gli studi sulla comunicazione mediata da agenti fisici.