MICROWAVE BIOELECTROMAGNETICS IN EUROPE

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Abstract

The paper results from a survey made among about fourty european research teams. It is divided according to research areas. References are replaced by the names and addresses of contributors, noted by alphabetical order of the city in which they are located, in view of possible cooperations.

Introduction

Microwave bioelectromagnetics is quite active in Europe, with theory and experiment, research and clinical treatment, throughout the microwave spectrum and well into the millimeter wave range. The abundance of the material is beyond expectation. To save space, and despite of the interest of most of the contributions, the text is organized in short factual reports. A few abbreviations are used :

em	electromagnetic
EEG	electroencephalogram
FDTD	finite difference in time domain
MMW	millimeter waves
MW	microwaves
SAR	specific absorption rate

Behavioural Effects

Behavioural effects of MW are investigated, showing the connection between behavioural effects and endocrine responses. White rats, aged 3-4 months, were exposed to 2.45 GHz CW and 3 GHz pulsed (400 pps, duration 2 us, mostly in burst every 3.75 s, SAR was 0.27 mW/g/mW/cm2). Histology of the thyroid gland demonstrated increased functional activity after CW irradiation, while it decreased under pulsed MW at any level. CW irradiation (1mW/cm2, 7 h/day) revealed the increase of the activity of the zona biomerulosa that plays an important role in the regulation of the mineral metabolism, from which it is assumed that there is an increase of the secretion of mineralcorticoids, mainly aldosterone. (Kiev, Navakatikyan).

Biophysics

The macroscopic behaviour of biological systems emerges out of quantum dynamics yielding the physics of "living matter", to a point where biochemistry has to be taken into account. The interface between the physics of living matter and molecular biology is where time ordering in chemical reactions and "systemic" behaviour (coherence, tissue formation, large non-molecular dimensional scale) appear. The filamentory (self-focusing) type of propagation of the em field plays a crucial role in the cytoskeleton dynamics and formation. Weak forces may have relevant effects due to the nonlinearity of the dynamics, and this introduces a conceptual framework completely different from the "perturbative framework" where it is always possible to select dominant forces. It is considered that the living system is the endpoint of an evolution whose starting point is a set of many electric dipoles (biomolecules) open to environmental influence. Boson condensation in biology, as well as magnetic flux quantization and Josephson behaviour in living systems are investigated. (Salerno) (Milano).

The effects of extremely low energy MMW (37-78 GHz), with resonant character regarded as its distinctive feature, are measured using a number of techniques, including biomolecular spectroscopy and Raman spectrum lines. MMW has been shown to act on aminoacids, nucleotides, proteins, nucleic acids in free and intercellular states, bacterial cells and native blood, and blood plasma. A significant action is observed upon intensity, halfwidth, and shape of the energy levels connected with vibrations of phosphodiester bond atoms in free DNA. The intensity of shortwave polyen band (360 nm) changes under the influence of MMW radiation at 37.5 GHz (action upon spectral and kinetic parameters of albumin crystal luminescence with polyen structure additives). The refractive index of a 2% solution of human blood plasma increased by 2.10E-4 (25 times the device sensitivity), as soon as the irradiation started. An accumulation character is shown, the action occurring in number of cases some time (up to one hour) after turn-on. Also, there appears to be a memory in the effect, with changes maintained for hours after turn-off. (Kiev, Litvinov).

Quantum considerations and coherent em effects are evaluated in view of possible "biocomputing". (Moscow, Bannikov).

Cells, Membranes, and Micro-organisms

A system for the irradiation of cell structures, in volumes between 5 and 50 cc, at 2.45 GHz, pulsed, 300 W peak, is developed. Two modes are possible : temperature control, down to a stability of 0.05°C for at least 2 hours, and E-field controlled mode in which the power is steered so that the measured E-field closely follows any prescribed time course. (Ghent, De Wagter).

Experiments in vitro, with as a basis a model in which MW interact with the cell surface by affecting receptors, and induce changes of functional character. The manifestation of complex regulation processes is observed on the levels of cells and their components. Low MMW intensities are used to investigate the role of cellular surfaces in the MW effects. The attention is focused on biochemical changes connected with cell receptors and enzymes, and changes in DNA. (Brno).

65-73 GHz are used on C.albicans cells suspension, and the variation of the bacterial growth is evaluated. Ku-band

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irradiation, used on E.insidiosa and C.albicans, shows a reduction of the multiplication capacity of the irradiated samples. 12-18 GHz are presently used to irradiate bacterial colonies and evaluate the growth. (Palermo).
(1) Nonlinear analysis of the effects of em fields on excitable membranes with results. Simulation of the response induced by a MW field on the neuronal activity with results. Experiment on the effect of pulsed amplitude modulated MW fields on the membrane electrical activity in neurons of gastropods showed a reversible alteration of the action-potential threshold voltage when a snail neuron is exposed (2.45 GHz, 10 us width, 100 Hz repetition, average SAR 174 mW/g). Possible action on membrane sodium channels, or a microthermal effect of thermoelastic expansion (2) Detected a MW action on the behaviour of the acetylcholine-activated ionic channels, due to an experimental method to measure the transmembrane channel currents activated by extracellular messengers, using the patch-clamp technique. Results indicate that MW field may interfere with the acetylcholine-receptor desensitization processes that develop in myotubes (3) Experimenting on artificial membranes doped with Gramicidin-A, the conductance is observed to significantly increase in non-zero MW fields. It is SAR-dependent and shown to be a non-thermal effect. MW induce Ca influxes on the lipid structure in liposome, with an effect depending on exposure time. (Rome, La Sapienza).
Cellular effects of ELF magnetic fields combined with MW are under scrutiny : cell cultures and small animals (mice) will be exposed to uniform ELF magnetic fields (0.5 mT) and to a combination of ELF with 2.45 GHz. Four of the basic cellular systems will be tested (membrane permeability and transport, DNA/RNA synthesis, protein synthesis, proxidant state). They may indeed be engaged in neoplastic transformation, in response to exposure to ELF magnetic fields. (Warsaw).
Thorough studies on isolated blood cells of gonadotropes, testosterone, etc, concluded that MMW affect both differentiating and proliferation of lymphocytes, and also their dynamic activity. The effect on the immunity is obtained via the neuroendocrinal system and biochemical mechanisms, i.e. neuromediators and the hormonal system. (Odessa).
Effects of MW on in vitro V79 and human lymphocytes cell cultures have been followed-up, with a special emphasis on DNA-synthesis. The cells are exposed to 7.7 GHz, 0.5, 10, and 30 mW/cm2, and an exposure time of 10, 20, 30, and 60 min. When compared to controls, irradiated cells are exhibiting a significant increase in the number of specific chromosome lesions, i.e. unstable aberrations such as dicentrics and rings. The micronucleus test shows evidence of changes in the genome. (Zagreb, Garaj-Vrhovac).

Clinical Investigations

Transcerebral exposure is found effective in patients with diseases followed by immunological and endocrine disturbances. There is a normalization of neuroendocrine regulation of immune response, with a more reciprocal relations between hypothalamic and peripheral hormones. Most changes are in T-lymphocyte values and their activity. Apparently, the em exposure acts as the trigger mechanism of homeostatic changes. (Moscow, Mallavin).
Methods of MMW therapy have been worked out for benign tumors and pretumorous processes of the female reproductive system, as well as for endometrial hyperplasia, myoma uteri and uterine cancer during the post-operative period to prevent and cure purulent and septic after-effects. It is found that MMW (7.1 mm) irradiation inhibits further growth and development of myoma uteri and, in a number of cases, yields myomatous knots regression. It also cancels immuno-depression development during the post-operative period, as well as during chemiotherapy and gamma rays in uterine cancer patients, so that those were able to receive the whole course of treatment. (Odessa).
53-78 GHz non-invasive stimulation of acupoints shows a therapeutic affect. There is a proposal for using it for patients suffering from AIDS. (Moscow, Teppone).
EHF-treatment is mentioned as having been applied to thousands of patients. The theoretical accent is on harmonous restoring. (Moscow, Golant).

Development and Genetics

Teratological effects of long-term low-level CW and AM in-utero MW exposure on mice are investigated, as well as morphological and biochemical evaluations of the sequential generation. The protein synthesis is measured on the level of translation in the brain and liver tissue. The morphological evaluation of development in sequential generations of mice after long-term low-level exposure is obtained by separating in normal and not-normal (abnormal, malformed, non-developed) groups of generations while the aminoacilation is measured, using C14 amino-acid in transfer-RNA (tRNA) and amino-acid tRNA synthesis in the brain and liver tissues of irradiated mice and rats. (Budapest).
A 4-year study has been led on genetic effects of MW and RF, with U.Stockholm. Bacteria are tested for different mutations or prophage induction, with no increase in the mutation frequency and a small but significant increase in the cellular rate growth for all MW exposures. With U.Umea, embryos of Drosophila were tested at 2.45 GHz. A sensitive somatic test system was used, in which mutagenicity was measured as the frequency of somatic mutations in a gene controlling eye pigment. No increase in mutation frequency is obtained, when compared with the non-exposed conttrols. (Göteborg).
(1) About the genome role in physical mechanics of cell response to low intensity em fields, a general model is presented, based on internal em field sources in a living cell. The generation of collective modes, arising from the hydrogen bond system in the DNA, is possible at definite frequencies in a wide frequency range. A resonant effect on E.coli cells (at 51.7 GHz) and on rat or human leucocytes is observed on the Genome Conformational State (GCS) (2) The low-intensity MMW exposure (200 uW/cm2) of rat thymocytes resulted in CGS changes, resonant at 41.65 GHz. The time-course of Ca++ proved to be most sensitive : there is a 10% reduction in the intracellular Ca++ after a 10-min exposure, so MMW induced changes in the CGS may be related to the Ca-dependent processes in the cell (3) MMW exposure (46.35 GHz, 100 uW/cm2, 2 hours) of early Drosophila melanogaster embryos following an ionizing treatment (1.5 Gy of X-rays) resulted in strong modification of radiation injury, hence non-thermal MMW can be used as a radiomodificator with a high selective influence. The modification has only "positive" results and can protect biological objects from radiation hazards (4) Drosophila melanogaster under low intensity MMW exposure (less than 100 uW/cm2) exhibited large and significantly non-random variations of a survival in control groups, determining two-directional embryos response to MMW exposure. (Moscow, Belyaev).

Dosimetry and Radar Effects

Em fields induced in the operator of portable radio transmitters are calculated, using FDTD on a 3D-model of the head derived from Magnetic Resonance Imaging, in cooperation with U.Lund. (Ghent, De Zutter).

Whole body and local SAR are measured on laboratory animals, in anechoic chambers, with an electrophysiological computer aided recording system for EEG, cerebral blood flow, brain tissue impedance, and temperature. Exposure can be acute and chronic (long-term), thermal and non-thermal, CW and AM, in the 1-10 GHz frequency range. (Budapest).
For the em field prediction inside biological bodies (direct scattering), numerical methods take into account mutual coupling between the source and the body. The overconstrained moment method has been developed to achieve higher accuracy in modelling both em energy deposition and field distribution in lossy dielectric bodies. It is based on a redundant number of testing functions and on the use of a pseudoinversion transformation to solve the related overdetermined system of equations. (Genova).
FDTD has been used to calculate the whole body and the maximum of the SAR, in a 807-cell model of a human being, between 10 and 100 MHz, both in free space and in the presence of a perfect reflecting wall. (Rome, La Sapienza).
Field intensities are measured at a variety of frequencies and modulations, in view of establishing safety zones around em sources. An analysis made in 1991 on about 10,000 subjects, working in a RF/MW environment, revealed no increased morbidity, like heart/circulatory disorders, gastro-intestinal syndromes, including stomach/duodenal ulcers, and organic lesions of the nervous system. A high number however show a lowered immune status. There are also higher rates of haemopoietic/lymphatic malignancies, brain tumors, and melanomas. (Warsaw).
In another study, where signs of lesions in the central nervous system are investigated in radar engineers and technicians, occupationally exposed to MW, 9 out of 13 subjects have abnormal protein in the cerebrospinal fluid (analysis by iso-electric focusing) as compared to 1 out of 10 in a control group. (Göteborg).
A study on 250 radar operators and workers, with a control group of 100 subjects, showed pathological changes and functional disorders 10% higher for the radar subjects, essentially in biochemical and hematological parameters, with no significant hormonal deviations. (Belgrade).
In 49 radar operators, examined for 18 months, with a control group of 46 subjects, significant changes between a first and a second series of measurements were found in the exposed group only, in hematological and biochemical parameters, inelectrical brain activity, and in capillaroscopic and ophtalmological findings. (Zagreb, Goldoni).
Structural chromosome damage was found in the examinees. Occupational exposure to MW radiation causes detectable changes in the genome of lymphocytes in the peripheral blood. (Zagreb, Garaj-Vrhovac).

Heart

Effects of pulsed MW on isolated chick embryo hearts are studied since 1983 (2.45 GHz, duty cycle 0.2-0.5). By increasing the modulation frequency above the unperturbated rate, the heartbeat follows the stimulating modulation. There is a coincidence between the modulating pulses and the negative wave of the cardiac signal, which suggests that a synchronization takes place if modulating pulses are applied in the diastolic phase. It is suggested that pulsed MW stimulation produces a biological phenomenon related to the calcium currents. A simulation, using the Noble and Noble model, yields a calculated time delay of 0.15 s, which agrees with experiment. (Palermo).

Hyperthermia

A 4-channel system for clinical hyperthermia at 433 MHz is under development, with an accurate control of the amplitude and phase of the 4 antennas. The control mechanism is based on the feedback from the invasively measured temperatures. Furthermore, a new technique is developed in order to measure non-invasely temperature distributions in biological tissues, using a MW Resonance Imaging scanner. Temperature maps have been obtained on phantoms with a resolution better than 1°C thermally and 3 mm spatially. (Ghent, De Wagter).
Design of applicators at several frequencies, and treatment of more than 150 patients by external waveguide hyperthermia applicators. (Prague).
A number of applicators have been designed for external and interstitial hyperthermia (planar, coaxial, flexible). A thermal map in the tissues during a hyperthermia session is obtained by solving the bioheat equation. The calculated radiometric power is compared to the power measured during the treatment. Electromagnetic, thermal, and radiometric models are coupled in a computer program. (Lille).
MW hyperthermia is used in treating benign prostatic hyperplasia, using intraurethral applicators. A combination with non-specific immunotherapy may increase the rate of remission of cancers. Improvement was obtained in 80% of the cases. On a group, it has been shown that hyperthermia resulted in a transient stimulation of T-lymphocytes and natural cytotoxic mechanisms. (Warsaw).

Imaging

Active techniques are organized according to two main directions (1) In-situ assessment of existing equipment. A planar MW camera (2.45 GHz) has rapid capabilities (1 s for recording amplitude and phase distributions over a 22 cm by 22 cm area). The following applications are considered. 1. Non-invasive control of deep hyperthermia treatments (in cooperation with institutions in Paris, Amsterdam, Utrecht, and Rotterdam). 2. Follow-up of renal canine transplants, to make some correlation between rejection processes and microwave images during the days following the transplant. 3. Early detection of fibrosis after accidental or therapeutic irradiations : fibrosis is expected to modify quite significantly the dielectric constant of the tissues (2) Toward a new generation of imaging equipment. Reconstruction codes providing quantitative imaging are necessary, which requires solving a non-linear inverse problem. (Gif-sur-Yvette).
Dielectric permittivity distributions are reconstructed inside an inhomogeneously biological body. A main goal is in developing effective algorithms for the scattering-data inversion, using the moment method and the pseudoinversion transformation for 2D- and 3D-geometries. Recently, two new methods of imaging in the space domain have been proposed. The first is based on a modified version of the Born approximation. In the second, Markov random fields are used to model the distributions of dielectric features, and a stochastic relaxation algorithm was developed to solve the imaging problem. (Genova).
(1) Experiments have been made inside a phantom structure consisting of a 3-layer box construction. The uniform temperatures of the external layers are separately controlled in time by thermostats. A comparison between thermocouples and a 4-channel radiometer data (1.1, 2.5, 4.5, 5.5 GHz), and a theoretical model, shows good agreement (1°C). The transient temperature profile is retrieved by a Kalman filtering of data (2) An experiment on a phantom has been performed to evaluate the use of multifrequency MW radiometry in the production of maps of temperature inside cylindrical regions down to a depth of a few centimeters from the surface. A small tube containing a saline solution identical to that of the phantom, but at a different temperature, is moved inside of the phantom. (Rome, Tor Vergata).

Immune System and Immunology

Weak and strong MW exposures indicate that lymphocytes and macrophages are very sensitive cells in vitro. They react with biphasic response to a gradual increase of the temperature of the incubating medium, followed by a rapid inhibition of cell functions above 40°C. Long-term (several weeks, 2 h/day, 2.45 GHz) exposure of mices lowered their immune status and their non-specific anti-infective and anti-neoplastic resistance, which was accompanied by a faster development of chemically-induced (3,4-alpha-benzopyrene) skin neoplasms. Suspensions of cells, exposed to combinations of MW and low frequency E- and H-fields in search of synergetic effects on Ca-ions release, showed that the response of Ca-flux from brain tissues in vitro to E- and/or 16 Hz H-fields depends upon the combination of the fields and the intensity of the natural geomagnetic field. (Warsaw).

The effects of MMW on the immune system are investigated by studying the immunity condition of guinea-pigs, both intact and with endometrial hyperplastia, induced by estrogens before and after MMW irradiation. A frequency and temporal dependence to MMW is found, of a cumulative nature. A 7.1 mm irradiation turned out to be the most efficient, resulting in an increase of a number of the T- and B-lymphocyte systems indices. A morphological study of the uterine tissues and of the immunogenesis organs showed that MMW promoted a decrease of hyperplasia expression, with changes in the thymus gland, the spleen, and the lymph nodes, which led to therapeutic methods. (Odessa).

Nerves and Nervous System

A "dolour-meter" has been designed, yielding a quantitative electrical measurement of a pain threshold on rabbits. The increase in the pain threshold is a quantitative comparison of antalgic drugs and processes. By comparison, the injection of MW (2.45 GHz) into acupuncture points is shown to be efficiently antalgic. The measurement of neurotransmitter release in the brain shows that the variation of release is proportional to the increase of the pain threshold, hence to the anesthesia. The implantation of MW applicators along the spinal cord is in preparation (the near field of the applicator in the inhomogeneous medium has been calculated). The purpose is the investigation of the effect of MW pulses along the transmission between the peripheral and the central nervous system. (Louvain-la-Neuve).

The response of the central nervous system is observed by multi-channel in-vivo polygraphic recording by electrophysiological transducers, in acute and chronic experiments (EEG, cerebral blood flow, brain tissue impedance, and temperature. (Budapest).

Light and electron microscopic examinations reveal minimal, transient acute changes in the retina and brain of rabbits (3.1 GHz, 55 mW/cm2 pulsed MW, 1 h/day for 3 days). However, after 2-4 months, an increasing frequency of degenerative nerve cell changes is observed, as well as glial reactions. Immunohistochemical data support the results. A full-size phantom to determine the local SAR-distribution is available. (Göteborg).

The effect of MMW irradiation at 5, 6, and 7.1 mm is evaluated on the background activity of the cerebral cortex and on the induced stimulation foci, in particular of epileptic activity. Electrophysiological studies, namely measurements of guinea-pigs' and cats' EEG show that MMW application results in changes of biological activity of the brain, and also in the suppression of epilectic activity foci induced in the experiment, with however, in a generalized epileptic activity, a supplementary generalization of epilectic activity. (Odessa).

Acknowledgements

The author gratefully ackowledges his european colleagues, who were kind enough to send well on time adequate information on their research topics and results. He apologizes for any mistake which could appear in the text, for which he is solely responsible.

Sources

Belgrade. Z.Stojanovic. Vazduhoplovnomedicinski Institut, 11274, Beograd, Serbia.

Brno. D.Rotkovska. Biofyzikalni ustav CSAV, Kralovopolska 135, 61265 Brno, Czechoslovakia.

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