The Bioelectromagnetics Society
29th Annual Meeting
Abstract Collection

Kanazawa-shi Bunka Hall
Kanazawa, Japan
June 10 - 15, 2007
Foreword

Abstracts for the 29th Bioelectromagnetics Society Annual Meeting
June 10 - 15, 2007
Kanazawa, Japan

The following abstracts were reviewed by the Technical Program Committee and approved for presentation at the Twenty-Ninth Annual Meeting. While the Technical Program Committee reviewed the content of these abstracts, they may not present completed work nor were they formally peer-reviewed for technical content.

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Contributions by students (as the first author) are marked by a ‘*’ in the book.
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Monday

Plenary I: Bioelectromagnetic Applications to Cancer Diagnosis and Treatment

ELECTROMAGNETIC IMAGING OF THE BREAST

Keith D. Paulsen
Dartmouth College, Hanover, NH, USA

Objectives. The goal of this work is to develop, optimize and evaluate electromagnetic imaging methods for application in clinical breast imaging.

Methods. Three imaging methods have been developed which exploit different portions of the electromagnetic spectrum in order to investigate the image contrast that can be generated in both asymptomatic and symptomatic breasts during clinical exams: (1) Electrical Impedance Spectroscopy (EIS) from 10 KHz to 10 MHz, (2) Microwave Imaging Spectroscopy (MIS) from 500 MHz to 3 GHz and (3) Near Infrared Diffuse Optical Tomography (NIR) from 650 nm to 850 nm. The techniques involve source/sensor arrays which are positioned around the pendant breast to produce anatomically-coronal cross-sectional distributions of the associated electrical properties — electrical permittivity and conductivity for EIS and MIS and optical absorption and scattering for NIR. In each modality, model-based computational methods are used to recover the spatial distribution of these tissue property parameters through estimation algorithms which minimize the squared difference between the measured and computed responses at the sensor locations. The estimation problem is ill-posed, the data contains measurement uncertainty and the model is an approximation of the physical interactions which are occurring between the induced electromagnetic fields and the breast; hence, regularization is required in order to overcome numerical instabilities.

Results. Preclinical studies have been conducted in phantoms having circular cross-sections of relevant diameters (typically 10 cm) with single inclusions (typically 5 -20 mm in size) embedded at varying depths, sometimes with additional layers intended to represent fat and fibroglandular structures within the breast in order to characterize the imaging performance of the systems which have been developed. Controlled clinical studies involving women with normal (BI-RADS 1) and abnormal (BI-RADS 4-5) mammography have been completed in an effort to provide initial estimates of the diagnostic potential of the imaging methods in the setting of screen-detected breast abnormalities. Investigations exploring the clinical potential of the imaging techniques for monitoring early response to neoadjuvant chemotherapy in women with locally-advanced disease are also underway where capturing changes associated with the functional status of the cancer are more important than detecting structural changes such as alterations in tumor size at high spatial resolution. The data shows that image property contrast ratios of 150-200% occur in breast abnormality regions of interest (ROIs) relative to the ipsilateral breast background. Analysis of variance indicate
statistically significant differences in ROI image summaries of mammographically normal versus abnormal breasts for EIS and across diagnostic groups for NIR, and for MIS when the analysis is restricted to lesions larger than 1 cm in size. ROC evaluation of the electromagnetic properties for cancers among BI-RADS 4/5 subjects compared to the BI-RADS 1 group yielded areas under the curve (AUC) ranging from 0.67 to 0.88. Histopathological correlations with mean vessel density, mean vessel area, and epithelium-to-stroma ratio suggest a biological origin of the image signals associated with disease.

**Conclusions.** Results from these initial preclinical and clinical studies establish an image contrast ranging from 150-200% or more for breast pathology and provide some evidence of the clinical potential of these methods in the detection and characterization of breast disease.

**Acknowledgements.** This work was supported in part by NIH grant number P01-CA80139 awarded by the National Cancer Institute.

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**MEDICAL APPLICATIONS OF MILLIMETER WAVES**

Marvin C. Ziskin  
Temple University Medical School, Philadelphia, PA, USA

**Objectives.** To provide a review of the therapeutic applications of millimeter waves and to explore the scientific basis and mechanisms underlying this little known therapeutic modality.

**Methods.** Millimeter wave (MW) therapy is the application of low-intensity millimeter wavelength electromagnetic waves in the alternative treatment of a variety of diseases. MW, a form of microwaves, are non-ionizing and administered onto a localized area of the skin at a sufficiently low intensity that there is no perceptible heating. The three most common frequencies used are 42.2, 53.6, and 61.2 GHz. The usual MW treatment regimen consists of daily applications of 15 to 30 minutes for 5 to 15 days. The MW applicator is typically a ”book-sized” instrument which is brought in close contact with the skin surface. The site of application depends on the disease being treated. Surface wounds and skin diseases are usually treated at the site of the lesion. In treating arthritis the site of application is at the affected joint. In treating internal diseases, the recommended site of application may be at any one of a number of anatomic or acupuncture points. A common site of application is the lower end of the sternum.
**Results.** Strikingly high success rates have been reported in the Former Soviet Union in the treatment of cardiovascular diseases, diabetes, dermatitis, gastrointestinal disorders, wound healing, pain relief, and the reduction of toxic side effects of chemotherapy and radiotherapy in cancer patients. Although MW therapy has been and continues to be used extensively throughout the former Soviet Union, it is virtually unknown to Western physicians. In addition to its reported effectiveness, it is a non-invasive, painless, relatively inexpensive modality with exceedingly rare and minor side effects.

**Conclusions.** In spite of the large numbers of patients treated and the very high success rates attributed to MW therapy by hospitals and clinics in the former Soviet Union, there have been just a handful of publications in peer-reviewed scientific journals with sufficient details to satisfy Western physicians and scientists. Because of this lack of details and quantitation, the interpretation and evaluation of the results are difficult and unreliable. Therefore, it has been necessary to independently test the validity of the Soviet claims before MW therapy can become an accepted alternative modality in clinical applications in the United States. Results of recent well controlled studies have been supportive of many of the Soviet claims, and it appears likely that millimeter wave therapy will be found useful in alternative and complementary medicine.

**Acknowledgements.** This work has been supported by NIH NCCAM grants: R01-AT 00492, R01-AT 00493, and P01-AT00205.

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**DEVELOPMENT OF CANCER TREATMENT SYSTEM BY INDUCTION HEATING WITH MAGNETIC FLUID (RESOVIST)**

Isamu Nagano  
Kanazawa University, Kanazawa, Japan

**Objectives.** We have developed a portable magnetic generator to be used in hyperthermia treatment of cancer with inductive heating. This device generates an intense ac magnetic field at the medium frequency around hundreds of kHz, which is applied to heat up a magnetic fluid injected into tumors, thereby selectively and non-invasively kill cancer cells. Through series of in-vitro experiments as well as in-vivo tests on animals, so far we have evaluated the heating characteristics of magnetic fluids under intense magnetic fields created by the developed device, and demonstrated its applicability for cancer treatment.

**Methods.** 1. Dextran Magnetite  
As a magnetic fluid injected into tumors, we use ”Dextran Magnetite” (DM for short). If we can concentrate DM around cancer cells in tumors exposed to an intense magnetic field, only those cancer cells will be selectively heated and killed by the increased temperature of DM. We have evaluated the heating characteristics of DM by conducting experiments in vitro. The total amount of heat generated by DM is empirically given as (1), where $k$ is a
coefficient of $3.14 \times 10^{-3} \text{ [W/ Hz/ (mg/Fe/cc)/ T}^2/ \text{ cc]}$, $f$ and $B$ are the frequency [kHz] and intensity [T] of the applied ac magnetic field, and $D$ is the concentration of DM [mgFe/cc].

$$Q = k f D B^2 \text{ [W/cc]}$$ (1)

From (1), we can estimate the temperature rising rate of DM concentration in the tumor, under a specific frequency and intensity of the applied magnetic field.

2. Portable Magnetic Generator

We have developed a portable magnetic generator as shown in Fig. 1, which can generate intense ac magnetic field to heat up the tumor as efficiently as possible. By using MOS-FET and high-frequency inverters, a large ac current is supplied to an applicator coil, which then creates an intense magnetic field. With this device we have achieved the maximum magnetic field intensity of about several milliteslas created around 180 mm away from the coil.

3. Tests on Animals

By using the developed magnetic generator and DM, we have tentatively designed the heating protocol and applied inductive heating treatment on tumor-bearing rabbits. We injected DM into the tumors and applied intense magnetic field, where tumor temperature was measured by fiber-optic thermometers inserted into the tumor. With the help of X-ray CT imageries, we identified the locations and sizes of tumors, as well as the distribution of injected DM.

Results. By applying the intense magnetic field created by the developed magnetic generator, we have measured its heating efficiency in vitro. By using "Resovist (R)," which is diluted DM, manufactured by Schering AG as contrast agent for MRI, as the magnetic fluid, the maximum temperature rising rate has reached 3 C/min/cc at 180 mm away from the coil, which should be intense enough to heat up tumors located deep inside human body.

In an example of tests on animals, we applied inductive heating treatment on 15 tumor-bearing rabbits (the control group of 8 rabbits, plus the heated group of 7 rabbits). After injecting Resovist uniformly over the tumors, we applied intense magnetic field to heat the tumors at 45 C for 20 minutes. The variations of tumor size as a function of days after treatment show that the suppression of the tumor growth observed in the heated group (7 rabbits) was significantly greater than that in the control group (8 rabbits). It should be noted that even complete regression of the cancer was observed on 3 rabbits in the heated group. This result strongly suggests the effectiveness and the applicability of the inductive heating method for cancer treatment.

Conclusions. We have developed an inductive heating system for cancer treatment, which can selectively heat only the target tumors with the magnetic fluid injected under an intense ac magnetic field, and demonstrated its anti-tumor effectiveness with the tests on animals. There are a couple of advantages in such a cancer treatment: no side effect, and minimally invasive (no pain) to the patient. We are now designing treatment protocols for future clinical applications, as well as developing an improved heating device on the basis of Good Clinical Practice (GCP).

Acknowledgements. We would like to thank Dr. Kenji Tazawa, Dr. Hirotsugu katayama, Mr. Hideo Nagae, and Mr. Yoshio Ikehata, for their help and support for the development
of the portable magnetic generator, as well as for conducting a series of in-vitro and in-vivo experiments.

**Figure 1.** A portable magnetic generator for inductive heating
Session 1: Cancer Detection, Therapy and other Human Studies

1-1 THERABIONIC IS A NOVEL TREATMENT OPTION FOR ADVANCED CANCER USING CANCER-SPECIFIC AMPLITUDE-MODULATED RADIOFREQUENCY ELECTROMAGNETIC FIELDS

Boris Pasche¹, Alexandre Barbault¹, Brad Bottger², Fin Bomholt³, Niels Kuster⁴
¹Cabinet Médical Avenue de la gare 6, Lausanne, Switzerland ²Danbury Hospital, Danbury, CT, USA ³SPEAG, Zurich, Switzerland ⁴Swiss Federal Institute of Technology, Zurich, Switzerland

Objectives. In vitro studies suggest that low levels of amplitude-modulated electromagnetic fields may modify cell growth. We have identified specific frequencies that may block cancer cell growth. We have developed the THERABIONIC device, a portable and programmable emitter of a 27.12 MHz radiofrequency signal, amplitude-modulated at cancerspecific frequencies ranging from 0.2 to 23,000 Hz with high precision. The device is connected to a spoon-like coupler, which is placed in the patient’s mouth during treatment. The levels of absorbed electromagnetic energy are well below safety limits.

Methods. A phase I study consisting of three daily 40 min treatments until disease progression or death. From March 2004 to September 2006, 24 patients with advanced solid tumors were enrolled. The median age was 57.0 ± 12.2 years. 16 patients were female. As of January 2007, 5 patients are still on therapy, 13 patients died of tumor progression, 2 patients are lost to follow-up and one patient withdrew consent. The most common tumor types were breast (7), ovary (5) and pancreas (3). 21 patients had received prior systemic therapy and 16 had documented tumor progression prior to study entry.

Results. The median duration of therapy was 15.7 ± 19.9 weeks (range: 0.4-72.0 weeks). There were no NCI grade 2/3/4 toxicities. Three patients experienced grade 1 fatigue during and immediately after treatment. 12 patients reported severe pain prior to study. Two of them reported significant pain relief with THERABIONIC treatment. Objective response could be assessed in 13 patients, 6 of whom also had elevated tumor markers. 6 additional patients could only be assessed by tumor markers. Among patients with progressive disease at study entry, one had a partial response for > 14.4 weeks associated with > 50% decrease in CEA, CA 125 and CA 15-3 (previously untreated metastatic breast cancer); one patient had a 50% decrease in CA 19-9 for 12.4 weeks (recurrent and previously systemically-treated pancreatic cancer). Among patients with stable disease at enrollment, four patients maintained stable disease for 17.0, > 19.4, 30.4 and > 63.4 weeks.
Conclusions. THERABIONIC is a safe and promising novel treatment modality for advanced cancer.

1-2 THERABIONIC IS AN EFFECTIVE TREATMENT FOR ADVANCED HEPATOCELULAR CARCINOMA (HCC): RESULTS FROM A PHASE II STUDY

Frederico P. Costa¹, Andre Cosme de Oliveira¹, Roberto Meirelles Jr¹, Rodrigo Surjan¹, Tatiana Zanesco¹, Maria Christina Chammas¹, Alexandre Barbault², Boris Pasche²
¹Hospital das Clínicas, São Paulo, Brazil ²Cabinet Médical Avenue de la Gare 6, Lausanne, Switzerland

Objectives. Phase I data show that low levels of electromagnetic fields modulated at specific frequencies administered intrabucally with the THERABIONIC device are a safe and potentially effective treatment for advanced cancer. The device emits a 27.12 MHz radiofrequency signal, amplitude-modulated at tumor-specific frequencies ranging from 0.2 to 23,000 Hz. The device is connected to a spoon-like coupler placed in the patient’s mouth during treatment. Patients with advanced HCC and limited therapeutic options were offered treatment with HCC-specific frequencies.

Methods. From October 2005 to October 2006, 38 patients with advanced HCC were recruited in a phase II study. The patients received three daily 40 min treatments until disease progression or death. The median age was 64.0 ± 14.2 years. 32 patients were male and 29 patients had documented progression of disease (POD) by IV contrast imaging prior to study entry. 8 patients had not received prior therapy because of metastases (3), poor medical condition (3), declined chemotherapy (2).

Results. As of January 2007, 12 patients are still on therapy, 20 patients died of tumor progression, 2 patients are lost to follow-up and 3 patients withdrew consent. 27 patients are eligible for response. The overall objective response rate as defined by partial response (PR) or stable disease (SD) in patients with prior documented POD was 31.6%; 3 PR and 9 SD. The median survival was 20.7 weeks with a median duration of therapy of 17.5 weeks. 13 patients have received therapy for more than six months. The median duration of response was 12.9 weeks. 12 patients reported pain at study entry: 8 of them (66%) experienced decreased pain during treatment. There were no NCI grade 2/3/4 toxicities. One patient had grade 1 mucositis and grade 1 fatigue.

Conclusions. In patients with advanced HCC, THERABIONIC is a safe and effective novel therapeutic option, which has significant anti-tumor effect and provides pain relief in the majority of patients.
1-3 LONG-TERM STUDY OF MICE EXHIBITING COMPLETE REMISSION OF MALIGNANT MELANOMA FOLLOWING NANOSECOND PULSED ELECTRIC FIELD TREATMENT

Richard Nuccitelli¹,², Jennifer Pomicter¹, Wei Ren¹, Karl H. Schoenbach¹
¹Old Dominion University, Norfolk, VA, USA ²BioElectroMed Corp., Norfolk, VA, USA

Objectives. Conduct long-term study of nsPEF-treated melanomas in 20 mice to determine if nanosecond pulsed electric field treatment eliminates murine melanomas without recurrence or metastasis for 120 days.

Methods. Pulse generator: We used a pulse-forming network with an impedance of 75 Ω. It generates a 300 ns long high voltage pulse with a 30 ns rise time.
Electrodes: We use parallel plates that are 5 mm in diameter and 1 mm apart.
Melanomas: Tumors were induced in 40 female SKH-1 mice (immunocompetent, hairless, albino strain, Charles River, Wilmington, MA) by injecting 10 µl containing 10⁶ B16-F10 murine melanoma cells just under the skin.

Results. We have discovered a new, drug-free therapy for treating solid skin tumors. Pulsed electric fields with rise times of 30 ns penetrate into the interior of tumor cells and cause tumor cell nuclei to rapidly shrink and tumor blood flow to stop(1). Melanomas shrink by 90% within two weeks following a total field exposure time of less than a millisecond. This new technique provides a highly localized targeting of tumor cells with only minor effects on overlying skin and involves depositing a very low energy of 0.2 J/pulse that increases the temperature of the treated region by only 3 °C. This new therapy is the first to both rapidly trigger pyknosis and reduce tumor blood flow without drugs. The first 120 mice treated with 300 pulses of at least 40 kV/cm nsPEF all exhibited dramatic tumor shrinkage and some tumors went away completely following a second 300-pulse treatment. However, they were routinely euthanized a month or so after treatment for histological analysis of the tumor site. For this long-term study, mice are being observed for at least 120 days following complete tumor remission and compared to untreated controls. The complete data set will be available by the time of the BEMS meeting and will be presented there. As of January, 2007, melanomas have been eliminated in the 14 experimental mice treated thus far and we are continuing to monitor them for the 120 days following complete remission. In contrast most of the controls have been euthanized because their tumors had already exceeded 1.3 cm or had become ulcerated.

Conclusions. These nsPEFs that we are using differ from those commonly used for classical electroporation in three ways: 1) they typically have a 100-fold faster rise time; 2) typically 1000-fold shorter duration; and 3) typically 20-fold larger amplitude. These differences in pulse parameters allow nanosecond pulses to penetrate into cells and electroporate organelle membranes in addition to the plasma membrane. Two separate mechanisms lead the intracellular penetration: 1) The rise time of the nsPEFs is faster than the charging time
of the plasma membrane, resulting in penetration of the electric field into the cell interior. This internal field will generate a current that charges the outer plasma membrane. Most cells exhibit a charging time constant of about 100 ns so they will be 95% charged at 300 ns. After this charging time, the resulting charge redistribution will screen out the electric field from the cell interior unless the field strength within the plasma membrane has become large enough to generate pores that provide the second mechanism for intracellular penetration: 2) If the potential difference across the membrane exceeds 1.6 volts, the formation of nanopores occurs within tens of nanoseconds (2-3); (3). This allows conduction current to enter the cell during the time that the pores are open. For the large field strengths that we use, all of the molecules and organelles inside the cell will be exposed to the imposed electric field for up to hundreds of nanoseconds during each pulse due to the timing of the charging current and the open time of the field-induced pores. By applying multiple pulses, the total time of field exposure can be increased in proportion to the number of pulses applied.

In each of the tumors treated in this study, two-three treatments of 300 pulses (40 kV/cm) separated by 2 weeks were sufficient to completely eliminate the tumor. Thus far there is no sign of recurrence in any of the animals treated, but we will know more in June.

Reference List

* 1-4 NEW, COMPREHENSIVE, HIGH RESOLUTION HYPERTERMIA TREATMENT PLANNING TOOL

Esra Z. Neufeld1,2, Nicolas P. Chavannes1, Niels Kuster1, Theodore Samaras3
1ETHZ, Zurich, Switzerland 2IT’IS Foundation, Zurich, Switzerland 3Aristotle University, Thessaloniki, Greece

Objectives. Hypertermia is a promising, relatively new treatment modality for various types of cancer. It aims at heating the tumor using EM fields. Usually antenna arrays are used to focus the energy. However, the difficulty of controlling the deposition has so far hindered the acceptance of hypertermia. Therefore a comprehensive tool should be developed to perform hypertermia treatment planning (HTP). It must include a powerful EM simulation package, a thermal model which correctly handles blood flow, a fast field
optimizer for antenna arrays and a segmentation toolbox. The treatment planning tool has to permit modeling and planning at a very high level of detailedness, accuracy and reliability. This is required to reduce hotspots and guarantee a good coverage of the tumor area.

**Methods.** *EM simulations:* An FDTD code (SEMCAD X) has been used. It works on graded meshes allowing for increased resolution in critical regions and uses a conformal sub-cell method reduce staircasing errors. The use of an ADI scheme and a dedicated hardware accelerator card permit the simulation of complex models within reasonable time. Working in the time domain makes it possible to use pulsed excitations and to extract information about several frequencies in one go. A feasibility study (simulation of BSD Sigma-60 applicator) and an in depth analysis of sensitive factors to consider when setting up the simulation has been presented (BEMS’05).

*Thermal simulations:* A new thermal model has been developed (BEMS’06). It is based on the Pennes model. Additionally, it uses tensorial heat conductivities and a connected pseudo-1D simulation of the discreet vessel network to better account for the effects of blood flow. Various tissue parameters (perfusion, heat generation rate…) can be temperature and time dependent. A newly developed conform method is used to reduce staircasing effects at boundaries. Flexible boundary conditions can be used to decouple the region of interest from the rest of the simulation domain, allowing for a larger stable time step (no low density/high thermal conductivity regions in simulation). Special initialization can be used to guess an initial distribution close to the steady state and additionally reduce simulation time. Resulting tissue damage and the local thermal dose (CEM43) can be obtained taking into account transient behavior.

*Optimization:* Speed is critical, as patient feedback about pain must be immediately considered and new optimized treatment parameters generated. A generalized Eigenvector method has been chosen. It puts restrictions on the possible form of the optimization functional, but both SAR and temperature field optimization is possible. Multiple targets can be specified and assigned heating priorities. Sensitivity factors and maximal exposure thresholds can be specified for healthy tissues. An iterative approach can be used to impose penalty weights on hotspots. A fast Mont Carlo method is used to determine how sensitive the optimum is to uncertainties of the antenna settings.

*Segmentation:* A toolbox (iSeg) has been constructed that allows flexible combining of various segmentation techniques (level-set, fuzzy connectedness, interactive watershed transformation, region growing, live wire, competitive marker based methods…) as well as various pre- and post-processing methods (interpolation, surface/contour-extraction, smoothing, noise reduction, hole/gap removal…). The tool can be used for CT and MRI images.

**Results.** *EM simulations:* The demonstrates how important it is to model the antennas and their proximity in detail and how high resolution of critical parts and detailed modeling of the tissue distribution is required to reliably detect hot-spots. Convergence can be an issue, and mode flipping has been observed. The conformal subcell method, ADI and pulsed excitations are crucial to allow highly detailed and reliable simulations (up to 20 million cells).

*Thermal simulations:* Initial simulations underscore the importance of including discrete
vessels and performing high resolution simulations. The newly developed conformal boundary technique has a major impact and underscores the importance of studying stair-casing effects in thermal simulations. Being able to calculate arbitrarily shaped regions using boundary conditions to close them of is of high value.

**Optimization:** Very satisfactory results were obtained. Good focusing is obtained fast, and patient complains can be easily considered.

**Segmentation:** Due to the often low quality of medical images, it is important to allow the user to combine mostly automatic methods (e.g., for bones) with highly interactive methods. Competitive methods and methods that use both region homogeneity and boundary information increase the robustness. 2D segmentation is generally preferable. The supported user interactions are critical for speed, comfort and usability.

**Conclusions.** A new effective and robust HTP tool that unifies all necessary steps in a single platform has been developed.

The results support the feasibility of creating a treatment planning tool for deep regional hyperthermia on a patient basis, using numerical models of unprecedented detailedness. This is made possible by applying nonuniform FDTD techniques, conform subcell methods and hardware acceleration.

The new thermo-solver and blood flow model open many possibilities in BioEM, as they allow a more realistic image of the induced temperature distribution. The proposed model includes many improvements over the Pennes model, while retaining its simplicity.

The implemented segmentation toolbox offers a good environment to quickly prototype new techniques and to combine them flexibly with the large number of existing techniques. This is needed to generate very detailed patient models.

The developed tool can also be used to train staff and to develop new applicators. Extensive experimental validation is ongoing.

**Acknowledgements.** We gladly acknowledge the support by CTI/KTI and the advice from the Erasmus MC in Rotterdam.
1-5 TREATMENT OF GYNOID LIPODYSTROPHY (CELLULITE) WITH DEEP OSCILLATION: A PILOT CLINICAL STUDY

Liudmila G. Korkina1, Jens Reinhold2, Lucrezia Rota1, Grazia Primavera1, Desanka Raskovic1
1Istituto Dermopatico dell’Immacolata, Rome, Italy 2Physiomed Elektromedizin AG, Schnaittach, Germany

Objectives. Gynoid lipodystrophy (cellulite) is a common condition in 85% of post-adolescent women for which treatment is frequently required. There are numerous treatments offered to female population concerned by unsightly appearance of the cellulite-affected thighs, buttocks, and hips. All treatment modalities attempt either to attenuate the aggravating factors (obesity, bad habits, and the lack of physical exercise), or to induce lipolysis, or to disrupt altered fibrous septae, or improve microcirculation, or diminish the local inflammation. The physical and mechanical methods including massage, pulsative suction, radiofrequency fields, infrared heat and laser light, and pharmacological agents applied topically or by intradermal injections are among the most popular although low efficient treatments of cellulite. A very high concern has been raised recently about the safety and efficacy of unreasonably expensive methods for the cellulite treatment.

Methods. A pilot open randomized clinical trial was carried out in the Department of Dermatology, Cosmetology, and Skin Pathophysiology of the Dermatology Institute to prove both safety and clinical efficacy of the DEEP OSCILLATION (R) method (Physiomed Elektromedizin AG, Germany). The physiotherapeutic method is based on the use of intermittent electrostatic fields of low intensity (U = 100-400V; I = 150µA) and extremely low frequency (F = 5-200Hz) which create deep oscillation in the underlying tissues (epidermis, derma, subcutaneous layer, and myofibrils). Thoroughly studied molecular and cellular mechanisms of DEEP OSCILLATION method allowed us to develop several protocols focused on pathophysiological features of cellulite: (1st protocol) to improve microcirculation in the dermal and subcutaneous layers; (2nd protocol) to diminish inflammation and edema; (3rd protocol) to disrupt or and prevent the formation of fibrous septae; and (4th protocol) to diminish number of estrogen receptors on the skin cells. Thirty women ( age = 39.0±9.6y; weight = 58.0±6.1 kg; BMI =1.63±0.07 ) with clinical features of cellulite of I-III grade (Grade I − 14; Grade II − 12; and Grade III − 4) were recruited after their informed consent and approval of the local Ethical Committee. They were treated with the DEEP OSCILLATION (R) anti-cellulite protocols twice a week for three months (the total duration of the treatment was 500-540 minutes). The clinical features were assessed by three independent dermatologists using high resolution digital photographs. The instrumental assessment included repeated measurements of circumferences (upper third of thigh, lower third of thigh, and upper third of leg), cutometry (the measurement of skin elasticity), ultrasound determination of microcirculation and fibrous tissue presence.

Results. The pilot study confirmed the absolute safety of the method (there were no any immediate or remote adverse effects or complaints from the participants), its high efficacy in 93% (n=28) of the women (the circumferences diminished from 59.0 to 57.1 cm, upper thigh, p<0.0002; from 51.4 to 49.8 cm, lower thigh, p<0.0001; from 40.7 to 38.5 cm, upper
leg, p<0.003). The elasticity characteristics were improved in 48% (n=14) of the patients; the edema, lymphostasis, and fibrous heterogeneity of subcutaneous layer were improved remarkably in 80% (n=24) of the patients.

**Conclusions.** The general conclusions of the experts were that the DEEP OSCILLATION (R) method was efficient in more than 80% of the cases with moderate (grade I-II) cellulite.

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1-6 THE DERMACORDER: A NEW INSTRUMENT FOR DETECTING MALIGNANT SKIN LESIONS BY THEIR ELECTRIC FIELD

Richard Nuccitelli¹, Pamela Nuccitelli¹, Changyi Li¹, Suman Narsing¹, Saleh Sheikh¹, Tracy Novosel², Cyndi Torosky², Antoinette F. Hood²

¹BioElectroMed Corp., Norfolk, VA, USA ²Eastern Virginia Medical School, Norfolk, VA, USA

**Objectives.** 1. Develop a non-invasive technique for detecting the electric field in human skin
2. Determine if the electric field near malignant lesions is significantly different from that near benign lesions.

**Methods.** The fundamental principal employed by the Bioelectric Field Imager (BFI) is that the skin surface potential can be determined by a capacitative coupling method. We hold a small flat metal sensor very close to the skin, forming a parallel plate capacitor. One plate of this capacitor is the conductive surface of the epidermis which has a certain voltage value that we want to detect. If we oscillate the metal sensor along an axis perpendicular to the skin surface, the distance between it and the skin will oscillate. The capacitance between the two surfaces is inversely proportional to this distance so this capacitance will also oscillate. This can be detected by measuring the charging current flow to the metal sensor as the capacitance oscillates. We can control the voltage on the metal sensor and if we hold it at the same voltage as on the skin surface, there will be no charge movement. Therefore, we can determine the unknown potential of the skin surface next to the sensor by finding the voltage at which no charging current flows.

**Results.** We sponsored a blinded study conducted by Drs. Antoinette Hood, Tracy Novosel and Cyndi Torosky at the Veterans Administration Medical Center in Hampton Virginia. Twenty veterans requesting treatment of various skin lesions were enrolled in the study and each signed an Informed Consent Form and had their lesion scanned by the hand-held BFI prior to the normal treatment which included a biopsy. The biopsy results were used to establish whether each lesion was benign or malignant and were not revealed until the end of the study, after the BFI scan data were analyzed. By blinding ourselves to the biopsy results, our analysis of the BFI data could not be biased. While this was a very small study, the results were quite striking. The electric field was usually greatest at the border
between the lesion and normal skin. The hand-held BFI detected a substantial electric field averaging 696 mV/mm at the borders of three of the four malignant lesions in the study. This 75% reliability rate in our first human clinical trial is encouraging. In addition, the average electric field measured near benign lesions was 223 mV/mm and that of normal skin was 100 mV/mm. This makes it very easy to distinguish between the malignant and benign lesions. In 9 out of 13 benign lesions (70%) we detected a very small electric field and predicted they were not malignant. We were impressed to see that the electric field near malignant basal and squamous cell carcinomas was so large since we had not studied these carcinomas prior to this. All of our previous data were collected from murine melanoma but we did not have any cases of human melanoma in this small clinical trial. These striking results from our first measurements of human skin lesions suggest that the hand-held BFI could provide some very useful data for the diagnosis of cutaneous malignancies.

Conclusions. Characterizing the electric field near benign cutaneous lesions:
There are three main classes of benign lesions, keratocytic, melanocytic, and dermal. Within each of these three classes, there are many subclasses. Therefore, in order to survey the electric field around all of the possible lesion types we would have to enroll on the order of one thousand patients. However, it is not the goal of this study to characterize the electric field around every known benign lesion. Rather we want to determine if the electric field generated by the most common benign lesions is significantly different from that measured near malignant lesions. If indeed there is a fairly large difference as suggested by preliminary data, we should be able to establish the efficacy of the BFI for diagnosis with a few hundred patients. The key will be to have sufficiently large numbers of malignant lesions with which to compare.

Characterize the electric field near malignant cutaneous lesions:
This population of lesions will be critical because their number is smaller than those in the benign category. Here we must have a subject pool of squamous and basal cell carcinoma that is large enough to provide strong statistical support for the reliability of the BFI at diagnosing malignancy. Fortunately, there are only three major classes of malignant lesions and we are not so worried about subclasses since anything malignant must be removed. Therefore the number of subjects required will be smaller than for the benign lesions. Our goal is to enroll approximately 100 malignant lesions in this study. That number is large enough to determine if there is a class of malignant lesions that does not exhibit the large electric fields evident from our preliminary data.
**1-7 THE INJURY EFFECTS OF EMP ON HIPPOCAMPUS AND THE EXPRESSION OF INJURY-RELATED GENES IN RATS**

Dewen Wang, Yu-Hong Li, Shui-ming Wang, Ya-Bing Gao, Rui-yun Peng
Academy of Military Medical Science, Beijing, China

**Objectives.** To explore the pathologic alterations of hippocampus and the expression of injury-related genes in rats induced by EMP.

**Methods.** Hippocampal sections with HE and TB Staining were observed for pathologic changes under light microscopy. The expression of Bcl-2[GFAP]c-fos genes were detected with SP immunochemistry staining.

**Results.** Decrease of Nissel bodies and consolidation of neurons were observed which revealed degeneration of neurons after $6 \times 10^4$V/m EMP radiation. The level of Bcl-2 protein rised markedly [$P < 0.05$] at 1h after radiation while decreased at 6~24h. GFAP expression increased immediately after exposure and the increase be prominent at 6~24h[$P < 0.05$]. A persistent higher level of c-fos expression which with a summit at 12h could be seen during 24h after exposure [$P < 0.01$].

**Conclusions.** EMP radiation can damage hippocampal neurons in rats and Bcl-2[GFAP]c-fos genes be partly responsible for the injury and repair mechanism.

* 1-8 HUMAN ACUTE EXPOSURE TO A 60 HZ, 1800 MICROTESLA MAGNETIC FIELD: PHYSIOLOGICAL, NEUROPHYSIOLOGICAL AND BEHAVIORAL EFFECTS

Alexandre G. Legros$^1$, David A. McNamee$^1$, Anne Beuter$^2$, Daniel Goulet$^3$, Michel Plante$^3$, Jacques Lambrozo$^4$, Frank S. Prato$^1$, Alex W. Thomas$^1$

$^1$Lawson Health Research Institute and University of Western Ontario, London, ON, Canada
$^2$Université Victor Segalen Bordeaux 2, Bordeaux, France
$^3$Hydro-Québec, Montréal, QC, Canada
$^4$Electricité de France-Gaz de France, Paris, France

**Objectives.** Various aspects of human behaviours have been studied in response to acute exposure to Extremely Low Frequency (ELF) magnetic fields (MF). The more consistent results show an increase in occipital alpha rhythm of resting electroencephalographic activity (EEG) with exposure. Interestingly, other studies have demonstrated that human motor behaviour can be modulated by ELF MF, showing a reduction of standing balance amplitude and a decrease in physiological tremor intensity. However, to establish a connection between these observations would require a project that, in one procedure, investigates physiological, neurophysiological and behavioural parameters.

The main objective of this study is therefore to evaluate subtle effects of a 60 Hz MF exposure at 1800 $\mu$T on human physiology, neurophysiology and motor functions in a single
We hypothesize that MF exposure will (1) decrease peripheral blood flow but not affect ECG, (2) increase EEG power in alpha rhythm, especially in the posterior regions of the brain, (3) decrease of standing balance amplitude, (4) not affect performance in voluntary movements of the hands, and (5) decrease physiological tremor amplitude. Effects should appear after several minutes of exposure.

**Methods.** This is a currently ongoing study (University of Western Ontario Health Sciences Research Ethics Board # 11956E). To date, 31 subjects have completed the experiment. 70 healthy adults between 18 and 55 years of age will have completed the study by the end of April 2007. The experiment consist in 2 counterbalanced exposure sessions given on 2 separate days (with at least 2 days in between): 1 active (real) and 1 control session (sham) as (Figure 1a). A double blind computer driven procedure (National Instrument Inc., USA) controlling for variables is used such that neither the participant nor the experimenter know when the real or sham condition occurs.

Each session includes 4 blocks of testing (15 minutes each) spaced with 15 minutes rest in between (Figure 1a): Blocks of testing are given 15 minutes before the beginning of the exposure, and then 15 minutes and 45 minutes after the beginning of the exposure, and finally 15 minutes after the end of the exposure.

During each block, recordings are done following the time frame detailed in the Figure 1b: Resting EEG (Siesta, Compumedics Inc., USA), physiological tremor (tip of the dominant index finger, Micro laser sensor, Matsushita Electronic Work, Ltd., Japan), voluntary movements of the hands (Liberty, Polhemus inc., USA), and standing balance (OR6-7-1000, AMTI, USA). Local blood perfusion (tip of the non dominant middle finger) and systolic blood pressure, (PF 5010 Laser Doppler Perfusion and blood pressure Monitoring unit, Perimed, Sweden) as well as ECG (Siesta unit) are also collected.

Skin temperature is monitored throughout the experiment. After each block, the subject answers the Field Status Questionnaire to assess his ability to detect the presence of the field.

**Results.** As an ongoing study, data are still being collected and analyzed (SPSS 15.0, SPSS Inc., Chicago, USA). The full results will be presented at the BEMS meeting, but currently only preliminary data are available: Occipital EEG, postural tremor and postural oscillations have been analyzed in 6 subjects.

It has been chosen at this step to focus on data acquired in the blocks 1 and 3 (see Figure 1a). Within-subjects ANOVAs were conducted on selected computed characteristics: ANOVA 2 (eyes open vs. eyes closed) x 2 (block1 vs. block3) x 2 (sham vs. real).

No Block main significant effect has been found for EEG, postural tremor and postural oscillations. However, with eyes closed, subjects had significantly higher EEG alpha activity in the occipital region (O1: \( F = 24.85, p < .01, \eta^2 = .86 \); O2: \( F = 20.54, p < .05, \eta^2 = .83 \)), larger and faster postural oscillations (sway area: \( F = 35.14, p < .005, \eta^2 = .89 \); sway velocity: \( F = 51.47, p < .005, \eta^2 = .92 \)), and higher index finger drift (\( F = 12.19, p < .05, \eta^2 = .75 \)) with eyes closed than with eyes open. No interaction effect was found.

**Conclusions.** Preliminary results confirm that this protocol is adapted to detect subtle changes in the investigated characteristics, despite the small number of subjects analyzed.
at this point. Indeed, significant differences were found between open and closed eyes conditions in EEG, tremor and postural sway. Due to the small number of subjects tested so far, we did not detect any significant effect due to MF exposure. A sample size calculation has been conducted: 68 subjects would be required to obtain significant differences between the real and sham conditions for the sway velocity index (i.e. standing balance, p fixed at .05, power = .80). It suggests that our final results (including 70 subjects) may carry out effects of the exposure on specific human behaviours.

Acknowledgements. Research funded by Hydro-Québec, EDF-RTE (France), ORDCF (Ontario), CIHR (Canada) and LHRI. The authors acknowledge Lynn Keenliside for building the exposure system and for all the technical support.

![Figure 1](image.png)

**Figure 1.** a. Time course of the real and sham exposure sessions. The horizontal black line represents the MF status (OFF when down, ON when up). Note that during the sham exposure session, the MF is never ON. Vertical grey bands represent the four 15-minute blocks of testing. b. Zoom on the time course of a block of testing (the same for each block). White cells represent resting periods and grey cells represent testing periods (duration is displayed in seconds inside the cells). The table specifies the corresponding tests.
* 2-1 ASSESSMENT OF ELF ELECTROMAGNETIC EXPOSURE OF THE GENERAL PUBLIC DUE TO DISTRIBUTION SUBSTATIONS

Wout Joseph, Leen Verloock, Luc Martens
Ghent University / IBBT, Ghent, Belgium

Objectives. Distribution substations that transform typically voltages of 11,000 V to voltages of 220/230 and 400 V, are often located close to places where people are present e.g., in buildings, between houses,... The objective of this paper is to determine the exposure of the general public due to extremely low frequency (ELF) electromagnetic fields of distribution substations and to compare the fields with the ICNIRP guidelines [1] (100 $\mu$T and 5 kV/m at 50 Hz) and the 0.4 $\mu$T value mentioned in epidemiological studies [2].

Methods. In order to check the compliance of the electromagnetic fields, distribution substations (with power of 160 kVA to 630 kVA) have been categorized. Four categories have been distinguished depending on their location: substations in buildings (mostly in basement), detached substations, substations between two houses (above ground level), and underground substations in the pavement. For each category two substations are selected (based upon power and possible exposure of general public) for the measurements. Thus in total eight substations have been investigated.

The fields are measured using an electric- and magnetic-field probe of type PMM EHP-50C. The magnetic fields depend upon the current load of the cables. Therefore, the course of the currents through the different cables of the substations is measured each 15 minutes during 24 hours at the day the field measurements are performed. The average, maximum, and nominal exposure due to the magnetic fields can then be calculated using the momentary measurement values and the course of the current, assuming that the course of the magnetic fields during 24 hours is similar to the course of the current.

The measurement procedure can be described as follows. First, the frequency spectrum of the magnetic and electric fields in the neighborhood of the substation is determined from 5 Hz to 100 kHz. Next, the location of the maximum value at each side of the substation is determined at 1.5 m above ground level. Fig. 1 shows an example of the normalized magnetic field $B$ [$\mu$T] around a detached substation with indication of the location of the maximal value. Then, the magnetic and electric fields at the location of the maximal values of each side are measured as a function of the distance to the substation. Finally, the safety distances are determined by comparing the fields with the ICNIRP [1] guidelines and the average fields with the 0.4 $\mu$T value [2].

Results. Fig. 2 shows the average magnetic field (24 hours) as a function of the distance for different sides of a distribution substation. These values are then used to determine the safety distances. The electric fields measured around the substations never exceeded 5 kV/m: the maximal measured value was 536.0 V/m. The value of 100 $\mu$T is never exceeded
for maximal exposure during a day. For exposure due to the nominal currents (no normal operational conditions) safety distances of maximally 0.90 m are obtained. The maximal safety distance (for the investigated substations) for the 0.4 μT value for average exposure is 5.4 m.

**Conclusions.** Distribution substations have been distinguished in four categories and for each category the fields of two substations have been measured. The safety distances for these substations have been determined. The magnetic and electric fields of the investigated substations satisfy the ICNIRP guidelines. When comparing the average exposure with the value of 0.4 μT, safety distances of maximally 5.4 m are obtained.

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**Figure 1.** Example of normalized magnetic field around detached distribution substation (A, B, C, and D indicate the different sides of the substation).
FIGURE 2. Averaged (day) magnetic field $B$ as a function of the distance to a detached substation (A, B, C, and D indicate the different sides of the substation).

2-2 THE “VIRTUAL FAMILY” – NOVEL CAD BASED ANATOMICAL MODELS OF TWO ADULTS AND TWO CHILDREN FOR DOSIMETRY AND IMPLANT EVALUATIONS

Wolfgang Kainz¹, Andreas Christ², Katharina Honegger², Eckhart Hahn³, Jianxiang Shen⁴, Wolfgang Rascher³, Rolf Janka³, Werner Bautz³, Berthold Kiefer⁵, Peter Schmitt⁵, Hans-Peter Hollenbach⁵, Ji Chen⁴, Anthony Kam⁶, Esra Z. Neufeld², Michael Oberle², Niels Kuster²

¹U.S. Food and Drug Administration (FDA), Rockville, MD, USA ²Foundation for Research on Information Technologies in Society, Zurich, Switzerland ³Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany ⁴University of Houston, Houston, TX, USA ⁵Siemens Medical Solutions, Erlangen, Germany ⁶National Institutes of Health (NIH), Bethesda, MD, USA

Objectives. Our goal is the development of four high-resolution anatomical models of an adult female, an adult male and two children (3-6 and 7-14 years of age). The models consist of CAD (Computer Aided Design) objects with smooth surfaces. Every organ, bone or muscle will be represented by a separate CAD object. This approach allows the generation of voxel models with the required grid step sizes without
introducing additional uncertainties due to multiple sampling procedures. A set of tools to visualize, re-discretize, and extract various model parts or regions is planned. All four models will be provided to the scientific community at no cost.

**Methods.** After approval of the project by the ethics commission of the Friedrich-Alexander-Universität, Germany and the FDA research review board, two adults and two children of average weight and height were recruited. The four volunteers have the following specifications: male, 34 years, 1.74m, 70kg, female, 26 years, 1.60m, 58kg, girl, 11 years, 1.48m, 34kg, and boy, 6 years, 1.07m, 17kg. We tried to position the person as close as possible to a standing person with the arms close to the body, pointing straight down. The adults received an intravascular contrast agent for delineation of the blood vessels and Buscopan to reduce bowel movements. MR-scans were performed using a 1.5T Siemens Magnetom Avanto Tim (Total Imaging Matrix) scanner. The scanning protocol was used in the following steps: 1. heart: triggered mode 0.5x0.5x1.5mm³, 2. head: T1 weighted MPRAGE (Magnetization Prepared Gradient Echo) 0.5x0.5x1.0mm³, 3. thorax: SPACE (performance optimized 3dim. turbo spin echo) 0.9x0.9x2.0mm³, 4. application of Buscopan, 5. abdomen, legs and feet, SPACE 0.9x0.9x2mm³, 6. application of blood vessel contrast agent, 7. first pass angiography (arteries only), FLASH sequence 1.0x1.5x1.0mm³, 8. torso steady state angiography (arteries and veins) with VIBE sequence 1.0x1.5x1.0mm³, 9. left and right arm steady state angiography (arteries and veins), VIBE sequence 1.0x1.5x1.0mm³, and 10. right and left arm anatomy, SPACE, 0.9x0.9x2mm³. The total session time including positioning, scanning time and recovery breaks for the adults was about 6 hours and for the children about 3 hours.

For the segmentation of the MR images into 80 different tissue regions we developed a new toolbox called iSeg. iSeg provides image processing algorithms like thresholding, region growing, fuzzy connectedness, interactive watershed transformation, and contouring as well as semi-automatic pre- and post processing. With iSeg we are able to quickly prototype new segmentation techniques and combine them flexibly. After the models are segmented with iSeg we use Amira (software for segmentation and CAD object generation) to combine the segmented data sets into CAD objects.

**Results.** Instead of representing anatomical structures as a composition of voxels the Virtual Family is composed of CAD objects for individual organs. All modern simulation software imports CAD data in different standardized formats. The main advantages of the Virtual Family are: 1. every organ and the whole models can easily be scaled, 2. boundaries of the organs are well defined by smooth surfaces, 3. the model can be meshed in any resolution as needed and graded meshes need no re-meshing, 4. tissue with the same electrical properties can be combined in groups, 5. data formats are standardized and can be translated into other formats, and 6. the posture of the model can be changed using existing CAD software.

**Conclusions.** The developed models overcome the restrictions of currently existing anatomical models with respect to numerical resolution and anatomical details. The Virtual Family will reduce the numerical modeling uncertainty by providing a unified and comprehensive database of human models to the whole scientific community. It also provides the
first anatomically correct whole body models of two children. Besides computational applications the Virtual Family will be used by the Gesellschaft für Medizinische Ausbildung (Society of Medical Education, Germany) for educational purposes. We expect to complete the models by end of 2007.

Figure 1. iSeg, left: MRI picture, right: segmented slice
2-3 ASSESSMENT OF INDUCED ELECTROMAGNETIC FIELDS IN THE HUMAN BODY IN THE PRESENCE OF HETEROGENEOUS FIELD DISTRIBUTIONS

Sven Kühn\textsuperscript{1}, Wayne Jennings\textsuperscript{2}, Niels Kuster\textsuperscript{1}
\textsuperscript{1}ETH Zurich, Zurich, Switzerland \textsuperscript{2}SPEAG, Zurich, Switzerland

\textbf{Objectives.} Current safety standards limiting radiofrequency (RF) exposure of humans derive the reference values for the general public from specific absorption rate (SAR) calculations in prolate spheroidal models [3] for incident plane-waves. Despite the fact that at the time the model was developed better approximations were not possible due to lack of computational power this model retains some advantages at present: 1) it is simple and available over a broad-frequency range; 2) it represents an integral value of the absorbed power (whole-body) in the human body and hence allows spatial averaging.
of the incident field to be applied. The main disadvantage of the model is that it does not reveal a realistic estimation of localized exposure due to missing anatomical details. The aim of this study was to derive a 1) correlation between incident fields with different distribution characteristics and the resulting induced fields (SAR) and 2) the verification of the reference levels with respect to SAR limits for whole-body and spatial peak SAR in anatomical human models.

Methods. The local and the whole-body averaged absorbed energy in anatomical human models at 835 and 2140MHz were studied for indoor exposure environments composed as a superposition of plane-waves. In a first step, the minimal grid resolution providing reasonable uncertainties was determined. Then, an in-depth evaluation of the impact of the plane wave field incidence, i.e., the propagation direction and the polarization, on the field induced in the Visible Human model was conducted by determining the induced whole-body and 10g spatial peak SAR for 1) varied incident field direction in 15° steps from the front of the model to its back side with two polarizations each; 2) varied incident field polarization in 15° steps for incidence to the front of the model; and 3) the induced whole-body and 10g peak spatial SAR levels for quasi-isotropic incidence to the Visible Human and Japanese Female [1] models (Figure 1), i.e., all major plane wave incidence with waves propagating from all 6 sides and 2 polarizations each. The percentage of the resulting whole-body average and peak spatial SAR values with respect to the basic restrictions for incident exposures at the ICNIRP reference levels were then determined for the head and trunk, arm and leg regions.

Results. The resulting worst-case whole-body SAR values were much closer to the basic restrictions than expected, indicating that exposures at the reference levels do not guarantee compliance with the basic restrictions for all human anatomies. The 10g peak spatial SAR values were higher than those expected from the planar worst-case model [2] due to partial body resonances. The ratios between whole-body and peak spatial SAR with respect to the corresponding limits were only 1.4-6.4.

Conclusions. If typical peak to average values of the indoor field distributions (6-12dB) are compared with the whole-body to spatial peak SAR ratios (factors ranging from 1.4 for the plane wave case to 6.4 for the isotropic incidence), it is quite apparent that the localized SAR is likely to be the most restrictive quantity with respect to the ICNIRP basic restrictions.

Acknowledgements. We would like to acknowledge the financial support of the CTI, Switzerland and the Mobile Manufacturers Forum.


**Figure 1.** Surface SAR on the Visible Human model for quasi-isotropically incident plane waves at 2140 MHz.
Objectives. The electric field has been used for therapeutic purpose. To analyze the biological effects of ELF electric field, the coupling between the field and a human body has to be well understood. When a human body enters a uniform electric field, the field distribution is perturbed and the field concentrates on some parts of the body. In an AC electric field, a displacement current is induced inside the body, as well. There has been much study on the calculation of the ELF electric field on the body and the induced current inside the body. However, most of them have been case-specific, and have not been for general use. To provide a useful tool to understand the field-human interaction in practical applications, we have developed a handy software which visualizes the spatial distribution of the ELF electric field and the induced current around and at a human body.

Methods. For the fast numerical calculation of the electric potentials, a finite difference method (FDM) is used. The FDM starts with the division of the object region into a mesh configuration followed by transforming the Laplace’s equation into a finite difference form at each nodal point of the mesh. To obtain finite difference equations, we expand the electric potentials at each grid into the Taylor’s series using the surrounding grid potentials and abridge them after the third term.

In our calculations, an iterative method is used to solve the resultant set of simultaneous equations, since the problems have a large number of mesh points. To facilitate the convergence in the calculation, the successive over-relaxation method is used.

The electric field vector is obtained from the spatial derivatives of the potential in x-, y- and z- directions. The induced current was obtained by the surface integral of the surface electric field. The current density inside the body is estimated by dividing the induced current by the cross sectional area of the body part.

Results. Figure 1 shows the electric field at a body surface. The boundary of the potential calculation consists of a ceiling, a floor, walls and a human body. This is the condition in which a human body is exposed to an ELF electric field using the instrument for the electric field therapy. A high voltage (10 kV/m) was applied beneath the feet of the subject. Above the top of a subject’s head, a counter electrode with a grounded potential was suspended from the ceiling. All the ceiling, the walls and the floor were grounded also.

The field concentration was observed at some parts of the body. They are the head top, the shoulder, the outer side of arms, the hands and the shanks. It was found that the electric field was weak around the genital area. The electric field at the top of the head was about 100 kV/m when 10 kV was applied beneath the feet.

Figure 2 shows the induced current density at some parts of the body. Larger current
density was observed at lower limbs. A large value was found at the ankle where the cross sectional area was small. The current density was 0.59 mA/m² and 22.5 mA/m² at the head and the ankle, respectively. The computational time of these calculations was within a few minutes using a common lap-top computer. The agreement between the calculation by the developed software and the measurement was confirmed.

Conclusions. We have developed an application software for the field calculation with high adaptability for different conditions of a human subject and its physical environments. This software has an excellent performance of a graphic user interface (GUI) and enables the field calculation with relatively simple operation in practical time. For the numerical analysis of electric field, a finite difference method (FDM) with high computational efficiency was used. From the result of the calculation, the field distributions around/at a human body and the current distribution induced inside the body can be presented in a versatile 3 dimensional graphic display. The accuracy of the calculation has been confirmed in the measurement with a human model using a therapeutic field-exposure equipment commercially available. This technique enables us to evaluate the field coupling to a human body with high degree of freedom, and will provide a useful tool for the study of biological effects of electric field.

Acknowledgements. The authors wish to thank Dr. Yoshinori Taka and Mr. Itaru Nakata for their effort of the software development when they were with Graduate School of Engineering, Hokkaido University, Sapporo, Japan.

![Figure 1. Electric field distribution at body surface.](image)
Objectives. This study investigates the correlation between locally averaged SAR distribution in a human body exposed to RF fields and the distribution of the corresponding steady state temperature rise. Several locally averaged SAR quantities related to averaging volumes with different tissue mass have been considered in the analysis to establish which of those quantities correlates best with temperature rise.

Methods. The analysis is based on the numerical simulations of human body exposure to plane waves in the frequency range of 30 MHz to 1 GHz. This modeling allows computing SAR and related temperature rise distributions inside the body and perform the required post processing to obtain the correlation information between those two distributions. The simulations were performed using the FDTD based electromagnetic and thermal solver FDTDLab.
A 3 mm resolution heterogeneous human body model with 39 different tissues (based on Brooks AFB, TX, visible man dataset) has been employed for this modeling. The electric properties of the tissues for this model are from Gabriel et al. (*Physics in Medicine and Biology*, Vol. 41, pp. 2251–2269, 1996) while the thermal properties including metabolic heat production rates and blood perfusion parameters for each tissue were compiled from different sources: Bernardi et al. (*IEEE Transaction on Biomedical Engineering*, 50(3):295-304, 2003), Flyckt, et al. (*Physics in Medicine and Biology*, 51(11):5007−5021, 2006) and Li et al. (*IEEE Transaction on MTT*, 54(7):3146-3154, 2006).

At each of the analyzed frequencies three different plane wave impinging directions were considered (front, back and side exposure). For all simulated scenarios, point SAR as well as locally averaged SAR values were computed using standard (IEEE Std. C95.3-2002) averaging procedure while different cubic averaging volumes containing 1 g, 50 g, and 100 g of tissue were considered in addition to the standard 10-g average SAR metric. The temperature rise was derived from the base temperature distribution in the body which in turn had been obtained from simulating the steady state condition without exposure. The steady state temperature rise was normalized to the incident RF power that produced the maximum permissible 10-g average peak SAR level in the body. This information is not required for correlation analysis, but was useful to evaluate the possible absolute temperature rise and absolute temperature value that can be reached in the human body due to maximum allowed exposure.

The correlation between temperature rise and the computed SAR distribution was computed point by point within the volume of the body. In addition, to exclude possible errors due to limited simulation accuracy the correlation coefficients were computed only for the body regions where SAR was above certain threshold level from its peak value: -10 dB and also -20 dB threshold levels relative to the peak were considered for example below which the SAR was excluded from correlation analysis.

**Results.** In general the temperature rise distribution within the body is a much smoother function than point SAR, which varies rapidly within the body. The locally averaged SAR on the other hand is closer to the temperature distribution and the degree of correlation depends on the SAR averaging volume. The larger the volume the smoother the SAR distribution. The results are also frequency dependent. Fig.1 shows an example of temperature rise distribution computed for front plane wave exposure at 75 MHz and corresponding SAR distributions. Visual comparison of the pictures shows that 1-g, 10-g and 50-g SAR follow the temperature rise distribution much better than point SAR or 100 g SAR. The computation of correlation coefficients allows quantifying systematically this relationship even when the difference is not apparent.

**Conclusions.** Based on current scientific evidence, thermal effect is recognized as the basis for establishing safety level of exposure in the international RF exposure safety standards (IEEE, ICNIRP). At the same time 10-g SAR is used as a surrogate for temperature due to relative simplicity of its evaluation in experimental measurements and compliance testing.
The present study provides systematic way to quantify the degree of correlation between various locally averaged SAR metrics and associated temperature rise distribution. This approach increases the understanding of the relationship between SAR and temperature in addition to other reported studies where the correlation between only peak SAR and peak temperature rise has been considered.

![Figure 1](image)

**Figure 1.** SAR and temperature rise distribution in the body exposed to plane wave at 75 MHz (front exposure). Color scale is compressed to show all distributions on one scale:
- a) point (voxel) SAR;
- b) 1-g SAR;
- c) 10-g SAR;
- d) 50-g SAR;
- e) 100-g SAR;
- and f) temperature rise.

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2-6 A FORMULA FOR PREDICTING WHOLE-BODY AVERAGE SAR IN HUMAN MODELS FOR FAR-FIELD EXPOSURE AT GHZ BANDS

Akimasa Hirata\(^1\), Yoshio Nagaya\(^1\), Osamu Fujiwara\(^1\), Tomoaki Nagaoka\(^2\), Soichi Watanabe\(^2\)

\(^1\)Nagoya institute of Technology, Nagoya, Japan  \(^2\)National Institute of Information and Communications Technology, Tokyo, Japan

**Objectives.** For RF far-field exposures, whole-body average specific absorption rate (SAR) largely depends on the frequency of the incident wave despite the same power density. That peak appears at several tens megahertz for an adult. This peak is attributed to a standing wave over the whole body. At this frequency, the human height is approximately 0.4 wavelengths of EM waves in free space. Additionally, the whole-body average SAR has another peak around 2 GHz under the ICNIRP reference level, which is caused by the relaxation of the reference level. The whole-body average SAR at this frequency band was larger than that of the adult model, and then that in child models exceeded the basic limits in the ICNIRP guidelines by up to 20% (Dimbylow. Phys. Med. Biol. 2002). However, the
models for children were developed by linearly scaling down the dimension of adult. Wang et al. (Phys. Med. Biol. 2006) developed a realistic 7-year child model based on the adult model using a scaling technique. Then, the same tendency was shown as in the Dimbylow (2002).

The objective of this study is to propose a formula for predicting whole-body average SAR in anatomically-based human models for far-field exposures, in order to discuss the uncertainty of whole-body average SAR in different human models. Realistic 3-year, 5-year, 7-year child models were used, together with adult models. The frequency considered was GHz bands where the whole-body average SAR takes maxima under the ICNIRP reference level. The formula proposed in this study is based on a good correlation between model surface area and absorption cross section.

Methods. Numeric Japanese adult and child models are used in this study. Whole-body voxel models for the adult male and female were developed by Nagaoka et al (Phys. Med. Biol. 2004). The resolution of these models was 2mm segmented into 51 anatomic regions. The models for 3-year, 5-year, and 7-year children were developed by applying a free form deformation algorithm (Nagaoka et al., BEMS Meeting 2006). In this study, the whole-body average SAR in an anatomically-based human model was investigated with the FDTD method. The separation between the human model and 12-layered uni-axial PML was kept to 60 mm (30 cells). A plane wave with a vertical polarization was considered as an incident wave. The electrical constants of tissues were taken from the report by Gabriel (Brooks Air Force Base, 1996).

Results. For the total of five Japanese models, we calculated the absorption cross section and then attempted to correlate with the model surface area. Specifically, the regression line was determined by the least mean square method. The coefficient of determination was 0.99 and the slope of the regression line was 0.196. Namely, excellent correlation was found between the model surface area and the absorption cross section. It is known that the human surface area can be estimated with an equation in terms of the weight and height (Fujimoto et al., Nippon Eiseigaku Zasshi, 1968). Then, we developed a formula for predicting whole-body average SAR in terms of the correlation between the model surface area and absorption cross section, together with the equation for estimating the human surface area. The feature of the developed formula is that only two parameters, i.e., human height and weight, are required to predict whole-body average SAR for a given incident power density.

Conclusions. A formula for predicting whole-body average SAR was proposed based on the correlation between the model surface area and absorption cross section. In future work, we will examine the applicability of the equation to different human body models.
2-7 STATISTICAL DOSIMETRY ANALYSIS FOR FREE-RUNNING RATS IN A CIRCULARLY POLARIZED WHOLE-BODY EXPOSURE SETUP

Jianqing Wang, Osamu Fujiwara
Nagoya Institute of Technology, Nagoya, Japan

Objectives. To simulate a great variety of coupling between the RF fields and free constraint exposed subjects, we have proposed a circularly polarized whole body exposure setup, and have applied it to a study for investigating whether or not RF base station exposure of W-CDMA cellular system affects prenatal and postnatal rats. In the design of the exposure setup, although much attention has been paid to keep a stable exposure level, the free movement of rats still yields a variation in the whole-body averaged specific absorption rate (SAR). In this study, we attempt a statistical analysis for the SARs in both the mother rats and new-born young rats using anatomical rat models and a numerical simulation technique.

Methods. The developed exposure setup was made of metal enclosure with a horizontal dimension of 90 cm x 90 cm and a height of 40 cm (Fig. 1). Its insides, except for the roof, were inlaid with 6-cm-thick planar RF absorber for simulating a free space. The reflection loss of the absorber was more than 20 dB at 2.14 GHz. The exposure antenna was two 3/2-wavelength horizontal dipoles that intersect at right angles and have a phase shift of 90°. This structure induced a circularly polarized RF field in the far-field region. The extension of the dipole antenna to 3/2-wavelength resulted from shaping an exposure field level for rats as uniformly as possible. The exposed rats were kept in each of four plastic cages, which were placed equally at the bottom of the exposure setup, with a distance of 1.4 - 1.8 wavelengths (20 cm - 26 cm) under the dipole antennas. In each cage there were one mother rat and eight young rats.

We simulated the entire exposure setup and rats with the finite difference time domain (FDTD) technique. Both the mother rat and the young rat models were developed based on anatomical image data. The mother rat model consisted of 11 tissue types with a weight of 325 g, while the young rat models were simplified as muscle. Based on the growth curve of rats, the young rats had a weight of 20 g at 1-week after birth, 35 g at 2-week after birth and 65 g at 3-week after birth. To analyze statistically the SAR variation, we built 19 FDTD numerical models in which the location and posture of each mother rat and young rat were modeled realistically based on their actual situations in the exposure setup.

Results. As a result, via the FDTD simulations, we obtained 76 and 608 sample data of the whole-body averaged SAR for the mother rats and for the young rats, respectively. Fig. 2 shows the percentage of each whole-body averaged SAR level for young rats. As can be seen, the younger the new-born rats, the higher the whole-body averaged SAR and the larger the SAR variation. For 1 W input power of the exposure antenna, the mean values of the whole-body averaged SAR are 49.2 mW/kg for the mother rats, and 82.5, 81.9 and 75.2 mW/kg for the 1-week, 2-week and 3-week rats after birth, respectively. The corresponding standard deviations of the whole-body averaged SAR are 7.1 mW/kg for the mother rats, and 38.3, 36.5 and 29.8 mW/kg for the 1-week, 2-week and 3-week rats after birth, respectively. Compared to the 1-week rats, the mean value and the standard deviation
of the whole-body averaged SAR for 3-week rats decreases 9% and 22%, respectively. The SAR variation for the mother rats is much smaller than that for the young rats. This should be attributed to the heavy weight and larger volume. In addition, when the young rats locate separately in each cage, their whole-body averaged SAR exhibits a $1.5 - 1.9$ times larger value compared to the mean value. This should be due to the larger exposed surface area in the separate young rats.

**Conclusions.** The statistical dosimetry analysis has shown that the circularly polarized whole body exposure setup could provide a fairly uniform exposure. The variations of the whole-body averaged SAR for both the mother rats and young rats do not exceed 50% of the mean value.

**Acknowledgements.** This study was entrusted and supported by the National Institute of Information and Communications Technology, Japan.

![Figure 1. Whole body exposure setup.](image-url)
2-8 WORST-CASE SAR ESTIMATION FROM RADIATED POWER MEASUREMENTS: UNCERTAINTY EVALUATION

Vikass Monebhurrun
Supelec, Gif-sur-Yvette, France

Objectives. A novel approach for rapid SAR (Specific Absorption Rate) estimation from radiated power measurements was proposed previously. In addition to the radiation performance of the mobile phone — both with and without the presence of the SAM (Specific Anthropomorphic Mannequin) phantom — worst-case SAR can be rapidly deduced — typically a few minutes for several mobile phone use positions — from radiated power measurements performed using a unique test facility such as an anechoic chamber or a reverberation chamber. Obviously, the knowledge of the worst-case SAR of a mobile phone is useful if the value obtained does not exceed the basic restriction defined by the standards i.e. 2 W/kg for GSM (Global System for Mobile communications) mobile phones. For instance, using the measured radiated power of a DECT (Digital Enhanced Cordless Telephone) phone which is typically 10 mW, a worst-case SAR10g (maximum 10g averaged SAR) of 1 W/kg is predicted by assuming that all the power is actually absorbed in 10g of tissue. Since the average radiated powers of GSM mobile phones are in the range 125-250 mW, the worst-case SAR10g thus obtained would be useless because they would exceed the 2 W/kg limit. Therefore, it becomes necessary to perform complementary expensive and time-consuming standard dosimetric measurements. Nevertheless, the definition of an appropriate minimum
absorption mass herein denoted as Meff — much higher than 10g for GSM mobile phones — can provide consistent worst-case SAR10g for a rapid SAR assessment, for example on a go/no go basis or when only radiated power measurements are available. Indeed, although the near-field electromagnetic behavior of mobile phones vary significantly between different phone models and designs or even sometimes among a given family of mobile phones, the geometrical and RF characteristics of current mobile phones — essentially dictated by physical as well as electromagnetic constraints (for example, battery size to achieve compactness or antenna size for efficient radiation) — are not arbitrary. Furthermore, SAR is measured using the same phantom and intended use positions at a given frequency.

Methods. Following these assumptions, the mobile phone/phantom coupling problem can be simplified to that of equivalent surface interactions between two objects. Obviously the distribution of local SAR cannot be easily predicted but the total power dissipated in the phantom is restricted to a given volume (or effective mass) much smaller than the total volume of the phantom. A tedious theoretical analysis may provide the minimum value for the effective mass but the relatively high value obtained would prove useless for practical SAR assessments. Therefore, we herein use values deduced from previous SAR measurements. From an ensemble of about 40 previously measured dual-band mobile phones consisting of bar-phone, clam-shell and slider designs, the minimum values of the effective mass are deduced at 900 MHz and 1800 MHz. The worst-case SARs for newly measured mobile phones with similar designs are then estimated using the relation SAR10g = Pabs/Meff. Due to the uncertainty of the measurement systems — both dosimetric (for the actual SAR) and antenna (for the estimated SAR) test facilities — it can be expected that the estimated worst-case SAR does not always provide an overestimate of the actual SAR. To evaluate the uncertainty of the radiated power measurement system — herein a compact reverberation chamber is employed — two sets of same family prototype mobile phone models consisting of 8 bar-phone and 15 clam-shell exact replica models are also measured. The standard deviation of the measurements of each set is deduced to estimate the repeatibility error of the test facility.

Results. Fig. 1 (a) and (b) show plots of the averaged 10g SARs et 900 MHz and 1800 MHz, respectively. The worst-case SAR can be estimated in two different ways: either using the radiated power of the mobile phone alone (denoted "Radiated Power") or using the total power absorbed by the phantom (denoted "Absorbed Power"). In the first case, a maximum absorption coefficient — also deduced from previous observations — is applied to obtain a worst-case absorption power prior to using the previously mentioned relation. For the measurements presented herein, the worst-case SARs deduced at 1800 MHz are always higher than the actual SAR. In rare cases, the worst-case SAR deduced from the radiated power of the mobile phone alone is slightly above the 2 W/kg basic restriction limit. As mentioned previously, in certain cases the worst-case SARs are of the same order as or, in some extreme cases, slightly lower than, the actual SAR. The analysis of the two sets of prototype phone models yields a maximum standard deviation of 1.0 dB which is comparable to the typical uncertainty of a standard dosimetric test facility.
Conclusions. Considering the measurement uncertainties and the multitude of phone designs available on the market, consistent worst-case SAR estimations are obtained for currently available mobile phones.
**3-1 IS THE INTERACTION OF LOW-LEVEL RADIOFREQUENCY ENERGY WITH BIOLOGICAL SYSTEMS A MYSTERY?**

Mays L. Swicord\(^1\), Quirino Balzano\(^2\)
\(^1\)Consultant, Ft. Lauderdale, FL, USA \(^2\)University of Maryland, College Park, MD, USA

**Objectives.** The physics of interactions of radiofrequency (RF) emissions with biological systems is examined and compared with other familiar parts of the electromagnetic spectrum to determine any uniqueness and the possibility of the existence of low-level non-thermal effects. The mystery can thus to be resolved.

**Methods.** We are all familiar with optical and infrared emissions, and nature has developed sensory organs in animals and humans to detect this life sustaining part of the spectrum. The background level of natural RF emissions is very low and featureless over a very wide spectrum, but not zero. Thus evolution has not developed refined and sensitive organs for this frequency range leading to a level of unfamiliarity. Nevertheless, RF emissions are safe at levels emitted by all warm bodies and harmful at high levels due to excessive heating. Is it possible that non-thermal, low levels of RF can cause a biological response without organs of specific sensitivity for this type of energy?

**Results.** A single RF photon is not energetic enough to excite molecular modes or cause structural or conformational changes, thus coherent fields of sufficient strength are necessary for any possible non-thermal interaction. Field interactions fall into two classes: (1) fields sufficiently large enough to modulate endogenous fields and (2) those RF fields that can have direct interaction with the structure of the system.

Systemic functions are governed by electric fields and currents and have been measured and described by Nuccitelli\(^1\). Two examples from Nuccitelli\(^1\) are physiological steady state fields on the order of 1 to 200 V/m and 0 to 100 Hz embryonic development fields on the order of 10 to 150 V/m. Fields across membranes (10\(^6\) to 10\(^7\) V/m) and chemical bonds (>10\(^9\) V/m) can only be affected by extremely large externally applied fields. RF fields with low frequency modulation can affect these endogenous fields only if the biological system has a means of demodulating the RF signal. According to Pickard and Rosenbaum\(^2\) this can happen up to about 10 MHz but only with very large RF field strengths. Demodulation becomes less efficient as the frequency is increased. This observation is supported by the more recent studies of humans by Silny\(^3\). The large pulsed fields (not RF) used in electroporation and supra-electroproation result in well established effects on the cell membrane and organelles. This raises the question as to whether RF pulses of the same magnitude could cause similar effects. The RF field would need to remain in one direction (about 1\(\frac{1}{2}\) cycle) long enough to effectively charge the cell or organelle surface, thereby possibly requiring frequencies in the low MHz range.

The ubiquitous presence of bound water in all living cells damps or eliminates vibrational...
modes in cellular components below a few hundred GHz. In fact, water plays a prohibitive role in a large number of proposed RF interaction mechanisms to be discussed. Other proposed mechanisms (e.g., free radical formation.) are frequency limited and again require relatively large fields at a few MHz to be observed. Such RF-molecular interactions, below a few MHz, have not shown to alter biochemical processes.

Conclusions. The resulting effect of electromagnetic energy inter-reacting with biological systems varies across the spectrum but the physics of interaction is understood and there is no mystery. Thus any observed effect must have a physical explanation or reason. Non-thermal effects are possible below a few MHz but require fields large compared to normal environmental exposure. Some mechanisms in this area such as free radical formation governed by the presence of magnetic fields may be of interest for further investigation. However, there is no established theory predicting low-level non-thermal RF effects between a few MHz and a few hundred GHz.

References:

Acknowledgements. This work was supported, in part, by Motorola

3-2 THE MMF BIOELECTROMAGNETICS RESEARCH PROGRAM

Michael Milligan1, Tomas Persson2, Sakari Lang3, Joe Elder4
1 Mobile Manufacturers Forum, Brussels, Belgium 2 Ericsson AB, Stockholm, Sweden 3 Nokia Corporation, Espoo, Finland 4 Motorola, Fort Lauderdale, FL, USA

Objectives. To provide an overview of the MMF’s Bioelectromagnetics Research Program

Methods. The MMF (Mobile Manufacturers Forum) is an international association of radio equipment manufacturers whose members include Alcatel-Lucent, Ericsson, Mitsubishi Electric, Motorola, Nokia, Panasonic, Philips, Sagem, Samsung, Siemens, Sony Ericsson and T & A Mobile Phones. The MMF was formed in 1998 to support key research projects, as well as to cooperate on standards, regulatory issues and communications activities concerning health and mobile phones. The research program of the MMF is adopted from the WHO Research Agenda that recommends areas in which further studies are needed or
would be useful for public health risk assessment. In supporting research, the MMF seeks to sponsor projects jointly with national and international health and scientific research bodies. The MMF also encourages all research findings to be published in peer-reviewed scientific journals to ensure openness and transparency in our research programs. The following constitutes the main parts of the current MMF research program.

**Results.** N/A

**Conclusions.** PROGRAM 1 – PERFORM A: This program, led by the Fraunhofer Institute in Hannover, Germany, included work in six European countries. The work, co-funded by the MMF, the GSM Association (GSMA) and the European Commission was undertaken under the 5th Framework program and includes 6 long-term animal studies investigating whether RF fields are capable of inducing cancer or promoting cancer development.

PROGRAM 2 – PERFORM B: This program involved both in vivo (spatial working memory in rodents) and in vitro replication studies (activity of the enzyme ODC and genotoxicity) performed by NRPB, ENEA, University of Kuopio, PIOM, and the University of Strasbourg and was co-funded by the MMF, GSMA and several national governments.

PROGRAM 3 – INTERPHONE: This project is a population based case-control study of cancer in relation to mobile telephone use. The project involves 13 countries with overall coordination being provided by the International Agency for Research on Cancer (IARC). The research is co-funded by the MMF, GSMA, the European Commission and several national governments.

PROGRAM 4 – Human study: The MMF is supporting research at the Karolinska Institute in Sweden that includes investigations with both normal and self reported sensitive subjects on: Effects on sleep and EEG with exposure before sleep, skin hypersensitivity response and reaction time and cardiovascular reactions and subjective symptoms.

PROGRAM 5 – Follow-up/Replication Studies:
- Zhejiang University: Replication of the PERFORM-A study investigating DMBA-induced mammary tumors.
- Battelle Pacific Northwest National Laboratory: Follow-up project to earlier work on the blood brain barrier.
- University of Bordeaux & Institute of Biophysics, Moscow: Collaborative project under WHO coordination to attempt replication/confirmation of earlier Russian immunology studies.

PROGRAM 6 – MTHR Research Program: The UK established a national research program in which the MMF and UK network operators provide joint funding with the UK Government. The program currently consists of more than 20 research projects.

PROGRAM 7 – Mechanism studies: A number of theoretical studies have been done to examine the plausibility of different mechanisms for RF interaction with biological systems. The studies were done at the University of Pennsylvania, University of Colorado, Purdue University, University of Maine and MIT.

PROGRAM 8 – Dosimetry and Measurement: MMF also supports a number of dosimetry and measurement projects related to RF compliance assessment and exposure standardization.
Further information about MMF and its EMF research program can be found at: www.mmfai.org.

3-3 LOCAL AND WHOLE-BODY THERMAL EFFECTS OF HUMAN EXPOSURE TO 100 MHZ RADIO FREQUENCY RADIATION: COMPARISON OF STANDING AND SEATED MODELS

David A. Nelson\textsuperscript{1,2}, Allen R. Curran\textsuperscript{2}, Hans A. Nyberg\textsuperscript{3}, Eric A. Marttila\textsuperscript{2}
\textsuperscript{1}University of South Alabama, Mobile, AL, USA \textsuperscript{2}ThermoAnalytics, Inc., Calumet, MI, USA \textsuperscript{3}Michigan Technological Univ, Houghton, MI, USA

**Objectives.** Body position and orientation may have significant effects on specific absorption rates (SAR) and resultant temperature increases in humans exposed to radio frequency (RF) fields. Experimental investigations generally have been restricted to evaluating seated subjects, while some previous models (e.g., Brooks Man) have reflected a standing posture. The whole-body rate of energy absorption, as well as the peak SAR, may be affected by the subject pose, (e.g., seated vs. standing). Under some conditions, such differences could manifest differential effects on core or local temperatures.

The objectives of this investigation were: (1) Predict SAR, and core and local temperatures in a seated adult male and a standing adult male exposed to 100 MHz RF (far-field) at power densities of 4 mW/cm\textsuperscript{2} and 8 mW/cm\textsuperscript{2} (whole-body) for 45 minutes at each of three ambient temperatures (24 °C, 28 °C, 31 °C). (2) Compare location and intensity of SAR "hot spots" in a seated and a standing adult male exposed to 100 MHz RF (far-field) at power densities of 4 mW/cm\textsuperscript{2} and 8 mW/cm\textsuperscript{2} (whole-body) for 45 minutes. (3) Compare core and local temperature changes in a seated and a standing adult male exposed to 100 MHz RF (far-field).

**Methods.** Simulations consisted of calculating local SAR values, which provide an input to the transient thermal code. The SAR calculations were performed by a finite-difference, time domain (FDTD) code. The local SAR values were then used to calculate tissue temperatures over time, using a finite difference thermal solver (ThermoReg). The thermal code incorporates effects of blood flow, metabolism, surface heating and cooling (including evaporative cooling) and active thermoregulation (sweating, vasodilation, vasoconstriction). The code also incorporates a clothing model.

Simulations were performed using two versions of the Brooks Man voxel model: a standing adult male and a seated adult male. The voxel dimensions were the same for both models (2 mm x 2 mm x 2 mm), although the seated model consisted of more voxels (1.30 x 10\textsuperscript{9}, vs 4.68 x 10\textsuperscript{8} voxels for the standing model).

The exposures simulated were consistent with the protocol of published experiments involving human subjects, and consisted of a 30-min equilibration period, followed by a 45 minute exposure (or sham exposure) and a 10 minute cool-down period. Exposures were simulated
at three ambient temperatures ($T_{\text{amb}} = 24^\circ \text{C}, 28^\circ \text{C}, 31^\circ \text{C}$) and 40 % relative humidity at each of two power densities (4 mW/cm$^2$, 8 mW/cm$^2$), plus a sham exposure. The model was clothed with only a pair denim shorts.

**Results.** Normalized, whole-body SAR values for the sitting and standing models were 0.087 (W/kg)/(mW/cm$^2$) and 0.100 (W/kg)/(mW/cm$^2$) respectively. Core temperature changes (hypothalamic and blood pool) were similar for sitting and standing models in each case. The maximum core temperature increase was 0.4 °C, following the 45 min., 8 mW/cm$^2$ exposure at 31 °C ambient temperature. Rectal and esophageal temperatures were calculated for the seated model only, and tracked changes in the hypothalamic and blood pool temperatures throughout the course of each exposure. The difference between core temperatures of the two models (seated vs. standing) following exposure did not exceed 0.2 °C for any of the cases examined. The standing model did exhibit a slightly greater rate of thermoregulatory sweating during exposure at the two higher ambient temperatures, compared to the sitting model under similar conditions.

Internal tissue temperatures for the seated model are shown in Figure 1 at the intermediate of the three ambient temperatures considered ($T_{\text{amb}} = 28^\circ \text{C}$). The left-hand image for each model corresponds to the end of the 30-minute equilibration period at the stated ambient temperature, and prior to any RF exposure. Internal tissues show some areas of moderate temperature elevation ($2 - 3^\circ \text{C}$), compared to the nominal pre-exposure level ($37^\circ \text{C}$). Some localized temperature elevation is evident in the lateral abdominal areas.

Typical surface temperature results (seated model) are shown as Figure 2, following exposure at 8 mW/cm$^2$ and at $T_{\text{amb}} = 28^\circ \text{C}$.

**Conclusions.** Whole body heating effects from 100 MHz exposure generally are similar for seated and standing models, under the conditions examined here. Local temperature increases may differ between the two models, under some conditions and in certain regions. Surface temperature patterns appear consistent with SAR distribution.

![Figure 1](image_url)

**Figure 1.** Coronal mid-plane temperatures are shown for the sitting model at the end of the equilibration period, and following 45 minutes of RF exposure (or sham exposure).
Figure 2. Surface temperatures (back and front surface views) are shown for the seated model, following 45 minute exposure at 8 mW/cm², $T_{amb} = 28 \degree C$.

3-4 EFFECTS OF ELECTROMAGNETIC FIELD EXPOSURE FROM MOBILE PHONE BASE STATIONS: DOES IT DIFFER BETWEEN SUBJECTS WITH MOBILE PHONE RELATED SYMPTOM AND THOSE WITHOUT? – A POPULATION-BASED QUESTIONNAIRE SURVEY AND PROVOCATION STUDY IN JAPAN –

Yoshikazu Ugawa¹, Yasuo Terao¹, Toshiaki Furubayashi¹, Yoko Mizuno¹, Kei Shirasawa¹, Akira Kageyama¹, Tomoko Okano¹, Masami Nishikawa², Kaori Miyawaki¹, Asako Yasuda¹, Mitsunori Uchiyama¹, Hitomi Kobayashi Yamashita¹, Akira Ushiyama³, Hiroshi Masuda³, Shogo Hirota³, Miyuki Takahashi³, Shigeru Sokejima⁴, Eiji Maruyama⁵, Pornanong Pongpaibool⁶, Kanako Wake⁶, Soichi Watanabe⁶, Masao Taki⁷, Chiyoji Ohkubo⁸

¹Division of Neuroscience, University of Tokyo, Tokyo, Japan ²Kawamura Gakuen Woman’s University, Chiba, Japan ³National Institute of Public Health, Saitama, Japan ⁴National Institute of Public Health, Saitama, Japan ⁵Kobe University, Kobe, Japan ⁶National Institute of Information and Communications Technology, Tokyo, Japan ⁷Tokyo Metropolitan University, Tokyo, Japan ⁸World Health Organization, Geneva, Switzerland
**Objectives.** Wide use of mobile phone has given rise to growing concerns about its health effect, above all, the effect of the electromagnetic fields (EMFs) emitted from the base stations. Whereas some health effects may be common to every individual, other effects are reportedly observed only in individuals who are especially susceptible to EMF. However, there has been a controversy as to whether the persons who report subjective symptoms actually have more symptoms when exposed to EMF emitted by mobile phone terminals or that emitted by mobile phone base stations (Regel et al., 2006). This is the first population-based questionnaire survey conducted in Japan as to the prevalence of individuals with mobile phone related symptoms (MPRS). In randomly sampled subjects responding to a questionnaire, we also investigated whether subjects with MPRS are more susceptible to the effect of EMF than controls in any respect, i.e. have more symptoms or show more changes in psychological, physiological or autonomic measures when exposed to EMF simulating that emitted from a base station.

**Methods.** A questionnaire including the frequency of mobile phone use and the presence or absence of MPRS was sent to 5000 women living in or close to the Kanto area, Japan. Out of the 2472 women who gave valid responses and were eligible for the provocation study, 29 (1.2 %) seriously considered that some adverse MPRSs were caused by mobile phone use. According to the tentative definition of electromagnetic hypersensitivity (EHS) that the subjects consider that health is disturbed by mobile phone use, the rate of EHS is 1.2%. Some other subjects reported to have MPRSs but they did not consider it an adverse effect of the phone. We randomly sampled 11 subjects from these two groups with MPRS along with 43 control subjects without MPRS, who gave informed consent to participate in the following experiments. A double blind, cross-over design randomized within participants was used. At the beginning of the experiment session, the participants were screened for mental disorders using the Structured Clinical Interview for DSM-IV (MINI) and checked on personality trait using the Neo Five-Factor Inventory (NEO-FFI). The following psychological and cognitive parameters were measured before and after exposure to EMF for 30 minutes: profiles of mood states (POMS) and reaction time (RT) in the precued choice RT task (Terao et al., 2006). Throughout the entire session, physiological measures of autonomic function were also monitored, including the skin surface temperature, arterial oxygen saturation, heart rate, and local blood flow of the finger tip. In addition, to test whether the subjects were able to judge the on or off of EMF, they were asked if they considered to have perceived EMF or felt any discomfort during the experiment every 5 minutes. There were four exposure conditions all lasting 30 minutes: continuous EMF exposure, intermittent exposure in which EMF was turned on or off randomly every five minutes, sham exposure without EMF, and exposure to pink noise (65dB(A)) without EMF. The subjects were exposed to a 2 GHz W-CDMA EMF at an intensity of 10 V/m from a horn antenna simulating base stations. Preliminary numerical simulation with a realistic human model exposed to plane wave revealed that the whole-body averaged SAR of the subject is 1.4 mW/kg. (Detailed investigation considering the reflection from the walls of the room etc is now undertaken.)

**Results.** The subjects showing EHS like symptoms due to mobile phone use comprised 1.2% of the 2472 women. The MPRS subjects were not different from control subjects in their personality trait. The two groups did not differ in their sensitivity to detect the
presence or absence of EMF, i.e. both were at random level, but the MPRS subjects consistently felt more discomfort regardless of the presence or absence of EMF than those without. Both groups of subjects showed higher POMS subscores for fatigue, confusion after exposure than before, regardless of whether the exposure was real or sham. The overall RT of the MPRS group was longer than the control group, although both groups showed a similar slowing of RT after exposure than before. Exposure, whether sham or real, did not have significant effects on any of the physiological measures.

Conclusions. Our results are consistent with those of previous studies in that the two groups of subjects did not show any difference in response to EMF exposure in terms of the psychological, physiological and cognitive measures, whether the exposure was real or sham. In addition, the two groups did not differ in their ability to determine whether the EMF was on or off, although the MPRS group complained of more discomfort. Together, no evidence was found in support of the subjects’ self-report of MRPS. The findings rather suggest that subjects with MRPS were more susceptible to the stress elicited by the exposure conditions than were control subjects, although this was noted across real, sham or noise exposures. This latter finding is in line with the results of Regel et al (2006) and Hietanen et al (2002) who reported no casual link between hypersensitivity symptoms and EMF exposures emitted from mobile phone base stations or mobile telephone terminals.


Acknowledgements. This study was financially supported by The Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields, the Ministry of Internal Affairs and Communications, Japan.

3-5 THE EMF DOSIMETRY HANDBOOK GUIDELINES FOR THE SAFETY ASSESSMENT OF METALLIC IMPLANTS IN RF EXPOSED WORKERS

Vitas Anderson¹,², Robert L. McIntosh²
¹Kordia Pty Ltd, St Leonards, Sydney, NSW, Australia ²Australian Centre for Radiofrequency Bioeffects Research, Hawthorn, Melbourne, VIC, Australia

Objectives. To provide publicly accessible guidelines in the International EMF Dosimetry Handbook for assessing the safety impact of metallic objects implanted inside personnel exposed to radiofrequency (RF) fields. Such assessments are required by both the ICNIRP
(1998) guidelines and the IEEE C95.1 (2005) RF safety standard to safeguard against the possibility of substantially enhanced RF fields around metallic implants.

**Methods.** We have extensively reviewed the available literature describing RF enhancement around various types of metallic implants. In addition, we have conducted our own research on both simplified canonical models and three very detailed case studies to further help us formulate general rules of thumb for assessing implants.

The canonical models entailed RF planar analyses through layered tissues (skin/muscle/bone) to gauge the shielding effect of the outer layers of the body. It also included an extensive parametric study of RF enhancements around rods of varying length, orientation and tip shape subjected to plane wave exposure in an infinite medium of muscle or bone tissue. These analyses were conducted using the EMSS FEKO MoM software. During these assessments we found that a 10 cm$^3$ average Volumetric Absorption Rate (VAR) is a better metric for assessing RF heating effects around implants than 10 g average SAR as it is not incidentally affected by mass density changes between the metal implant and the surrounding tissue and is more closely related to temperature rise.

For the detailed case studies, we used the Remcom XFDTD software to examine RF enhancements around a metal plate in the head, a cochlear implant system, and a long pin in the ankle of the visible human model. We also developed a Finite Difference thermal code to calculate the temperature rises in our models, particularly around the examined implants.

**Results.** From our review of the literature and from our own research we were able to establish a number of useful observations for assessing implants, including the following:

1) RF field enhancements around an implant are affected by the frequency of exposure, the shape and size of the implant, its orientation with respect to the polarization of the in situ field and the dielectric properties of the surrounding tissue medium.

2) The absolute level of the induced SAR around an implant is affected by the incident RF field levels in the body area around the implant. Thus, implants located in parts of the body which are relatively well shielded would not generally require assessment.

3) A metallic implant is a passive re-radiator, and of itself cannot create additional RF power absorption in the body. Thus the overall RF heating in the general vicinity of the implant will remain about the same.

4) Constructive and destructive interference effects can enhance or diminish the RF field level in the tissue layers above bone depending on the thickness of the layers and the frequency of exposure, thereby affecting the incident exposure of an implant located there.

5) RF attenuation at the skin surface is very substantial at frequencies above 6 GHz and generally provides sufficient RF shielding protection against metallic implant enhancements in the body.

6) In low loss tissues such as bone, a maximal resonant response for E parallel rods occurs when the rod length is equal to one third of the exposure wavelength. For rods and other linear structures, the enhancement mostly occurs at the end tips and increases linearly with the length of the rod. This resonance effect is somewhat damped out in tissues with higher electrical conductivity such as muscle.

7) Short rods less than 20 mm in length do not cause significant field enhancement around
the implant, which may in part be due to the averaging effect of the 10 cm$^3$ VAR volume (or 10 g SAR mass). Thus objects with a maximum dimension of 20 mm or less will not generally require assessment.

8) RF enhancement at the tips of implants exposed at frequencies above the resonant response is negligible.

9) For rods of all length immersed in muscle, the 10 cm$^3$ VAR enhancement is low ($< x1.4$) for frequencies above 500 MHz. Similar observations may apply in other high loss tissues. The re-radiated fields around an implant tend to decay very quickly in a lossy dielectric tissue.

10) The RF field enhancement at the ends of an implant is constant for frequencies below resonance. The level of this enhancement increases with the rod length and is independent of the dielectric properties of the surrounding tissue.

11) The 10 cm$^3$ VAR enhancement at the tips of linear implants diminishes substantially for non parallel E polarizations. No field enhancement is seen for E polarizations that are perpendicular to rods.

12) The tip shapes on rods have negligible impact on localised RF heating. This is probably a consequence of the small size of tips relative to the 10 cm$^3$ VAR averaging volume.

In addition to the above observations, we have developed additional assessment advice for the following types of implants: screws, arterial stents, wide plates, pacemakers, loops, cochlear implant systems, spectacles, jewellery, tooth fillings and orthodontic prostheses, shrapnel and shotgun pellets.

**Conclusions.** Our implant assessment guidelines are available for public viewing and use as a chapter of the International EMF Dosimetry Handbook at http://www.emfdosimetry.org/. There still remain some complex implant cases which cannot be adequately assessed by our guidelines, and will require further detailed study. This will be addressed in part by further updates to our implant chapter.

**Acknowledgements.** This project is based on research sponsored by the Air Force Research Laboratory, under agreement number FA4869-06-1-0115. The project has been reviewed by the Australian Centre for Radiofrequency Bioeffects Research (ACRBR).
3-6 CHASING THE BASIC RESTRICTIONS - A NEW METHOD
SIMPLIFYING EXPOSURE ASSESSMENT

Hannah Heinrich¹, Fritz Börner²
¹2h-engineering, Hausen, Germany ²BG-Institute for Occupational Safety, Sankt Augustin, Germany

Objectives. Low-frequency electromagnetic fields are present at nearly all modern workplaces. Several international and national guidelines, standards and regulations require compliance with basic restrictions (e.g. current density or electric field strength in the tissue) in order to ensure the safety of the workers. To simplify the assessment process an additional set of directly measurable reference levels (e.g. electric and magnetic field strength or magnetic flux density) is given, which inherently comply with the basic restrictions.

While in most workplaces compliance with these standards and regulations can be checked by measuring the low-frequency electric and magnetic fields present and comparing these values with the reference levels, there exists quite a number of workplaces which are deemed non-compliant when using this approach and therefore require a more detailed analysis in order to avoid unnecessary measures.

Often, numerical simulations with anatomical body models and detailed source models are used in order to calculate the current density or electric field strength in the tissue and compare these values with the basic restrictions given. However this approach is time-consuming and requires quite some expertise in order to do the modeling.

Methods. In a first step FDTD calculations of the current density distribution in the torso were done using an anatomical body model (resolution 3mm) and a set of simple magnetic field sources at power frequency (50 Hz) and given distances either in the front or the back of the torso. Special attention was focused on the area around the spinal cord and the current densities present there.

In a second step the data obtained was analyzed and converted in an easy to use set of equations and procedures.

Results. Depending on the location of the field source (front/back of the torso) two major sets of results could be obtained. For field sources near the back of the body a simple straight forward model could be derived, directly linking the external magnetic field strength or flux density at the body surface to the induced electric field strength at the location of the spinal cord. For field sources located in the front of the body additional parameters must be taken into account. Comparing only values for current densities to the basic restrictions can be misleading, if anatomical details are neglected. In general the electric field strength in the tissue is a metric that is more robust and less error prone.

Conclusions. The new approach allows to simplify the exposure assessment by directly checking for compliance with the basic restrictions without the need for complex and time-consuming modeling and calculations. Furthermore it is shown, that alternative methods using homogeneous volume conductors, which regrettably can already be found in several standards, can create the need for additional unnecessary measures without improving safety
in the workplace environment. The new data presented could also be taken into account for setting limits in future safety standards.

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**3-7 EXPOSURE OF THE GENERAL PUBLIC TO RF-RADIATION OF GSM MICROCELLS IN SHOPPING STREETS**

Gilbert Decat, Leo Deckx, Guy Meynen, Daniel Wilczek
VITO, Mol, Belgium

**Objectives.** Estimating the RF field strength from microcells the general public is exposed to by walking in shopping streets and compliance testing.

**Methods.** After random generation of 30 streets where at least one microcell was active, the RF field was selectively measured at three heights (0.1, 1 and 1.75 m), in three different axes (fig. 1) and at doubling distances between 0 and 50 m from the microcell. Measurements were made by means of the Narda SRM 3000 spectrometer.

**Results.** Table 1 shows the maximum E-field (900 MHz - 1850 MHz) obtained in a 6 minute registration time and averaged over the three measurement heights (whole body RF-distribution), over the 3 axes and over the 30 shopping streets. The maximum E-field that was observed in 1 of the 30 sampled shopping streets was 11.5 V/m. The table also shows that in some cases a maximum field strength of about 2 V/m can be found at a distance of 50 cm from the microcell. Figure 2 shows that the strongest exposure is found when a person is at a distance between 2 and 4 m from the microcell.

**Conclusions.** Our results show that if a person is walking in a shopping street the probability is 95% that he/she is exposed to a maximum E-field between 1 and 1.5 V/m. All the measured data were conform with the exposure limits recommended by the Belgian (2005) and the ICNIRP (1998) standards respectively. However, since the E-field can widely vary from a few V/m up to 11.5 V/m and every measurement is only a momentum registration of the real exposure, the gap in the present methodology is that no repeated measurements on the same locations could be performed. Therefore it is recommended that the magnitude of the E-field generated by microcells should periodically (e.g. once a year) randomly be checked and corrected for compliance there where needed.

**Acknowledgement**
The present paper is a part of a report on the EMF exposure (0 Hz - 3 GHz) of the general public in public places and public transport (2006). We are grateful to the department of Environment, Nature and Energy of the Flemish Government for funding this study.
Figure 1. Illustration of three axes method for the E-field registration below microcells.

Figure 2. Averaged maximum E-field with 95% confidence limits versus distance to the microcells.
NIGHT-TIME EXPOSURE TO ELECTROMAGNETIC FIELDS AND CHILDHOOD LEUKEMIA: AN EXTENDED POOLED ANALYSIS

Joachim Schüz, Anne Louise Svendsen, Martha Linet, Mary McBride, Eve Roman, Maria Feychting, Leeka Kheifets, Tracy Lightfoot, Gabor Mezei, Jill Simpson, Anders Ahlbom

1Institute of Cancer Epidemiology, Copenhagen, Denmark 2National Cancer Institute, Rockville, MD, USA 3British Columbia Cancer Research Center, Vancouver, BC, Canada 4University of York, York, United Kingdom 5Karolinska Institute, Stockholm, Sweden 6UCLA School of Public Health, Los Angeles, CA, USA 7Electric Power Research Institute, Palo Alto, CA, USA

Objectives. It has been hypothesized that night-time bedroom measurements may represent a more accurate reflection of exposure to extremely low-frequency magnetic fields (ELF-EMF) and have greater biological relevance than previously used 24/48 hour measurements. Accordingly, a pooled analysis of studies on exposure to ELF-EMF and the risk of childhood leukemia has been extended to examine night-time residential exposures.

Methods. The present study uses data from a previous pooled analysis (Ahlbom et al, Br J Cancer, 2000), focusing on studies that included residential measurements at least 24 hours in length from which night-time ELF-EMF could be extracted. The studies in Canada, Germany, the UK and the US met the eligibility criteria. The four studies comprise 1842 children with leukemia and 3099 controls. For all studies, the night-time period was defined as the time between 10 pm and 6 am, exposure was categorized into $<0.1 \mu T$, $0.1 - <0.2 \mu T$, $0.2 - <0.4 \mu T$, and $\geq 0.4 \mu T$.

Results. The odds ratios for night-time ELF-EMF for exposure categories of $0.1-0.2 \mu T$, $0.2-0.4 \mu T$, and $\geq 0.4 \mu T$ compared to $<0.1 \mu T$ were 1.11 (95 percent confidence interval, 0.91, 1.36), 1.37 (0.99, 1.90) and 1.93 (1.11, 3.35). The fact that these estimates are similar to those derived using 24/48 hour geometric means (the odds ratios being 1.09, 1.20, and 1.98 respectively), indicates that the night-time component cannot, on its own, account for the pattern observed. Country-level differences were stronger, with night-time risks higher than the 24-hour average in Germany, while the difference was not as pronounced in the U.S., although there was a slight tendency towards stronger association for night-time exposure in the intermediate category at $0.2 - 0.4 \mu T$. No difference by exposure measure was seen in UK data. Canada showed an opposite effect to Germany, with a weaker association for the night-time ELF-EMF as compared to the 24-hour ELF-EMF.

Conclusions. In conclusion, our results do not support the hypotheses that night-time measures are more appropriate, and hence the observed association between ELF-EMF and childhood leukemia still lacks a plausible explanation.
4-1 NANOELECTROPORATION OF PHOSPHOLIPID BILAYERS – ENERGY-MINIMIZED, FIELD-DRIVEN REORGANIZATION OF INTERFACIAL WATER DIPOLES

P. Thomas Vernier¹,², Matthew J. Ziegler²,³, D. Peter Tieleman⁴
¹University of Southern California, Los Angeles, CA, USA ²University of Southern California, Marina del Rey, CA, USA ³University of Southern California, Los Angeles, CA, USA ⁴University of Calgary, Calgary, AB, Canada

Objectives. MD simulations of phospholipid bilayers in supraphysiological electric fields show a tight association between PS externalization and membrane pore formation on a nanosecond time scale that is consistent with experimental evidence for electropermeabilization and anode-directed PS translocation after nanosecond electric pulse exposure, suggesting a molecular mechanism for nanoelectroporation and nanosecond PS externalization: electrophoretic migration of the negatively charged PS head group along the surface of nanometer-diameter electropores initiated by field-driven alignment of water dipoles at the membrane interface. In order to identify the molecular mechanisms operative on a nanosecond time scale during electroporation of phospholipid bilayers, we construct molecular dynamics simulations of phospholipid bilayers in high electric fields to reveal details of electroporation kinetics and dynamics not directly accessible by experiment.

Methods. Single and double bilayer systems are simulated using GROMACS version 3.2.1. Test systems are energy minimized and then equilibrated for 25 ns. Periodic boundary conditions are employed, and simulation time steps are 2 fs. Electrostatic interactions are calculated with a Particle Mesh Ewald algorithm using fast Fourier transforms with conductive boundary conditions and a real space cutoff radius of 1 nm for coulombic interactions and Lennard-Jones interactions.

Results. Pore formation is driven by electric field-induced rearrangements and realignments of dipoles at the membrane-water interface. Pore development is a molecular process, an extension of water defects into hydrophobic and then hydrophilic, nanometer-diameter pores. This process takes place in a few nanoseconds, and it involves water, phospholipid head groups, and the hydrocarbon phospholipid tails. The occurrence of electroporation even in octane membranes suggests that the headgroups play a secondary role. Mechanical forces on the membrane (flexure, tension, compression) are not required for poration in these simulations, beyond the electrostatic torques, repulsions, and attractions expressed at the molecular level, nor are large statistical fluctuations involving the entire transmembrane region required for the nanometer scale electroporation observed in our systems. Water defect propagation into the bilayer interior is enhanced by an energetically unstable alignment of interfacial water dipoles in the applied electric field, which lowers the barrier for
this pore-propagating configuration. The extent and direction of the water dipole ordering is influenced by the length and degree of saturation of the lipid hydrocarbon tails and is relatively insensitive to the head group dipole moment and charge.

**Conclusions.** Water dipoles oriented by the electric field and by entropic and enthalpic considerations at the membrane interface are the primary transducers for converting applied electric field energy into membrane pores. The mechanism of pore formation represented in these simulations — extension of stochastic water defects into bilayer-spanning water channels which are lined and stabilized by the diffusive migration of phospholipid head groups along the incipient nanometer-diameter pore walls within nanoseconds — is consistent with observations of artificial membranes and living cells in electric fields, and with continuum physical and electrostatic models. The key electric field-sensitive determinant of poration is the ordering of membrane-associated water dipoles, the result of competitive and cooperative interactions of water dipole rotation, hydrogen bond formation, and lipid solvation interactions in different regions of the membrane interface.

**Acknowledgements.** Computation resources provided by the University of Southern California Center for High Performance Computing and Communications (www.usc.edu/hpcc/). PTV and MJZ are supported by MOSIS, Information Sciences Institute, Viterbi School of Engineering, University of Southern California. DPT is an AHFMR Senior Scholar, CIHR New Investigator, and Sloan Foundation Fellow. Work in his group is supported by NSERC.

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**4-2 PLASMA MEMBRANE CHARGING OF JURKAT CELLS BY NANOSECOND PULSED ELECTRIC FIELDS**

Juergen F. Kolb¹, Jody A. White¹, Uwe Pliquett¹, Stephen J. Beebe²,¹, Ravindra P. Joshi³,¹, Richard Nuccitelli¹, Karl H. Schoenbach¹

¹Old Dominion University, Norfolk, VA, USA ²Old Dominion University, Norfolk, VA, USA ³Eastern Virginia Medical School, Norfolk, VA, USA

**Objectives.** With the application of pulsed electric fields of only nanosecond duration but field strengths of several megavolts per centimeter apoptosis can be induced in tumor cells. The detailed mechanisms of this process are not completely understood yet. The accumulation of charges along the membranes in the applied nanosecond pulsed electric field (nsPEF) is likely the primary trigger. This first response is observed as a sudden shift in the plasma transmembrane potential that is faster than can be attributed to any physiological event. These immediate, yet transient, effects are only measurable if the diagnostic is faster than the exposure, i.e. on a nanosecond timescale. In this study, we monitored changes in the plasma transmembrane potential of Jurkat cells exposed to nsPEFs of 60 ns and amplitudes from 0.5 to 9 MV/m with a temporal resolution of 5 ns by means of the fast responding voltage-sensitive dye, Annine-6. It is generally assumed that an increase in
the transmembrane voltage of about 1 V will eventually lead to the "breakdown" of the lipid bilayer and pores will form, which will allow the exchange of ions. We investigated membrane charging of mammalian cells in real-time, i.e. with a resolution that is short compared to the duration of the administered pulse of 60 ns. The applied electric field was varied between 0.5 MV/m and 9 MV/m. Membrane potentials were monitored using Annine-6. The fast temporal resolution was achieved by the pulsed excitation of the dye with a 5 ns laser pulse.

**Methods.** Jurkat cells (ATCC, Manassas, VA) were cultured in 75-cm² flasks in phenol red RPMI 1640 medium (Mediatech Cellgro, Herndon, VA) supplemented with 10% fetal bovine serum (Atlanta Biologicals, Norcross, GA), 1% L-glutamine, and 1% penicillin/streptomycin (Mediatech Cellgro, Herndon, VA), and incubated at 37°C with 5% CO2. Cells in log-phase were removed from the culture and resuspended in a physiological buffer (pH 7.4) prior to experimentation. Cells were stained with Annine-6 (Sensitive Dyes GbR, Germany). Stained cells in suspension were placed between two stainless steel electrodes (type 301) mounted on a standard (25 mm x 75 mm) microscope slide. The gap distance between the electrodes is 100 µm. A homogeneous electric field was applied in this microreactor by means of a Blumlein line pulse generator matched to the load resistance of the sample between the electrodes. The Blumlein pulse generator delivers an almost rectangular pulse of 60 ns duration (FWHM: full width half maximum) with a rise- and fall-time of about 2-5 ns.

The required nanosecond pulsed excitation of the voltage sensitive dye was accomplished with a dye laser (PDL-2, Quanta Ray), which provided a wavelength close to the excitation maximum of Annine-6. The duration of the laser pulse was 5 ns (FWHM). Consequently, it is possible to collect images with the corresponding temporal resolution by illuminating the cells at different times during the 60 ns exposure.

Pictures before, during, and after the exposure were taken with a magnification of 63X on an inverted microscope (IX71, Olympus). The fluorescence response was observed and recorded in 12-bit grayscale images with a signal-amplifying camera (DiCAM Pro, PCO). Relative changes in the fluorescence intensity were analyzed with MATLAB (The MathWorks, Natick, MA).

**Results.** In order to analyze charging and discharging mechanisms of cell membranes exposed to nsPEFs, cells stained with Annine-6 were exposed to pulsed electric fields with different field strengths of 0.5, 1.25, 5, and 9 MV/m for 60 ns. The voltage at the anodic pole changes very fast and moderate transient voltages that would correspond to an increase in fluorescence intensity could not be captured within the 5 ns resolution limit of our method. Instead, the apparent immediate decrease of the fluorescence intensity at both poles of the cell indicates a fast rise in the transmembrane voltage, with a change of more than 1 V occurring at the anodic pole for all conditions. The reorientation of lipid polar headgroups by the applied electric field is the likely cause for this voltage jump. After the initial sudden increase to 1 V, the potential differences at the anodic pole continue to rise at a more moderate rate to ∼1.6 V for applied field strengths equal to, or greater than, 50 kV/cm. Once this peak value is attained, the transmembrane voltage begins to decrease and it is notable that this instant drop in voltage occurs while the electric field is still being
applied. This event suggests that a threshold voltage has been reached. The rate of change from the initial jump up to the peak values is approximately the same for both hemispheres of the cell. However, values at the cathode pole are generally 1 V lower than the voltages at the anode side. Once the electric field application is removed, the resting transmembrane voltage starts to decrease again towards resting values.

Conclusions. Our experiments support the hypothesis of a membrane charging threshold related to a biological response. To instigate a lasting physiological response it seems necessary to reach a transmembrane voltage of 1.4-1.6 V across the anodic hemisphere. The comparison of conditions that enable a cell to reach the threshold value for a sustained membrane poration, to those reported to induce apoptosis, suggest that the pulse parameters for electric field and pulse duration are similar. We theorize that it is the initial plasma membrane or intracellular membrane effects on a nanosecond timescale that cause other signaling cascades (in the seconds to minutes timescale) to be activated.

Acknowledgements. This study was funded by an AFOSR DoD MURI grant on ”Subcellular Response to Narrow Band and Wide Band Radio Frequency Radiation” administered by Old Dominion University.

4-3 NON-IONIZING RADIATION GENERATED BY NANOSECOND PULSED ELECTRIC FIELDS INDUCE APOPTOSIS BY MULTIPLE MECHANISMS

Stephen J. Beebe¹, Emily H. Hall¹, Wentia W. Ford¹, Sandra A. Anderson¹, Peter Blackmore¹, Karl H. Schoenbach²
¹Eastern Virginia Medical School, Norfolk, VA, USA ²Old Dominion University, Norfolk, VA, USA

Objectives. Applications of non-ionizing radiation produced by nsPEFs to cells and tissues have emerged recently as a new basic science and therapeutic tool acting as a non-ligand agonist to affect cell structures and functions, including apoptosis induction in cancer cells. These studies were designed to continue to investigate the cellular targets that are affected by nsPEFs and to identify mechanisms and pathways that are recruited in response to nsPEF-induced apoptosis in several cancer cell lines.

Methods. Jurkat, HL-60, HCT116 colon carcinoma, and B16f10 mouse melanoma cells were treated with nsPEFs in cuvettes in the presence and absence of calcium chelators and analyzed for caspase activation 30-45 minutes post pulse using a cell permeable, irreversible inhibitor of active caspases, FITC-VAD-fmk (Val-Ala-Asp-fluoroethylketone labeled with fluorescein isothiocyanate), by flow cytometry. Cytochrome c release was determined using a monoclonal anti- cytochrome c antibody followed by Alexa Fluor 488 goat anti-mouse at various times post pulse. Cells were evaluated by flow cytometry, by isolated subcellular fractionation on Western blots, or by co-localization with or without mitochondria...
labeled with Mito-Tractor-Red using fluorescent microscopy. Cell viability was determined by Coulter Counting 24-hours post-pulse or by clonogenic assays.

**Results.** NsPEFs induce apoptosis in Jurkat and HL-60 cells (one pulse, 10, 60, or 300ns at 100-250, 60, or 26 kV/cm, respectively) by a mechanism that involves concomitant release of cytochrome c and caspase activation within the first 30-45 minutes post-pulse, suggesting a role for mitochondria and cytochrome c in caspase activation. Significant caspase activation in Jurkat and HL-60 cells does not require calcium. In contrast, nsPEFs induced apoptosis in HCT116 colon carcinoma cells (five 300ns, 60 kV/cm pulses) with caspase activation (35-40 minutes) before cytochrome c release (between 1-5 hours), suggesting mitochondria- and cytochrome c-independent mechanism(s) for apoptosis. Based on present concepts, this is likely due (1) in Jurkat cells by recruitment of an intrinsic-like apoptosis pathway, which is activated in response to intracellular stresses and dependent on cytochrome c release from the mitochondria into the cytoplasm for caspase activation; and (2) in HCT116 cells by recruitment of an extrinsic-like apoptosis pathway, which responds to extracellular membrane agonists such as Fas and can be independent of cytochrome c involvement for caspase activation. Our newest cancer model is B16f10 cells, an aggressive, metastatic mouse melanoma, which undergoes calcium-independent caspase activation that is coincident with apoptotic cell death. We anticipate B16f10 cells will exhibit the extrinsic-like, mitochondrial-independent apoptotic pathway seen in HCT116 cells, because both cell lines, unlike Jurkat, respond with lethal doses for 50% cell death (LD50) in the same treatment condition range (multiple pulses, 300ns, 30-60kV/cm). Preliminary evidence indicates that B16 cells, which survive initial nsPEF treatment, are more susceptible to a second nsPEF treatment.

**Conclusions.** We anticipate that fewer pulse numbers and shorter duration used to induce apoptosis in Jurkat and HL-60 have less effects on the plasma membranes, likely resulting in intracellular effects that recruit the intrinsic-like, cytochrome c-dependent apoptosis pathway. Greater pulse numbers and longer durations used in HCT116 and B16 cells have greater effects on the plasma membrane that may mimic the extrinsic-like, cytochrome c-independent apoptosis pathway. The results demonstrate that nsPEFs act as non-ligand agonists with cancer therapeutic potential that can have effects on plasma membranes and intracellular membranes to recruit different apoptosis pathways depending on the cell type and/or the pulse conditions.

**Acknowledgements.** This work was supported by the U.S. Air Force Office of Scientific Research/DOD MURI grant on Subcellular Responses to Narrow Band and Wide Band Radio Frequency Radiation, administered by Old Dominion University, the American Cancer Society, the Frank Reidy Research Center for Bioelectrics, Old Dominion University, and Eastern Virginia Medical School.
**4-4** NANOSECOND PULSED ELECTRIC FIELDS (NSPEFS) INHIBIT B16-F10 MELANOMA TUMORS BY ENHANCING APOPTOSIS AND REDUCING ANGIOGENESIS

Xinhua Chen¹,², James R. Swanson²,³, Richard Nuccitelli³
¹The 1st Teaching Hospital of Medical School, Zhejiang University, Hangzhou, China ²Old Dominion University, Norfolk, VA, USA ³Old Dominion University, Norfolk, VA, USA

**Objectives.** Previous studies conducted in our lab show that B16-F10 melanoma was reduced in host animals after multiple treatment of nsPEFs. In this study we have explored apoptosis and angiogenesis involvement in the biological effects of nsPEFs.

**Methods.** We injected B16-F10 cells into 120 female SKH-1 mice to derive our melanoma tumor model. After multiple nsPEF treatments (40 kV/cm field strength; 30 ns rise time; 300 ns duration), morphologic changes were observed with light (LM)- and transmission electron- microscopy (TEM). Tumor growth and blood vessels were recorded by transillumination and power Doppler. Vascular growth or regression was also investigated by tissue microarray to determine expression of angiogenic factors in the treated melanomas. Apoptosis in situ was detected by several immunohistochemistry (IHC) methods: (1) terminal deoxynucleotidyl transferase biotin-dUTP nick end labeling (TUNEL); (2) caspase-3, 6 and 7 in combination; and (3) histone H2AX.

**Results.** After multiple nsPEFs application, tumor blood supply was disrupted and melanomas shrank by 90% compared to control tumors. Multiple treatments can result in reduction of existing vessels and inhibition of new blood vessel formation. LM and TEM revealed condensed dark-staining structures within the nucleus. Increasing TUNEL fluorescence suggested apoptotic activity. These alterations were associated with significantly increased caspase 3, 6, 7 and histone H2AX fluorescence. Intra-tumoral microvessel density (IMD) assessed by CD31, CD34 and CD105 all had significantly lower expression in the treated groups compared to the control group (p<0.05). Protein expression of vascular endothelial growth factor (VEGF) and platelet-derived endothelial cell growth factor (PD-ECGF) were down regulated.

**Conclusions.** Our study suggests that increased apoptosis and reduced angiogenesis play an important role in the biological effects caused by nsPEFs. Therefore nsPEFs may have application potential in cancer therapy, gene regulation and biophysical research by non-invasively disrupting intracellular compartments and inducing apoptosis in malignant tumor.
4-5 GENOMIC AND PROTEOMIC ALTERATIONS AFTER EXPOSURE OF HUMAN 244B HUMAN LYMPHOBLASTOID CELLS IN VITRO TO EXTREMELY HIGH PEAK POWER 10 NS PULSED ELECTROMAGNETIC FIELDS

Martin L. Meltz\textsuperscript{1}, Bijaya Nayak\textsuperscript{1}, Cynthia Galindo\textsuperscript{1}, Karl H. Schoenbach\textsuperscript{3}, Kevin Hakala\textsuperscript{2}, Susan Weintraub\textsuperscript{2}
\textsuperscript{1}Univ. of Texas Health Science Center, San Antonio, TX, USA \textsuperscript{2}University of Texas Health Science Center, San Antonio, TX, USA \textsuperscript{3}Old Dominion University, Norfolk, VA, USA

\textbf{Objectives.} Our laboratories have been performing an extensive investigation of genomic and proteomic changes that have been observed to occur after exposure of 244B human lymphoblastoid cells to extremely high peak power (20 MV/m) pulsed electromagnetic fields (PEMFs) with a pulse width of 10 ns.

\textbf{Methods.} Because of the very large number of variables involved in performing these exposures, and the costs and technical skill needed for the quality performance of the genomic and proteomic assays, the decision was made to investigate the effects of a defined number of pulses. Initially, a total exposure of 25 pulses, at a pulse repetition rate of 1 pulse per 1.5 sec, was chosen. This exposure had been demonstrated to result in readily measurable cell killing, but allowed for the viability of the surviving cells to remain at 70\% (when measured at 2 hr post exposure). The logic for the selection was that if we are interested in genomic and proteomic changes, and their alterations over time, we should be more interested in the changes occurring in a predominantly viable population of cells than in a population of dying or dead cells. Microarray analysis of isolated RNA, and 2DI gels with mass spec analysis of isolated nuclear or cytoplasmic protein, are being employed (as appropriate).

\textbf{Results.} The genomic changes observed included both increases and decreases in a wide range of genes at 2 hr and 24 hr post-exposure. The experiments were expanded to include exposures of the cells to 3 or 10 pulses. A range of genomic changes were again observed.

\textbf{Conclusions.} The gene changes are being examined using pathway analysis software, to attempt to understand any relationship(s) between the different changes observed. Proteomic changes have also been observed at 2 hr and 4 hr post exposure, and an effort is being made to relate these changes to the earliest gene changes observed.

\textbf{Acknowledgements.} This research was supported by two grants from the Air Force Office of Scientific Research, AFOSR No. F49620-01-10349 and AFOSR No. F49620-02-10320 (through Old Dominion University).
THE CHARACTERISTICS OF NANOSECOND PULSED ELECTRIC FIELD STIMULATION ON PLATELET AGGREGATION IN VITRO

Stephen J. Beebe\textsuperscript{1}, Jue Zhang\textsuperscript{2}, Barbara Hargrave\textsuperscript{2}, Peter Blackmore\textsuperscript{1}, Shu Xiao\textsuperscript{2}, Karl H. Schoenbach\textsuperscript{2}

\textsuperscript{1}Eastern Virginia Medical School, Norfolk, VA, USA \textsuperscript{2}Old Dominion University, Norfolk, VA, USA

Objectives. Nanosecond pulsed electric field (nsPEF) stimulation of a variety of cells produces a wide range of physiological responses (e.g. apoptosis, stimulation of calcium (Ca\textsuperscript{2+}) fluxes, changes in membrane potential). In this study, we investigated the effect of nsPEFs on human platelet aggregation, intracellular free Ca\textsuperscript{2+} ion concentration and platelet-derived growth factor (PDGF) release.

Methods. Newly outdated platelets, provided by the American Red Cross, were centrifuged and resuspended in Ca\textsuperscript{2+} free modified Tyrodes buffer with HEPES. In some experiments platelet rich plasma was pulsed directly without washing, and aggregation measured, which also produced a platelet gel. The platelets were exposed to nsPEFs in cuvettes with aluminum plate electrodes using single or multiple pulses of 10, 60 or 300ns at various electric fields between 7-30 kV/cm. For aggregation studies platelets were added to glass aggregometer cuvettes and stirred, Ca\textsuperscript{2+} was added, and a baseline optical measurement was collected. The platelets were then transferred to pulsing cuvette, pulsed and transferred back into the aggregation cuvette and optical measurements continued. Intracellular free Ca\textsuperscript{2+} was measured in platelets loaded with Fura-2 in a Photon spectrofluorometer. The sigmoidal curves were obtained using either Sigma Plot (R) 8.0 or Origin (R) 7.5. For measurement of PDGF release, platelets were stimulated with nsPEFs or thrombin and sedimented. The supernatant was then frozen and stored at -20 degrees C until the levels of PDGF were measured by ELISA.

Results. When platelet rich plasma was pulsed with one 300 ns pulse at 30 kV/cm, platelets aggregated and a platelet gel was produced. Aggregation was observed with pulses as low as 7 kV/cm with maximum effects seen with approximately 30 kV/cm. One nsPEF pulse at 300 ns produced a dose dependent increase in intracellular Ca\textsuperscript{2+} release and Ca\textsuperscript{2+} influx that was maximally stimulated with approximately 30 kV/cm. The increases in intracellular free Ca\textsuperscript{2+} induced by nsPEF (small intracellular Ca\textsuperscript{2+} release and a large Ca\textsuperscript{2+} influx) were similar to those seen with thapsigargin but not thrombin (which produced a larger intracellular Ca\textsuperscript{2+} release). We postulate that nsPEF caused Ca\textsuperscript{2+} to leak out of intracellular Ca\textsuperscript{2+} stores by a process that involves the formation of nanopores in organelle membranes. Multiple pulses produced less than additive effects on aggregation and increases in intracellular free Ca\textsuperscript{2+}. We postulate that the first pulse causes a desensitization of the Ca\textsuperscript{2+} influx process. Increases in aggregation were also correlated with PDGF release.

Conclusions. We conclude that nsPEFs dose-dependently cause platelets to rapidly aggregate, like other platelet agonists, and this is most likely initiated by the nsPEFs increasing intracellular Ca\textsuperscript{2+}, but by a different mechanism.
Acknowledgements. This work was supported by the U.S. Air Force Office of Scientific Research/DOD MURI grant on Subcellular Responses to Narrow Band and Wide Band Radio Frequency Radiation, administered by Old Dominion University, the American Cancer Society, the Frank Reidy Research Center for Bioelectrics, Old Dominion University, and Eastern Virginia Medical School.

4-7 FROM SUBMICROSECOND TO SUBNANOSECOND PULSES – ENTERING A NEW DOMAIN OF ELECTRIC FIELD–CELL INTERACTIONS

Juergen F. Kolb¹, Karl H. Schoenbach¹, Tammo Heeren¹, Thomas Camp¹, Shu Xiao¹, Jody A. White¹, Mark Migliaccio¹, Andrea DeAngelis¹, Ravindra P. Joshi¹, Richard Nuccitelli¹, Stephen J. Beebe²
¹Old Dominion University, Norfolk, VA, USA ²Eastern Virginia Medical School, Norfolk, VA, USA

Objectives. By reducing the duration of electrical pulses from microseconds into the nanosecond range, the electric field-cell interactions shift increasingly from the plasma membrane to subcellular structures. Yet another domain of pulsed electric field interactions with cell structures and functions opens when the pulse duration is reduced to values such that membrane charging becomes negligible, and direct electric field - molecule effects determine the biological mechanisms. For mammalian cells, this holds for a pulse duration of one nanosecond or less. At such pulse durations, the electric fields in the membrane are determined by the dielectric constants of both membrane and cytoplasm. In addition to entering a new domain of electric field-cell interactions, entering the subnanosecond temporal range will allow us to use wideband antennas, rather than needle or plate electrodes, to generate large pulsed electric fields with reasonable spatial resolution in tissue. Modeling results indicate that electric field intensities on the order of 100 kV/cm with a spatial resolution of mm can be generated with ellipsoidal reflectors and using state-of-the-art pulsed power technology.

Results. In order to study the biological effect of subnanosecond pulses, we have developed a sub-ns pulse generator capable of delivering 250 kV into a high impedance load. The pulse width is approximately 600 ps with a voltage rise of up to 1 MV/ns. The pulse rise-time can be adjusted by manipulation of a peaking gap, whereas the pulse-width can be changed by adjusting a crowbar-switch located close to the load. The voltage pulses are delivered to a cylindrical Teflon chamber with polished flat electrodes at either end. The distance between the electrodes is variable and allows us to generate electric fields of up to 1 MV/cm in cell suspensions. The pulses have been applied to B16 (murine melanoma) cells, and the plasma membrane integrity was studied by means of trypan blue exclusion. Experimental results show that the threshold for the uptake of trypan blue is dependent on the electrical energy over the range of electric fields from 150 kV/cm to 900 kV/cm.
The initial uptake of trypan blue, measured minutes after the pulsing, was found to exceed that measured hours later, by a large margin. This indicates that the plasma membrane integrity of a majority of the cells recovers with a time constant of 30 minutes to 1 hour, and consequently, excludes trypan blue at these later times. Molecular dynamics modeling of the plasma membrane confirms the experimental results and shows that, under these extreme electric field conditions, nanopores can be formed even by subnanosecond pulses.

Acknowledgements. This work is supported by Bioelectrics, Inc. and by an Air Force Office of Scientific Research Multidisciplinary University Research Initiative (MURI) grant on subcellular response to narrow-band and wide-band radio frequency radiation, administered through Old Dominion University.
Tuesday

Plenary II: Bioelectromagnetic Stimulation of Wound Healing and Regeneration

STIMULATING HUMAN WOUND HEALING WITH ELECTRIC FIELDS

Luther C. Kloth\textsuperscript{1,2}
\textsuperscript{1}Marquette University, Milwaukee, WI, USA \textsuperscript{2}The Medical College of Wisconsin, Wauwatosa, WI, USA

Objectives. Review EF for wound healing research

Methods. Wound Healing with EFs: Delivering EFs into chronic human wounds dates back to 1688 when smallpox lesions were treated with electrostatically charged gold leaf. Contemporary devices deliver capacitively coupled EFs (CCEFs) using DC, AC and PC (pulsed currents) in vivo for many therapeutic purposes.\textsuperscript{1} Unlike AC, PCs are either mono or biphasic electrical events (pulses) separated by a finite period of time.\textsuperscript{1} Non-contact, inductively coupled (IC) devices are also used to deliver therapeutic EFs in vivo. To enhance healing of chronic human wounds, practitioners use both EF methods as adjuncts to standard wound care (SWC).

Method of Wound Treatment with PC CCEFs: Clinicians deliver EFs to wounds by two methods: (1) direct (one electrode coupled to wound via saline-moist gauze; second electrode coupled to intact skin) OR 2) indirect (both electrodes coupled to intact skin so they straddle the wound kept moist with saline gauze). Polarity For monophasic PC and DC, the cathode is used clinically for its reported antibacterial effect \textsuperscript{2} and for facilitating epithelial migration.\textsuperscript{3} While some researchers maintained cathode to the wound during their study durations \textsuperscript{4} others have concluded that after initial therapy with the cathode, alternating polarity during subsequent treatments yields better wound healing outcomes than maintaining cathode or anode polarity.\textsuperscript{5} Voltage CCPC generators are classified according to voltage output ranges: "low" voltage devices 0 – 50 V; "high" voltage devices 50 – 500 V. These devices deliver constant current to treatment electrodes. Dosage – Several low or high volt PC studies reported stimulation parameters (pulse duration, amplitude, frequency) that allowed determination of the EF dosage delivered to the patient. These studies report positive wound healing outcomes by delivering accumulated pulse charge between 250 to 500 \(\mu\)C / s into wound tissues 1 hour daily at 100 pps, 5 to 7 days per week during the study duration.\textsuperscript{6–8} Reference 9 is a review paper.

FDA Device Approval – No CCEF or ICEF device has been labelled specifically for wound healing. Health care practitioners use these devices "off-label" for the treatment of chronic wounds that have failed standard care.

Medicare Reimbursement – Medicare reimburses for wound treatment with CCEF and ICEF devices (www.cms.hhs.gov)
Results. Literature Review: A literature review found 36 clinical studies that assessed effects of CCEFs on chronic wound healing. In 30 of these studies EFs were delivered to wounds at mA levels of either monophasic or biphasic PC. In the other 6 studies researchers utilized μA levels of continuous DC. Data from 2 DC studies show that after a mean of 8.4 weeks 109 (58%) of 189 wounds treated with DC plus SWC healed 18.25% per week, versus wounds treated with placebo DC plus SWC that healed 9.8% per week. Data from 3 PC studies (RCTs) show that over a mean of 4.7 weeks, 88 (83%) of 106 wounds treated with PC plus SWC healed at a rate of 21% per week compared to 5.6% for wounds treated with SWC alone. These findings agree with healing rates published in a meta-analysis of 591 wounds treated with CCEFs plus SWC and 212 control wounds treated with SWC alone. Authors reported that 95% confidence intervals of 18-26% for EF treated wounds and 3.8-14% for control wounds did not overlap and that the rate of healing per week was 22% for EF treated wounds and 9% for controls — a net effect of 13% per week for EF treated wounds.

Ten clinical studies were found that assessed the effects of PRF (27.12 MHz) non-contact, IC EFs on chronic human wounds. Only one of these studies (double-blind RCT) had reportable data indicating that over 12 weeks, 10 stage III pressure ulcers decreased in size 70.6% (5.9%/week) versus 20.7% reduction (1.7%/week) for placebo control wounds.

Conclusions. References

THE MOLECULAR GENETICS OF A CELL’S SENSE FOR ELECTRIC FIELDS DURING WOUND HEALING

Min Zhao
University of Aberdeen, Aberdeen, United Kingdom

Objectives. To determine the role of weak DC electric fields in wound healing and the signaling mechanism.

Methods. Endogenous wound electric field measurement: A Vibrating probe system was used to detect endogenous wound electric fields at cornea wounds, skin wounds of rat, mouse and human subjects.

Electric stimulation: A DC power supply is used to stimulate cells and tissues cultured in a specially made chamber, — electrotactic chamber. It can accommodate cells on planar culture or small pieces of tissue in 3-dimensional cultures in gels.

Cell and tissue culture: Primary cultures of cornea and skin epithelial cells were from wild type mice and PI3Kγ knockout mice. Three types of culture models are used to test the involvement of PI3Kγ signaling in electric field induce responses: dissociated cell culture, monolayer cell culture and cornea organ culture.

Time lapse imaging and imaging analysis: A MetaMorph imaging system was used to take time-lapse video of cellular response to the applied weak DC electric fields. Cell migration was quantified as migration speed and directionality of migration.

Fluorescence video imaging: HL60 cells expressing GFP-Akt were used to monitor activation site of PI3 kinase with a MetaMorph system.

Western blot: Epithelial cells were probe for PI3 kinase activation after electric field exposure with Western blotting.

Results. We verified that there are endogenous wound electric fields at cornea and skin wounds in various animals, including human. The endogenous wound currents flow out of the wounds with the maximum currents at the wound edges.

Application of electric fields induces directional cell migration of epithelial cells, with the threshold voltage of inducing directional migration close to 0.125V/cm. More importantly, when electric fields were tested against other well accepted directional cues, such as contact inhibition release, wound void and injury stimulation, electric signal is a predominant cue guiding cells to migrate. Application of an electric field to cornea organ culture and modification of endogenous electric fields at a cornea wound in vivo also had a significant effect on wound healing.
Application of weak DC electric fields activated PI3 kinase and MAP kinase signaling. Most significantly, such activation is spatially controlled by the electric field vector, so that the activation is biased towards the field direction. Reversal of the field polarity re-orientates the activation of PI3 kinase and directs the cell migration towards the new field direction. Genetic knockout of catalytic subunit of PI3Kγ significantly decreased the activation of PI3K signaling in an EF. Cells from mutant mouse lost electric field directed cell migration and healing response.

Using Dictyostelium as a model systems, we further tracked down several other important genetic elements important for electric field directed cell migration, those includes: Pten, PI3 kinases, RasGEF.

**Conclusions.** Endogenous wound electric fields have been measured for centuries. Recently developed techniques, including vibrating probes and micro-glass electrodes have been used to detect and verified the existence of wound electric fields (1-6). We demonstrated that there are indeed endogenous wound electric fields at various wounds. Many types of cells including skin and cornea epithelial cells showed robust directional migration in electric fields (7-11). Using wound healing model, we demonstrated that not only cell migration could be guided by electric signals, in the presence of other directional cues, electric signal is a predominant guidance cue (11). We showed that cells in vitro respond to applied EFs of the strength the same as those measured at in vivo wound show directional migration. When compared with other well accepted guidance cues, electric signals predominate in guiding cell to migrate.

PI3kinase signaling underlies chemotactic migration (12-15). Using genetic knockout mice (16), we demonstrated that PI3 kinaseγ as a genetic and signaling element essential for electric field directed cell migration in wound healing. Other new genetic components in the signalling mechanisms are emerging through new experimental model systems.

**References**

Acknowledgements. I thank members of my group for various contribution to the project.

THE USE OF APPLIED VOLTAGES IN HUMAN SPINAL CORD INJURY

Richard Borgens\textsuperscript{1,2}
\textsuperscript{1}Purdue University, West Lafayette, IN, USA \textsuperscript{2}Purdue University, West Lafayette, IN, USA

Results. The ability of weak gradients of voltage to both initiate and direct growth of nerve fiber \textit{in vitro} and \textit{in vivo} studies is well known. This laboratory’s approach has been to exploit this effect as a means to promote functional regeneration after spinal cord injury in laboratory animals - and in clinical cases of acute canine paraplegia in two separate ”blinded and controlled” Veterinary clinical trials. To affect bidirectional growth of nerve fibers in the cord requires the use of a slowly oscillating (15 min duty cycle) DC electrical field called Oscillating Field Stimulation (OFS). This novel therapy has completed ”phase one” FDA-approved human clinical trials (published in J. Neurosurgery, 2005 by Shapiro et al). Severe, acutely injured SCI patients are still being treated with OFS since that publication. Details of these patient’s quality of life improvements in motor and sensory recovery as they continue to emerge will be discussed, as will improvements in the design and use of clinically -approved stimulators. Finally, the prototypes of miniature stimulators, ”wireless” configurations, and ones able to be used in traumatic brain injury will be reviewed.
5-1 ALTERED CALCIUM DYNAMICS AND CELLULAR MECHANICS MEDIATE ELECTRICALLY ENHANCED STEM CELL DIFFERENTIATION

Michael Cho, Igor Titushkin, Shan Sun
Univ of IL, Chicago, IL, USA

Objectives. The role of cytosolic calcium oscillation and cellular mechanics has long been recognized in the regulation of cellular and molecular interactions. While information embedded in calcium oscillation can provide molecular cues for cell behaviors such as cell differentiation, biomechanical changes have been shown to regulate the cell fate in a calcium-dependent manner. Although calcium dynamics is versatile and likely to depend on the cell type, the calcium dynamics in human mesenchymal stem cells (hMSCs) and its role in differentiation are yet to be fully elucidated. Moreover, the use of external physical force to regulate the stem cell fate through manipulation of the mechanical properties may provide a unique biotechnology to influence the stem cell behavior. The current study is therefore aimed at elucidation of hMSC differentiation that is mediated by altered calcium signaling and cellular mechanics in response to non-invasive electrical stimulation.

Results. Our recent findings indicate that the frequency of calcium oscillations decreases rapidly with osteodifferentiation to the level observed in terminally differentiated human osteoblasts, whereas the amplitude of each oscillation remains essentially unchanged. Moreover, the calcium oscillation appears to serve as a bidirectional signal during hMSC differentiation. While an altered calcium oscillation pattern may be an indicator for hMSC differentiation, it is also likely involved in directing hMSC differentiation. Treatment of hMSCs with a non-invasive electrical stimulation, for example, not only altered the calcium oscillations but also facilitated osteodifferentiation. We tested the hypothesis that G-protein coupled receptors at the cell surface mediate the altered calcium dynamics and subsequent hMSC differentiation in response to non-invasive electrical stimulation. Further, we explored the effect of an electrical stimulation on the stem cell mechanics. Such physical stimulation is found to decrease the stem cell elasticity but has no effect on the hMSC membrane mechanics. We postulate that the calcium-dependent cellular cytoskeleton is re-modeled by the electrical stimulation, and these mechanical changes are utilized to control the hMSC proliferation/differentiation.

Conclusions. Based on our findings, it is plausible that an optimal external physical force may be applied to manipulate the differentiation mechanisms of stem cells through controlled changes in the calcium dynamics and cellular mechanics to improve, for example, the efficacy of stem cell-based tissue construct development. Physical forces could amplify stem cell differentiation into a tissue-specific lineage, and therefore may offer an alternate biotechnology to harness the unique properties of stem cells.
Acknowledgements. This work is supported by NIH grants (GM060741, EB006067) and a grant from the Office of Naval Research (N00014-06-1-0100).

5-2 THE B2-ADRENERGIC RECEPTOR IS A NEGATIVE REGULATOR OF WOUND HEALING IN VIVO.

Christine E. Pullar¹, Rivkah Isseroff²
¹University of Leicester, Leicester, United Kingdom ²University of California, Davis, Davis, CA, USA

Objectives. Wound healing is a complex process, requiring the coordinated, temporal orchestration of numerous processes, including galvanotaxis, to repair damaged tissue. Over the past 5 years, we have established a role for the B2 adrenergic receptor (B2-AR) in regulating electric guidance systems and wound healing using in vitro and ex-vivo models. In summary, our prior research suggests that an endogenous catecholamine/B2-AR network could regulate wound re-epithelialisation and contraction in vivo. Consequently, we established colonies of B2-AR+/+ (WT) and B2-AR−/− (KO) mice to investigate the role of the B2-AR in murine wound healing in vivo.

Methods. Murine keratinocytes and dermal fibroblasts were isolated from both WT and KO neonates and the effect of B2-AR agonists and antagonists on murine cell migration, ERK phosphorylation and galvanotaxis was studied, as previously described (1-6). Two 6mm full-thickness wounds were created along the dorsal mid-line of WT and KO mice. Wounds were treated daily, topically, with gel alone or gel containing 0.1% B2-AR agonist or antagonist (n = 5). They were photographed daily, then excised after either 3 or 5 days, fixed, embedded and sectioned for both hematoxylin/eosin and smooth muscle actin (SmaA) immuno-staining.

Results. B2-AR agonists decrease both ERK phosphorylation and the migratory capacity of WT murine keratinocytes, while blinding them to an applied electric field (EF). In contrast, B2-AR antagonists increase ERK phosphorylation, migration rate and galvanotaxis in WT keratinocytes. KO keratinocytes do not respond to B2-AR drugs but migrate faster and more directionally in an EF than their WT counterparts. Meanwhile, in WT dermal fibroblasts, both B2-AR agonists and antagonists increase ERK phosphorylation and speed of migration. KO dermal fibroblasts do not respond to B2-AR ligands but migrate faster than WT cells. Finally, we detect catecholamine synthesis enzymes and measure epinephrine in both WT and KO keratinocyte extracts.

Untreated wounds are 50% re-epithelialized after 5 days. B2-AR agonist treatment decreases (30%), while B2-AR antagonist treatment (57%) or loss of the B2-AR (65%) accelerates wound re-epithelialization. While untreated WT wounds are 86% of their
original size after 2 days, the size of B2-AR agonist-treated WT wounds is virtually unchanged. In contrast, WT B2-AR antagonist-treated wounds and KO wounds are only 70% and 67% of their original size, respectively. Wound contraction correlates with the appearance of SmaA-expressing myofibroblasts in the granulation tissue. Whereas SMaA staining is markedly reduced in B2-AR agonist-treated WT wounds (62%), it is markedly increased in B2-AR antagonist-treated WT wounds (2.2 fold) and KO wounds (27%).

Conclusions. In summary, we have demonstrated that while B2-AR agonist treatment delays wound healing, B2-AR antagonist treatment significantly augments wound healing in vivo, by modulating both wound re-epithelialization and contraction. Additionally, the fact that wound healing is accelerated in B2-AR KO mice provides convincing evidence that the B2-AR/catecholamine network is a negative regulator of wound healing in vivo. Our work demonstrates that B2-AR antagonists could be a potential therapy for promoting healing in chronic wounds.

Sponsored by NIH grants AR48827 (CEP) and AR44518 (RRI)

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* 5-3 EXTREMELY LOW FREQUENCY (ELF) MAGNETIC FIELDS ENHANCE CHEMICALLY INDUCED FORMATION OF APURINIC/APYRIMIDINIC (AP) SITES IN A172 CELLS

Shin Koyama¹, Tomonori Sakurai², Takehisa Nakahara², Junji Miyakoshi²
¹ Graduate School of Human and Environmental Studies, Kyoto University, Kyoto, Japan
² Faculty of Medicine, Hirosaki University, Hirosaki, Japan

Objectives. Extremely low frequency (ELF) magnetic fields are ubiquitous in daily life. Although these fields have many uses, there is increasing concern about the effects of ELF magnetic fields on human health. We performed experiments to detect apurinic/apyrimidinic (AP) sites in human glioblastoma A172 cells.

Methods. Human glioblastoma A172 cells were exposed to an ELF magnetic field. A 5 mT ELF magnetic field at 60 Hz was used and the duration of ELF electromagnetic exposure was 2, 4, 8, 16 and 24 hr. Cells were exposed to an ELF magnetic field alone, to genotoxic agent (methyl methanesulfonate (MMS)) alone, or to an ELF magnetic field with MMS in the medium. Cells were also exposed to an ELF magnetic field alone, to hydrogen peroxide (H₂O₂) and FeSO₄·7H₂O, or to an ELF magnetic field with H₂O₂ and FeSO₄·7H₂O in the medium. After exposure to the ELF magnetic field or sham exposure, the medium was removed and the cells were washed with PBS three times. Cells were collected using cell scrapers and counted using a hemacytometer after staining with trypan blue. Simultaneously, after exposure to the ELF magnetic field or sham exposure, DNA was extracted, and the number of AP sites was measured using a DNA damage quantification
kit, based on a calibration curve prepared using standard solutions of DNA containing 0-40 aldehyde-reactive probes (ARP)/10^5 bp.

**Results.** The number of AP sites was calculated based on a calibration curve obtained using standard ARP-DNA solutions. Formation of AP sites after exposure to an ELF magnetic field did not differ significantly from that with sham exposure (Fig. 1). The number of AP sites in MMS-treated cells or ELF+MMS-treated cells increased in a time-dependent manner, and AP-site formation in ELF+MMS-treated cells was enhanced compared with that in cells treated with MMS alone. The numbers of AP sites formed in H_2O_2- and ELF+H_2O_2-treated cells are shown in Fig. 2; formation of AP sites increased time-dependently under both conditions, but formation of AP sites in ELF+H_2O_2-treated cells was enhanced compared with that in cells treated with H_2O_2 alone.

**Conclusions.** There was no difference in the number of AP sites between cells exposed to an ELF magnetic field and sham controls. With MMS or H_2O_2 alone, the number of AP sites increased with longer treatment times. Exposure to an ELF magnetic field in combination with MMS increased AP-site levels after exposure for 4, 8, 16 and 24 h, compared with MMS alone, and combined treatment with H_2O_2 increased AP-site levels after exposure for 8, 16 and 24 h, compared with H_2O_2 alone. Our results suggest that exposure of cells to an ELF magnetic field alone has no effect on production of AP sites, but that the number of AP sites induced by MMS or H_2O_2 is enhanced by exposure to ELF magnetic fields. This may occur because such exposure can enhance the activity or lengthen the lifetime of reactive oxygen species (ROS).
Fig. 1

**Figure 1.** AP site formation in A172 cells exposed ELF magnetic fields, treated with MMS and ELF+MMS. Columns represent the means and bars represent the standard deviation from three independent experiments. Statistically analysis of the data was conducted using ANOVA followed by Fisher’s PLSD test.

* Statistically significant difference compared with MMS treatment alone. (p<0.05)
Figure 2. AP site formation in A172 cells exposed ELF magnetic fields, treated with H$_2$O$_2$ and ELF+H$_2$O$_2$
Columns represent the means and bars represent the standard deviation from three independent experiments.
Statistically analysis of the data was conducted using ANOVA followed by Fisher’s PLSD test.
* Statistically significant difference compared with H$_2$O$_2$ treatment alone. (p<0.05)
** Statistically significant difference compared with H$_2$O$_2$ treatment alone. (p<0.01)
DIFFERENTIATION AND APOPTOSIS IN RAT CHROMAFFIN CELLS EXPOSED TO 60 HZ ELECTROMAGNETIC FIELD

Tatiana N. Olivares-Bañuelos, Oscar Arias-Carrion, Marcela Palomero-Rivero, Rene Drucker-Colin
Instituto de Fisiologia Celular, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico

Objectives. Several in vitro studies have established that low frequency EMF exposure induces biological changes that include effects ranging from increased enzyme reaction rates to increased transcripts levels for specific genes [Goodman and Blank, 2002]. There are recent data that show a controversial effect of high frequency EMF on cell proliferation and apoptosis, two parameters sensitive to environmental stress [Port et al., 2003; Marinelli et al., 2004]. In our laboratory we have observed morphological, biochemical and genetic changes on rat chromaffin cells exposed to 60 Hz and 0.7 mT for 7 days [Drucker-Colin et al., 1994; Verdugo-Diaz et al., 1998; Olivares-Bañuelos et al., 2004]. The aim of this study was to examine whether a low frequency EMF could elicit changes on differentiation, and apoptosis processes in rat chromaffin cells.

Methods. Primary cultures of neonate rat chromaffin cells were exposed for 7 days, 4 hours per day (2 in the morning and 2 in the afternoon), to 60 Hz and 0.7 mT. Two control groups were done: 1) chromaffin cells without treatment and 2) chromaffin cells exposed to sham low frequency EMF. Differentiation gene expression was tested using cDNA microarrays with 15,000 rat genes. Results were analyzed using BRB Array-Tools version 3.01, TIGER-MIDAS version 2.17 and BAGEL 3.2. Internal positive controls were performed by real time PCR assays. Apoptosis was evaluated using the TdT-mediated dUTP nick end labelling (TUNEL) method of in-situ labeling. Apoptosis assay was established after exposing chromaffin cells for 4, 12, 20, and 28 hours to 60 Hz and 0.7 mT.

Results. Our data suggest that low frequency EMF induce significant modifications in the cellular gene expression system. We found that both Fumarylacetoacetate Hydrolase and WAP four-disulfide core domain-1 genes are significantly down-regulated versus control group. Meanwhile, both Inhibin and Adenylate Kinase-2 genes are up-regulated versus control group. Particularly inhibit protein, among other proteins, would be regulating the EMF differentiation processes at the cell cycle level. Apoptosis results showed: 1) significant differences between control and low frequency EMF group after 4 (10.1% vs. 6.7%) and 12 (4.8% vs. 3.3%) exposition hours; 2) the number of apoptotic chromaffin cells exposed to 60 Hz and 0.7 mT is lower than the number of these same cells in either the control or the sham group.

Conclusions. We conclude that our morphological, biochemical and genetic observations are not exclusively caused by the cellular death induced by the low frequency EMF exposition on rat chromaffin cells.
Acknowledgements. Supported by CONACYT 119311 to TNOB, CONACYT 25122-M to RDC, DEGAPA-UNAM IN-208799 to RDC, fideicomiso to RDC and IMPULSA-UNAM Grant for the Stem Cell Research Group.

5-5 EVALUATION OF MUTAGENICITY BY EXPOSURE TO INTERMEDIATE FREQUENCY MAGNETIC FIELDS IN MOUSE LYMPHOMA ASSAY

Masateru Ikehata¹, Yukihisa Suzuki², Sachiko Yoshie¹, Kanako Wake³, Satoshi Nakasono⁴, Masao Taki²
¹Railway Technical Research Institute, Kokubunji, Japan ²Tokyo Metropolitan University, Hachioji, Japan ³National Institute of Information and Communication Technology, Koganei, Japan ⁴Central Research Institute of Electric Power Industry, Abiko, Japan

Objectives. Biological effects of extremely low frequency (ELF) magnetic fields (MFs) and radio frequency (RF) electromagnetic fields (EMFs) have been intensively investigating through recent years, because the concern of health effects by exposure to the EMFs in environment have risen in our society. However, the biological effects of intermediate frequency (IF; from 300Hz to 10MHz) MFs have not been studied very well, although several technologies and equipments that generate IF MFs have already used in public and occupational environments. In this study, we have investigated the mutagenic potential of the IF MFs using mouse lymphoma assay (MLA).

Methods. Mouse lymphoma cells L5178Ytk⁺/⁻ 3.7.2C was used and derived from Health Science Research Resources Bank of Japan. An IF MFs exposure device, which use a resin incubator (inside dimension of 200mm x 200mm x 200mm) mounted over a plain coil (diameter of 160mm) was used. Sinusoidal IF MFs were generated using this device and maximum density of magnetic field within exposure area was up to 0.8mT at 2kHz and at 20kHz, respectively. Spatial distribution of magnetic field among the cells that was exposed to IF MFs using a T-25 flask is within 0.7 to 0.8mT. Spatial distribution of induced current density within the media in a T-25 flask was estimated by numerical analysis. Maximum induced current density was estimated approximately 0.16A/m² at 2kHz and 1.6A/m² at 20kHz. In the experiment, cells were inoculated in a T-25 flask filled with 5ml of RPMI1640 medium with 10% horse serum (2.5x10⁵ cells/ml) and were exposed to a IF MF for 24hr in 5% CO₂ at 37°C. Then, the cell concentration was readjusted 2.5x10⁵ cells/ml to prevent overgrowth and cells were exposed to an IF MF for another 24hr in a same condition. Methyl methanesulfonate (MMS) (10 µg/ml) was used as a positive control. Unexposed control cells were incubated in a conventional incubator. After exposure period, cells washed and re-suspend in RPMI1640 medium with 20% horse serum. Two cell suspensions were made in each group. One was for measurement of plate efficiency and the cell concentration was adjusted to 8 cells/ml. The other was for tk⁻/⁻ mutant selection and the cell concentration
was adjusted to 1x10^5 cells/ml with 3 µl/ml of 5-trifluorothymidine (TFT) as a selective agent. Both suspensions were dispensed into 96 well plates (200µl/well) and four replicates were made respectively. After 14 days incubation in CO\textsubscript{2} incubator, the plate efficiency and mutation frequency was determined.

**Results.** The plate efficiency that is representative index of acute toxicity was not affected by exposure to all IF MFs conditions. In addition, the mutation frequency at tk allele (tk\textsuperscript{+}/tk\textsuperscript{−} to tk\textsuperscript{−}/tk\textsuperscript{−}) is almost same between an IF MF exposed and unexposed cells in all IF MFs exposure conditions while MMS treatment caused significantly increase in mutation frequency compared with control. These results suggest that exposure to 2kHz and 20kHz, up to 0.8mT sinusoidal IF MFs did not induced gene mutations, larger scale chromosomal changes, recombination, aneuploidy and others that could be detected by MLA. It means that induced current density up to approximately 0.16A/m\textsuperscript{2} at 2kHz and 1.6A/m\textsuperscript{2} at 20kHz did not have the mutagenic effects. In ICNIRP guideline, basic restrictions are 4mA/m\textsuperscript{2} at 2kHz and 40mA/m\textsuperscript{2} at 20kHz. Thus, our results suggest that sinusoidal IF MFs (2, 20kHz) did not have mutagenic potential even in the induced electric current was 40 times as strong as the basic restrictions in general public exposure of ICNIRP guideline. Since previous reports showed similar results that 2, 20, 60 kHz, up to 1.1mT IF MFs did not show mutagenicity and co-mutagenicity in bacterial mutation assay (Nakasono etal, 27th Bioelectromagnetics society meeting, 2005), it was suggested that IF MFs will not be likely to cause mutation.

**Conclusions.** Experimental results suggest that exposure to 2kHz and 20kHz, up to 0.8mT sinusoidal IF MFs did not have any potential to induce genetic damages that could be detected by MLA.

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**5-6 PROTECTION OF DOPAMINERGIC NEURONS FROM INFLAMMATION BY PEMF IN A CULTURE MODEL MAY INVOLVE NITRIC OXIDE**

Diana Casper\textsuperscript{1}, Luna Alammar\textsuperscript{1}, Eric Taub\textsuperscript{1}, Arthur A. Pilla\textsuperscript{2}

\textsuperscript{1}Montefiore Medical Center, The Bronx, NY, USA \textsuperscript{2}Columbia University, New York, NY, USA

**Objectives.** Parkinson’s disease results from the selective degeneration of dopaminergic neurons in the substantia nigra, and there is growing evidence that an ongoing inflammatory process contributes to this neuronal loss. Previously, we demonstrated that anti-inflammatory drugs increase the survival of cultured dopaminergic neurons exposed to dopaminergic neurotoxins. Recent studies have shown that pulsed electromagnetic fields (PEMF) reduce limb edema and swelling, conditions associated with inflammation, in ulcerous wounds. In the current study we explored the potential for PEMF to attenuate microglial activation, the cellular mediators of inflammation in Parkinson’s disease.
**Methods.** To create a model of brain inflammation, primary cultures of neurons and glia from rat embryonic midbrain were established and exposed to lipopolysaccharide (LPS), a bacterial endotoxin, in the culture medium. To attenuate inflammation, cultures were treated with leucine methyl ester (LME), an agent that selectively kills microglia due to their high lysosomal esterase activity. PEMF signals, configured a priori to modulate Ca2+ binding to calmodulin (Ca/CaM), and consisting of 1-10 msec bursts of 27.12 MHz sinusoidal waves repeating at 1 to 5 bursts/sec, at 0.05 Gauss peak amplitude, were administered as daily 30 min exposures, either throughout the experiment, or beginning 24 hours before LPS or LME exposure at 6 days in vitro. After 1-2 days of LPS or LME exposure cultures were harvested and processed for tyrosine hydroxylase immunocytochemistry to identify dopaminergic neurons, or OX-42 immunocytochemistry to identify activated microglia. Cells were quantified in representative areas of each culture dish under magnification. In addition, levels of nitric oxide (NO) and cyclic GMP (cGMP), primary and secondary targets of Ca/CaM activation, respectively, were quantified. Effects of toxins and PEMF treatments on neurons, microglia, and these two molecules were analyzed by ANOVA.

**Results.** LPS had bimodal effects on numbers of dopaminergic neurons, killing about 60% in the mid-nanogram per milliliter range. PEMF signals alone decreased numbers of OX-42+ cells by approximately 30%. Chronic administration of PEMF before and after LPS exposure significantly protected neurons from LPS toxicity. Conversely, low millimolar concentrations of LME reduced numbers of activated microglia, with concomitant increases in numbers of dopaminergic neurons. Nitric oxide levels varied significantly after changing culture medium, but appeared to increase overall with PEMF. Significant three to four-fold increases in cGMP were also observed.

**Conclusions.** Activated microglia are more abundant in the substantia nigra of post-mortem brain tissue from Parkinson’s patients. These cells secrete inflammatory cytokines, superoxide radicals, and glutamate, all killing neurons at physiological concentrations. Although the primary pathological event in Parkinson’s disease is still unknown, it is likely that inflammation plays an important role. Our results suggest that PEMF signals act directly to attenuate the destructive activity of microglia, and also through a Ca/CaM-activated pathway involving NO and cGMP in neurons themselves. Therefore, this modality should be explored further for its potential to delay or prevent the death of dopaminergic neurons in Parkinson’s disease. Similar implications may be possible for other diseases in which brain inflammation results in neuronal death.

**Acknowledgements.** This research was supported by NIH grant 1R21NS052576 and Ivivi Technologies.
5-7 DIRECT AFM IMAGING OF SURFACTANT SEALING OF PERMEABILIZED CELL MEMBRANES

Raphael C. Lee1, Xu Tang1, Florin Despa1, Igor Titushkin2, Michael Cho2
1University of Chicago, Chicago, IL, USA 2University of Illinois, Chicago, Chicago, IL, USA

Objectives. The realization that surfactant block copolymers (Poloxamers) can be used to restore the structural integrity of permeabilized cell membranes [1] has established new methods for repairing electroporated[2, 3] and peroxidated cell membranes[4]. Due to the associated amphiphilic character, multiple interaction modes with a lipid bilayer can be postulated. Although many transport and cell survival studies indicate that surfactants can seal membranes, there are no reports of direct atomic imaging to verify restoration of molecular architecture. The main goal of the present work is to determine by AFM if surfactants restore structural integrity to damaged cell membranes.

Methods. Using tapping mode AFM, we measured pore density and size in a 5x5 micron area on detergent (0.01% Saponin x 10 min) permeabilized subconfluent monolayer HL 1080 fibroblast cell membranes after 1 hour treatment with 1mM 10kDa PEG, 1 mM Poloxamer 188 (P188) or media change under standard culture conditions initiated one hour after detergent removal. Cells were cultured onto glass cover slips in low density to ensure that individual cell can be separately imaged. After the cell attachment, the slips are transferred onto the AFM fluid cell. Scanning is carried out using tapping mode with a low drive amplitude. Downward deflection amplitude and scan diameter were measured for the pores on each cell. Statistical analysis of this data was compared across the experimental groups. In parallel experiments, we also performed a cell viability measurement. Ethidium homodimer-1 (EH) saponin/water and calcien-AM (Molecular Probes, Oregon)

Results. Pores in the cell membrane was defined as downward deflections greater the 10 nM. There was an approximate four fold increase (Figure 1) in number of defects in saponin lysed cells (13.3+/-.4) corresponding to 85+/-.5% loss of cell viability. P188 reduced pore count to 5.3+/-.0.7 (1.5x control) and prevent death in 80% of cell remaining attached. P188 had no effect on normal membranes. Pore size and depth also were reduced by P188. PEG had minimal effect on pore density or size.

Conclusions. Apparently, the structural recovery of the damaged membranes induced by P188 occurs on a molecular time scale, and the beneficial effect at the cellular level can be seen in less than 15 minutes. The delivery of P188 boluses for short periods of time can be highly effective in reducing cell death after membrane permeabilization and should result in an effective trauma therapy.

References

Acknowledgements. This work was funded by NIH. The research presented here has been supported by NIH grants R01-GM61101 (RCL), R01-GM64757-04 (RCL)

Fig. 1: Density of Pores/ 25 μM² on Human Fibroblasts

(μ ± s.e.m.)

5-8 PULSED ELECTRIC FIELDS PROMOTE POTATO TUBER CELL WALL CROSS-LINKING

P. Thomas Vernier¹,², Federico Gómez Galindo³, Petr Dejmek⁴, Antonio Vicente³, Martin A. Gundersen²
¹University of Southern California, Marina del Rey, CA, USA ²University of Southern California, Los Angeles, CA, USA ³Universidade do Minho, Braga, Portugal ⁴Lund University, Lund, Sweden

Objectives. Pulsed electric fields affect plant tissue not only by permeabilizing cell membranes but also through pulse-induced modifications of the cell wall. By monitoring cell membrane staining with FM1-43, which fluoresces intensely in phospholipid bilayers [1], we tracked increases in cross-linking (and reduction of porosity) in potato tuber cell walls after exposure to 1 ms rectangular electric pulses ranging in amplitude from 3 kV/m to
50 kV/m. A decrease in the FM1-43 diffusion rate through the cell wall occurs within 30 seconds after pulse delivery. This response is mimicked by exogenous H$_2$O$_2$ and is blocked by sodium azide, an inhibitor of the peroxidase-catalyzed production of H$_2$O$_2$, indicating that these pulse exposures activate a stress response in potato tuber cells that may be similar to the rapid, H$_2$O$_2$-mediated, oxidative cross-linking of cell wall proteins [2] that precedes longer-term defensive responses to wounding or environmental stress [3]. To identify changes in plant cell wall porosity (cross-linking of polymeric components of the cell wall) after exposure to millisecond, kilovolt-per-meter pulsed electric fields, which may be used for electrotransformation, electroporation of membranes, and for the electropermeabilization, and for the electroporative introduction of preservatives and other compounds into fruits, vegetables, and other food materials.

**Methods.** Potatoes (Solanum tuberosum cv. white rose) from a local market (Los Angeles, CA, USA) were manually washed, peeled, and sliced to obtain a rectangular core 1.5 cm long and 7.0 mm thick oriented perpendicular to the major tuber axis. Sections (7 mm x 7 mm x 1 mm) were cut from the phloem parenchyma tissue of the slice, rinsed with distilled water, and used immediately. Experimental samples were treated with 25 mM H$_2$O$_2$ in 5 mM KCl for 5 min, or pulsed after incubation in 10 mM sodium azide in 5 mM KCl for 15 minutes, or pulsed after incubation in 5 mM KCl. Electric pulses were delivered to tissue sections placed between two parallel, flat, stainless steel electrodes separated by 7 mm using a pulse generator designed and assembled in the department of Electrical Engineering, University of Southern California. Samples were exposed to a single 1 ms pulse at a range of applied field strengths (3, 10, 20, 30, 40, and 50 kV/m) and placed in 2 μM FM1-43 (Molecular Probes) in 5 mM KCl for 2 minutes before microscopic examination with a Zeiss Axiovert 200 epifluorescence microscope with a 10X objective. Images were captured and analyzed with a Zeiss camera (AxioCam MRm) and software (AxioVision 3.1).

**Results.** The rate of FM1-43 staining of potato tuber cell membranes, a function of the rate of diffusion of the dye through the cell wall matrix [4], is greatly reduced after incubation of the potato sample in H$_2$O$_2$, which decreases cell wall porosity by inducing oxidative cross-linking of cell wall proteins [5]. H$_2$O$_2$ alone does not affect FM1-43 fluorescence. Within 30 seconds after exposure of potato tissue to single, 1 ms electric pulses in the range of 20 to 50 kV/m we see a marked reduction in the FM1-43 staining rate, which we interpret as an increase in cell wall cross-linking. No effect was observed with pulsed fields of 3 and 10 kV/m. Diffusion of FM1-43 in the extracellular space after electropulsation is not affected by pre-treatment with sodium azide, a strong peroxidase inhibitor [5,6].

**Conclusions.** Millisecond, kilovolt-per-meter electric pulses stimulate cell wall-associated peroxidase production of H$_2$O$_2$ in potato tuber tissue, with an associate decrease in cell wall porosity, consistent with the rapid burst of H$_2$O$_2$ production in plant cells after elicitor treatment [7,8] or in response to a wound [6].


**Acknowledgements.** Supported by the Portuguese Foundation of Science and Technology, the Swedish Foundation for International Cooperation on Research and Higher Education, the Air Force Office of Scientific Research, and MOSIS.
Session 6: Mobile Phone Studies

6-1 EFFECTS OF A 900 MHZ GSM EXPOSURE ON SELF REPORTED SYMPTOMS AND BLOOD CHEMISTRY, AN EXPERIMENTAL PROVOCATION STUDY

Lena Hillert\textsuperscript{1,2}, Torbjörn Åkerstedt\textsuperscript{3}, Arne Lowden\textsuperscript{3}, Clairy Wiholm\textsuperscript{4,5}, Niels Kuster\textsuperscript{6}, Sven Ebert\textsuperscript{6}, Clémentine Boutry\textsuperscript{6}, Bengt B. Arnetz\textsuperscript{4,5}
\textsuperscript{1}Karolinska Institutet, Stockholm, Sweden \textsuperscript{2}Stockholm Centre for Public Health, Stockholm, Sweden \textsuperscript{3}Karolinska Institutet, Stockholm, Sweden \textsuperscript{4}Wayne State University, Detroit, MI, USA \textsuperscript{5}Uppsala University, Uppsala, Sweden \textsuperscript{6}Swiss Federal Institute of Technology (ETH), Zürich, Switzerland

Objectives. The objectives of the present provocation study were to investigate whether exposure to radio frequency fields (RF) caused by mobile phone use during the day has any acute effect on self-reported symptoms and possible biological correlates to these symptoms, and if subjects could correctly detect RF exposure. We applied, compared to prior studies, a longer exposure time and a wider range of outcome variables.

Methods. The study was designed to study effects of electromagnetic fields consistent with the exposure during mobile phone use. The exposure setup was developed and installed by the Foundation IT’IS (Zurich, Switzerland). The setup enabled the exposure of the left head hemisphere and was designed to maximize the exposure of brain tissue as it may occur during actual usage of GSM phones. The system was based on a low-weight, stacked micro patch antenna fixed on a headset and allowed the subject to move/rotate within a limited area without changing the exposure distribution. A fully computer-controlled signal unit allowed the application of GSM modulated RF exposures for two different subjects. The RF exposure was monitored, controlled and recorded in an encoded file at all times and was in compliance to double blind exposure protocols. The exposure signal consisted of a GSM signal at an average SAR of 1.4 W/kg simulating a conversation, i.e., including periods of DTX (active during talking) and Non-DTX (active during listening). A 2 degree increase in skin temperature of the ear lobe was induced during all sessions by laser heating of a small ceramic plate. Each exposure session lasted three hours.

The study group consisted of 71 subjects, age 18 to 45, including 38 subjects who reported symptoms in relations to mobile phone use (symptom group). Exclusion criteria were medical or psychological illness where association with current symptoms could not be excluded, present medication, sleep disorders, hypertension and ongoing pregnancy. Neurovegetative and skin symptoms, scored on a 7-point Likert scale, were assessed and blood samples were drawn before, after 1 \textfrac{1}{2} hour as well as at the end of the exposure sessions. Blood chemistry analyses included C-reactive protein (CRP), prolactin, cortisol, growth hormone, serum level of thyroid-stimulating hormone (TSH) and free thyroxin (free T4), dehydroepiandrosterone (DHEAS) and neuropeptide Y (NPY). The subjects’ beliefs in exposure status during the session (RF, sham or undecided) were reported at the end of the exposure sessions.
Data were analyzed with generalized linear models accounting for the serial correlation among the repeated measurements on the individuals (xtgee and logit in STATA 9.2, Stata Corp, USA). The basic model included the factors exposure (RF, sham), group (symptom, non-symptom), session (1, 2) and an exposure*group interaction factor.

**Results.** More subjects reported headache at the end of RF exposure as compared to sham, and the severity of reported headache was also higher. Generally, more subjects in the symptom group reported headache, but the difference between RF and sham was largely due to a difference in the non-symptom group (OR 0.25, 95% CI 0.09-0.71 for interaction exposure*group; OR 2.5, 95% CI 1.16-5.38 for RF compared to sham; OR 4.17, 95% CI 1.48-11.77 for symptom group compared to non-symptom group). Apart from a significant association between higher scores on the Likert scale for a sensation of heat from the left ear at the end of exposure (but not regarding the number of subjects who reported heat from the left ear) there were no significant associations between other symptoms and RF exposure. There was no association between reporting having experienced mobile phone related symptoms during the exposure session and actual RF exposure. Reporting a belief that RF exposure had been active was positively associated with experiencing the following symptoms: sensation of the face being swollen, reddening of the skin, heat in the skin, stinging pain and/or tingling in the skin and pain in the left ear region as well as reporting having experienced symptoms that the subjects themselves attributed to mobile phone use. Subjects could not classify exposure better than chance.

No significant main effect for exposure was observed with regard to change in blood chemistry from before to the end of the exposure sessions. There was a significant interaction between exposure and group for free T4. More subjects in the symptom group showed an increase in growth hormone, but no association with RF exposure was found. Experiencing headache was associated with a larger decrease in cortisol.

**Conclusions.** We observed an interaction effect (exposure by group) on headache for RF exposure, but no association between experiencing symptoms during the exposure sessions that the subjects themselves related to mobile phone use and actual RF exposure. No clear biochemical correlate for the association between headache and RF exposure was found.

**Acknowledgements.** Research Funding: Mobile Manufacturers Forum (MMF)
DO HIGH FREQUENCY ELECTROMAGNETIC FIELDS OF THE GSM AND/OR THE UMTS STANDARD FOR MOBILE COMMUNICATION AFFECT SLEEP?

Heidi Danker-Hoppe, Achim Bahr, Hans Dorn
1Charité - CBF, Berlin, Germany 2IMST GmbH, Kamp-Lintfort, Germany

Objectives. The increasing number of mobile phones which goes along with an increasing number of base stations lead to concerns in the population that this new technology might be harmful to health. In Germany, where these concerns are documented by annually performed surveys sleep problems are the leading impairment of health attributed to high frequency electromagnetic field exposition. The present study investigates possible effects of GSM and UMTS electromagnetic fields on sleep in a laboratory setting.

Methods. The sample comprises 30 carefully screened healthy males in the age range 20 to 30 years. Each participant spent 10 nights in the sleep laboratory. The first night served as adaptation night and as screening night. Subjects with a PLMAI-Index ≥ 20/h, an AHI-index ≥ 5/h, a sleep onset latency > 30 min and/or wake after sleep onset > 45 min were excluded. Subjects were exposed to sham, GSM and UMTS fields in a double-blind, randomised crossover design. Every condition was applied in three nights. Subjects were continuously exposed by a head-worn antenna simulating the spatial SAR distribution of common GSM/UMTS mobile phones. The RF power was set to approximate but not exceed 2W/kg (SAR10g). The effect of exposure on sleep was analysed separately for GSM and UMTS taking into account the paired nature of the data. For normally distributed traits differences between sham exposure and "verum" exposure, respectively, were tested by Student’s t test for paired observations. For not normally distributed traits a signed rank test for dependent data was used.

Results. With regard to (more than 100) conventional sleep parameters (e.g. sleep period time, total sleep time, sleep latency, REM sleep latency, sleep efficiency index, number of stage shifts, wake after sleep onset, REM sleep, stages 1 to 4 of NREM sleep) neither under GSM exposure nor under UMTS exposure a significant effect on sleep could be observed.

Conclusions. A statistically significant decrease in sleep latency (Mann and Roeschke 1996) and REM sleep latency (Mann and Roeschke 1996, Loughran et al 2005) which has been observed in earlier studies under GSM 900 MHz exposure could not be confirmed by the present study where the RF power was comparatively high (2W/kg; SAR10g). However, the results published by Mann and Roeschke in 1996 could not be replicated by subsequent studies performed by the same group. We also did not find a statistically significant reduction of wake after sleep onset as observed by the Zurich group (Borbély et al 1999). Our results are in agreement with results published recently by Hinrichs et al (2005). Overall the results seem to indicate that the macrostructure of sleep is not significantly affected by GSM and UMTS electromagnetic fields.
EXPOSURE FROM MOBILE PHONE SYSTEMS IN LARGE CROWDS

Yngve K. Hamnerius\textsuperscript{1}, Rana J. Mohammad\textsuperscript{1}, Jimmy Trulsson\textsuperscript{2}, Per Haglind\textsuperscript{3}, Irene Sjoberg\textsuperscript{3}\textsuperscript{.}

\textsuperscript{1}Chalmers University of Technology, Goteborg, Sweden \textsuperscript{2}Swedish Radiation Protection Authority, Stockholm, Sweden \textsuperscript{3}City of Goteborg, Goteborg, Sweden

Objectives. The purpose of this study was to determine the general public exposure of electromagnetic fields from radiofrequency sources in the range of 80 – 2500 MHz in a gathering of more than 30 000 persons. It can be estimated that the majority of the persons were carrying a mobile phone and that quite a few were using them simultaneously.

Methods. The radio frequency exposure was measured in large people gatherings in conjunction with the 19\textsuperscript{th} European Athletics Championships 2006 in Goteborg, Sweden. Measurements were performed at the inauguration ceremony at Gotaplatsen and at the championship at the Ullevi stadium. These measurements were compared with measurements performed at the same positions before the championship when no gatherings of peoples were present. The measurements were carried out using two separate sets of measuring equipment, based on different types of antennas and spectrum analyzers.

Results. The power density measured at Gotaplatsen was about 4 times higher during the inauguration than before it. The increase can be seen in figure 1 which shows the total measured power density (80 – 2500 MHz) at Gotaplatsen on August the 6\textsuperscript{th}. The first value shown is measured at 14:00 h, before the inauguration ceremony; the following values were measured at 18:30 h, 20:00 h during the ceremony and at 22:00 h at the end of the ceremony. Despite the increase in power density, the levels were far below the ICNIRP reference levels (the exposure varied between 7 and 16 ppm (parts per million) of ICNIRP’s reference levels). The levels of the electromagnetic fields at the Ullevi stadium were between 30 \% and 84 \% higher during the European Championship, than the week before. The exposure varied between 10 and 40 ppm of ICNIRP’s reference levels. The uplink traffic for GSM 900 at the Ullevi stadium during the championship is shown in figure 2, this should be compared with the traffic measured at the same position before the championship, se figure 3. The total power density for all sources between 80 to 2500 MHz was in the range of a few 100 µW/m\textsuperscript{2} at these measurement points. The dominating sources were downlinks from mobile phone base stations at both Gotaplatsen and Ullevi stadium. Similar results were achieved for both sets of measuring equipment.

Conclusions. The radiofrequency exposure measured in an assembly of more than 30 000 persons did increase up to four times compared to a measurement performed at the same position when only a few persons were present. However the total levels were still low, in the range of a few 100 µW/m\textsuperscript{2}, which is far below the ICNIRP reference levels for the general public. The local SAR exposure from using a mobile phone could be in the range of percents of the ICNIRP basic restrictions, while the measured exposure at these gatherings were just some ppm of the ICNIRP levels. This means that even in large gatherings exposure from the user’s own mobile phone usually will exceed the contributions from the surrounding sources.
### Acknowledgements

We would like to thank Thomas Uddmar for sharing experience and for lending software for the measurements.

**Figure 1.** Measured power density (80 – 2500 MHz) at Gotaplatsen before (14:00 h) and during (18:30 h - 22:00 h) the inauguration ceremony.

**Figure 2.** GSM 900 uplink traffic measured August the 8th, at the Ullevi stadium during the European Athletics Championships 2006. The number of spectators was around 30 000 persons.
Figure 3. GSM 900 uplink traffic measured August the 1st, at the same position at Ullevi stadium as in figure 2. This measurement was done before the European Athletics Championships 2006 when the arena was not used.

6-4 Long term effects of microwaves from GSM mobile phones on the rat brain

Jacob Eberhardt\textsuperscript{1}, Arne Brun\textsuperscript{3}, Gustav Grafström\textsuperscript{1}, Lars Malmgren\textsuperscript{4}, Bertil Persson\textsuperscript{1}, Leif G. Salford\textsuperscript{2}
\textsuperscript{1}Lund University, Lund, Sweden \textsuperscript{2}Lund University, Lund, Sweden \textsuperscript{3}Lund University, Lund, Sweden \textsuperscript{4}Lund University, Lund, Sweden

Objectives. In a recent study, we found signs of neuronal damage in the rat 28 and 50 days after a 2 hours exposure for GSM microwaves at 900 MHz with SAR < 0.2 W/kg. The object of the present investigation is to investigate in the rat long term effects on the brain of repeated exposures to GSM mobile phone radiation. For this purpose, the occurrence behavioral changes, leakage of the blood-brain barrier, neuronal damage and signs of premature aging after a one year period of weekly 2 hour exposures to radiation from a GSM mobile phone at different intensities is studied.

Methods. 48 male and female Fischer 344 rats were exposed or sham exposed for two hours once a week for 55 weeks in TEM-cells to radiation from a software programmable GSM-900 mobile telephone. The animals were awake during the exposure and could move and turn within the exposure chamber. The peak output power fed into the TEM cells were 5 or 500 mW, resulting into average whole body specific absorption rates of 1 or 100 mW/kg.
A further 8 animals served as cage controls: The latter stayed undisturbed in the animal facility during the whole period of the investigation. 3 weeks after the last exposure, all animals were subjected to two different behavioral tests: (i) the Open Field test for testing exploratory and motor behavior as well as anxiety, and (ii) the Episodic-like memory task for testing episodic memory and novelty preference [6]. After the behavioral testing period, the animals were anaesthetized and sacrificed by perfusion-fixation with 4% formaldehyde. Brain slices were stained for RNA/DNA with cresyl violet. Applying albumin antibodies (Dakopatts), albumin in the brain tissue and albumin uptake into neurons is revealed. Antibodies to glial fibrillary acedic protein reveal fibrils in astrocytes and gliosis. Gallyas silver staining demonstrates silver positive structures such as tangles in degenerated neurons and plaques plus dystrophic neurites. Luxol fast blue stains myelin. Lipofuscin pigment in neurons is shown by Sudan Black B. Synaptic defects can be demonstrated by synaptotofysin antibody staining.

Results. The occurrence of blood-brain barrier leakage and damaged (dark) neurons in different parts of the brain were judged semi-quantitatively by the neuropathologist. No increased number of albumin foci or dark neurons were found in exposed animals as compared to sham-exposed. Analyses of cytoskeleton changes, gliosis, myelin pathology, aging effects in neurons and synaptic function are in progress. The Open Field test revealed no effect of exposure on exploratory and motor behavior. The episodic memory test revealed worse short-term memory for exposed animals as compared to sham exposed animals.

Conclusions. The fact that no leakage of the blood-brain barrier and occurrence of dark neurons could be demonstrated in the present study, in contrast to earlier studies of our group with in which these parameters were studied 14, 28 and 50 days after one single exposure, might indicate that some adaptation of the CNS to repeated exposures can occur. However, temporal order memory was affected in our study, in the same way, but to a lesser extend, as in the group of understimulated "cage controls". This change in cognitive behavior might be caused by premature aging of the CNS of the exposed animals. For that reason, we investigate the possibility of occurrence of morphological signs of premature aging. The results of these analyses will be presented at the meeting.

Acknowledgements. Grants from The Swedish Council for Work Life and Social Research and the Hans and Märit Rausing Charitable foundation are gratefully acknowledged.
**6-5 EFFECTS OF 900 MHZ FIELDS ON THE CHEMOTACTIC RESPONSE OF HUMAN NEUTROPHILS TO GRADIENTS OF C-AMP**

Frank S. Barnes

1University of Colorado at Boulder, Boulder, CO, USA
2University of Colorado, Boulder, CO, USA
3University of Colorado, Boulder, CO, USA
4University of Colorado, Boulder, CO, USA
5University of Colorado, Boulder, CO, USA

**Objectives.** To improve our understanding of the effects of electric and magnetic fields at radio frequencies on the chemotactic response of human neutrophils.

**Methods.** We use the previously described strip diffusion technique,(GJ. Grimes, FS. Barnes. 1973. A technique for studying chemotaxis of leukocytes in well-defined chemotactic fields. Experimental Cell Research 79:375-385.) to establish a concentration gradient of a chemoattractant CAM-P. After active neutrophils have been observed moving up the concentration gradient a radio frequency field at 900MHz is applied via a modified strip line to the thin film of serum containing a delute mixture of red and white blood cells. Well isolated white blood cells (neutrophils) are located on the microscope slide and observed for several minutes. If these cell are observed to be moving up the concentration gradient of C-AMP they are tracked for about 15 minutes. An RF field at 900MHz is applied at approximately 0.4V/m and the motion of the cells are plotted for approximately 15 minutes. Then the RF fields are removed.

**Results.** Exposures to approximately 88.4 µW, with an electric field of 0.392 V/M in the fluid resulted in a change the direction and velocity of these cells in approximately 75 % of the cells that are tracking a known concentration gradient of C-AMP. Under the RF radiation, the neutrophil’s speed increased by about 50% above the speeds at the same temperatures without the RF being applied. Using the data for the temperature range from approximately 36°C to 41oC the average velocity for 60 cells without RF exposure was \( <v> = 3.13 \mu m/minute \) and the standard deviation \( \sigma = 1.08 \mu m/minute \). With the exposure of approximately 0.4 V/m at 900 MHz the average velocity for 47 cells was \( <v> = 6.46 \mu m/minute \) and \( \sigma = 0.88 \mu m/minute \). The estimated probability that this shift in the average speed occurs by chance gives value for p 10-4. The estimated temperature rise in the solution under the cover slip due to RF exposure was less than 10-6 oC and measured to be less than the 0.1 oC resolution of our measuring equipment. The thermal time constant was calculated to be 250 µs for a solution thickness of 10µm.

**Conclusions.** We believe these results are unlikely to be the result of thermal heating by the RF fields and that farther study will be needed to understand how RF fields can effect this part of the human immune system.

**Acknowledgements.** We appreciate the financial support of the students, their parents and the University of Colorado
6-6 "GERMAN MOBILE TELECOMMUNICATION RESEARCH PROGRAMME:" GENE REGULATION AT THE BBB IN VITRO FOLLOWING RF-EMF EXPOSURE

Helmut H. Franke¹, Volkert Hansen², Andreas Bitz², Volkert Hansen², Peter Young¹
¹University Hospital Münster, Münster, Germany ²University of Wuppertal, Wuppertal, Germany

Objectives. We have previously reported on the lack of effects of RF-EMF according to UMTS or GSM standards on the blood-brain barrier in vitro. As those studies focussed on selected parameters such as tight-junction proteins and barrier properties we now aim to extend the view by applying an hypothesis free approach. Therefore the focus of the actual study is to determine alterations in gene expression at the BBB in vitro following RF-EMF exposure in order to gain new insight in potential molecular targets and involved pathways affected due to RF-radiation.

Methods. Primary cultures of microvascular rat brain endothelial cells (RBEC) serve as in vitro model of the BBB. A characterization of this BBB-model had been carried out previously and was presented on BEMS 2006 (Cancun, Mexico). These cell cultures have been exposed to either a generic GSM1800 or UMTS-signal at SAR levels of 0.4, 1.0, 3.0 and 8.0 W/kg with sham exposed controls performed in parallel, both as quintuplicates. For this purpose two radial waveguides were used, each allowing exposure or sham-exposure of 5 samples of RBEC. Temperature of the cell culture medium and the field strength were permanently monitored. A positive control was introduced by heating the cell cultures to 40°C without EMF exposure.

After exposure of the BBB-model for 72h, the RNA was extracted from each individual cell sample using the Qiagen RNeasy Micro Kit, stored at -80°C and later hybridised onto the Affymetrix GeneChip (R) Rat Genome 230 2.0 Array. Quality control of RNA samples was carried out on Agilent Bioanalyzer LabChip-Kits. Data obtained after scanning the gene chips are evaluated statistically by means of bioinformatics software tools. Up- or downregulation of genes will be quantified and the regulation of selected genes will be verified by RT-PCR.

Results. Having established and characterized an in vitro model of the BBB derived from rat and set up an exposure device we could start exposing RBEC cultures to UMTS and GSM1800 RF-EMF. The exposure was typically started 5 days after isolation of the cells and continued permanently for 72h. The integrity of each cell monolayer could be verified by examination under a phase contrast microscope prior and after exposure. An excellent quality of the generated RNA samples was confirmed by RIN (RNA integrity number) values ranging from 8-10, mostly being close or equal to 10. Temperature surveillance revealed a negligible heating effect for the lower SARs whereas exposure at 8 W/kg elevated the culture medium temperature to 38°C. For this reason we decided to include a control group of cells maintained at 38°C but without RF-exposure. Changes in gene expression are currently evaluated an will be ready for presentation on the conference.
Conclusions. In the present study we examine the influence of radio frequency electromagnetic fields emitted by mobile phones on the blood-brain barrier by screening for differential gene expression with chip arrays. Identification of regulated genes will provide further insight on the target of RF-EMF interaction at the BBB and potentially help describing a mechanism at the molecular site.

The high efficiency of detecting changes with gene chip arrays will not only help to identify these molecular targets which are difficult to be predicted entirely by other methods, but also provide an excellent basis for analyses addressing changes in protein expression, functional assays of BBB related transporters, determination of dose-response ratios and a threshold of the biophysical interaction.

Acknowledgements. The study is part of the German Mobile Telecommunication Research Programme and we would like to acknowledge financial support by the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS).

6-7 MOBILE PHONE AND STRESS BIOMARKERS IN HUMAN VOLUNTEERS

René de Seze1, Albert Tasteyre2, Caroline Derome3, Cheikh Diack1, Yolène Thomas2, Guy Simoneau4, Valérie Ferriole3, Patrice Cagnon5, Hertsel Adhoute3, Jean-Emmanuel Gilbert2


Objectives. The present study was undertaken to investigate whether a 900 MHz GSM mobile phone signal exposure during normal use conditions could modulate biomarkers from blood, saliva and exhaled air. Of note, an exploratory pilot study indicated the feasibility of such study.

Methods. Twenty four non-smoking volunteers (12 men, 12 women) aged 20-35, not submitted to a stressed way-of-life neither intense sport, entered the study. Volunteers were randomly exposed either to a mobile or to a sham condition with no signal present. Each exposure lasted for 30 min and were double blind—that is, neither participants or researchers were told which time of response was present in which testing session. The following biological parameters were measured: hsp70 in saliva (ELISA, Stressgen, ref EKS-700B), alcans and halogeno-alcans in exhaled air (system Exp’Air (R)), MDA by HPLC and SOD, GPX (enzymatic activity) in red blood cells. Unfortunately, HSP70 measurement was not performed since the new formulation of the HSP70 ELISA kit, used in this study, failed in-house validation for use in saliva. Three samplings were performed before and after different times post exposure (exhaled air: 1st hr following exposure; saliva: 2nd hr following exposure; blood: within two hrs following exposure). Analysis was performed in two steps: 1)look
for identifying two different groups in measured values (categorisation for each parameter); 2) analyze differences in exposed and sham groups by paired t-test.

**Results.** Eighteen volunteers finished the study. Attribution to two groups was checked with respect to exposure recordings. Because the study just ends up before the abstract deadline, statistical analysis is still in progress but the final results will be presented at the meeting.

**Acknowledgements.** This study has been supported by Bouygues Telecom and France Telecom R&D

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**6-8 LACK OF ACTIVATION OF HSP27- AND HSP70-DEPENDENT STRESS RESPONSE IN HUMAN SPERMATOZOA EXPOSED TO 900MHZ GSM RADIATION**

Nadia Falzone¹, Carin Huysers², Francois le Roux Fourie³, Daniel R. Franken⁴, Dariusz Leszczynski⁵

¹Tshwane University of Technology, Pretoria, South Africa ²University of Pretoria, Pretoria, South Africa ³Standards South Africa, Pretoria, South Africa ⁴University of Stellenbosch, Cape Town, South Africa ⁵STUK, Helsinki, Finland

**Objectives.** Several studies have highlighted the possibility that radio-frequency electromagnetic fields (RF-EMF) used in mobile phone technology could influence DNA integrity of male germ cells (Aitken et al., 2005) as well as sperm motility (Davoudi et al., 2002; Fejes et al., 2005; Erogul et al., 2006). We have previously reported that 900MHz GSM exposure resulted in altered sperm motility parameters (BEMS, 2006; manuscript submitted). RF-EMF had no effect on DNA fragmentation, or apoptotic parameters (manuscript in preparation). However, we have observed that 900MHz GSM radiation caused a significant decrease in sperm area (cell shrinkage).

In the present study we have investigated the hypothesis that the sperm cell shrinkage could be caused by 900MHz GSM radiation-induced activation of stress response (Hsp27 & Hsp70). Hsp27 is known to be involved in stress fiber stabilization which controls cell size and shape (cells shrinkage & cell spreading), and in this way could account for the cell shrinkage noted in exposed spermatozoa.

**Methods.** Ejaculated, density purified, human spermatozoa obtained from donors (n=12) were exposed to 900MHz GSM mobile phone radiation at two specific absorption rate levels (SAR 2.0 and 5.7 W/kg) and examined at various time points post exposure. Hsp27 and Hsp70 expression and activity were analyzed using specific antibodies and flow cytometry as well as Western blot analysis. Stress fiber stabilization (F-actin polymerization) was visualized using fluorescent labeled phalloidin. As a positive control F-actin polymerization due to RF-EMF and heat shock was assessed in MCF-7 cells.
**Results.** RF-EMF had no effect on Hsp27 expression and phosphorylation or Hsp70 expression as determined by flow cytometry and Western blot analysis. Visual assessment of stress fiber stabilization after RF exposure in sperm cells did not show any increased F-actin accumulation in cells. In positive control experiments, heat shock but not RF-EMF exposure caused a significant increase in actin accumulation, aggregation and cell shrinkage in MCF-7 cells.

**Conclusions.** RF-EMF exposure did not induce a Hsp27- or Hsp70-dependent stress response in human spermatozoa. Therefore, it is likely that the sperm cell shrinkage observed at exposures of 2.0 and 5.7 W/kg, might be the result of an alternative non-Hsp27-dependent mechanism.

**Acknowledgements.** This Research was funded by the National Research Foundation & Mobility fund, Pretoria, South Africa (Grant No: 2054206) and by internal funds of STUK. Dosimetry support was provided by K. Jokela & T. Toivo, NIR Laboratory, STUK, Helsinki, Finland. R. Nylund and H. Tammio of STUK are thanked for the Western blot analyses.
Objectives. Can we physically manipulate functions of membrane proteins; especially the active transporters? This is a fascinating question which has attracted many scientists and engineers. Recently, we applied the physics concept of an electronic synchrotron in accelerating electronic beam to the biological system and considered activation of the pump molecules as a dynamic entrainment procedure. We developed a new technique that we call synchronization modulation (1), with which we realized significant activation of the Na/K pumps by a well designed oscillating electric field. The technique consists of two steps: synchronization of pump molecules to work at the same pace, and then gradually modulate their pumping rate to higher and higher value.

Many pumps, or carrier-mediated ion-exchangers, such as the Na/K pumps, move one kind of ions out of cells by exchanging another kind of ions. Microscopically, in each running loop, there should be two current components: outward current representing the outward ion-transport and inward current representing the inward transport. However, due to randomly running pace, the two components cannot be distinguished in the steady-state current measurements. For example, the Na/K pump extrudes 3Na ions and pumps in 2 K ions in each pumping cycle. The available pump currents measured from a normal running mode only show a unidirectional outward current without distinguishable inward component.

Methods. Based on available experimental results, the Na-extrusion and the K-influx in a pumping loop happen in a sequential pattern and move ions in the opposite directions. Transport of ions across the cell membrane requires energy to overcome the ionic concentration gradients of the cells and the membrane potential. We cannot change physiological ionic concentration gradients, but we can manage the membrane potential, therefore to control the energy barrier for the transports. Because two ion-transports moving ions to opposite directions, and therefore, have opposing voltage-dependence, we designed a special oscillating electric field which treats the Na- and K-transports differently so that alternatively change the energy barriers for the two transports.

As a result, the Na-extrusion will be trapped into positive half-cycles while the K-pumping in into negative half-cycles. In other words, pumping loops of individual pump molecules are forced at the same pumping pace as the field frequency.

Results. As a result, the synchronized pump currents show a separated outward and inward pump currents representing the Na-extrusion and K-pumping in, respectively. The magnitude of the outward pump currents is about three times of that from the randomly paced pump molecules. Magnitude ratio of the outward over the inward currents shows
about 3:2, which reflects the stoichiometric number of the Na/K pump molecules (Figure). As long as synchronized to an oscillating electric field, by gradually increasing the oscillating frequency, we are able to force the pump molecules to higher and higher pumping rate. By this way, we are currently able to accelerate the pumping rate up to eight-folds. This technique has been applied to different cells such as skeletal muscle fibers, mammalian cardiomyocytes, and PC 12 cell line in different experimental conditions such as without any channel blockers, treated by electroporation or hypoxia environment (2-4). The results showed that by synchronization modulation of the Na/K pump molecules, we are able to increase the ionic concentration gradient across the cell membrane and to hyperpolarize the membrane resting potential even at those severe non-physiological conditions.

**Conclusions.** Synchronization and modulation of pump molecules not only show a practical technique to physical manipulate the pump functions, but also provides a new method to study the functions of the pump molecules. To the best of our knowledge, this study is the first to realize entrainment of individual pump molecules by organizing their pumping pace and controlling their pumping rate. In the view of thermodynamics, these results mean that by wisely providing electrical energy we are able to organize individual pump molecules to work in the same pace which reducing disorderness or entropy of the biological system, and to accelerate the ion transport ions against their electrochemical potential differences. This technique may lead to development of a practical method to maintain and recover the ionic concentration gradients which is often lost during emergence such as injury or diseases.

In addition, the energy requirements of the Na/K pump molecules can constitute 20-80% of the cell=s resting metabolic rate depending on the extent of electrical activity of the tissue. Our body can only absorb energy through a food chain to generate ATP molecules in Krebs cycle. People dream that one day we are able to directly fuse the pump molecules. Our technique and experimental results in electrical synchronization and activation of the Na/K pump molecules allow us moving further toward this goal.

**References:**
1. Patent Pending

**Acknowledgements.** Acknowledgement: This study is partially supported by the research grants from National Institute of Health (NIH), 2R01 NIGM50785, and National Science Foundation, NSF 0515787.
7-2 THE GLYCOCALYX MAY SERVE AS AN ELECTROMECHANICAL TRANSUDER FOR WEAK, LOW-FREQUENCY ELECTRIC FIELDS

Francis X. Hart
The University of the South, Sewanee, TN, USA

Objectives. The glycocalyx is a network of glycoproteins that covers the exterior surface of endothelial cells. Weinbaum and his colleagues have described\(^1\)\(^2\) how the glycocalyx can serve as a mechanotransducer of fluid shear forces because of its coupling to the cytoskeleton. I propose that because these glycoproteins carry a significant negative charge, they can also serve as transducers of applied electric fields. Previously, I have suggested\(^3\) that cell surface integrins play such a role. Here, I use Weinbaum’s basic model in which the glycocalyx is represented as a hexagonal array of long, circular rods. In an alternating electric field a charged rod will oscillate about its cytoplasmic linkage point, subject to viscous drag from the surrounding fluid and a restoring force produced by the membrane. This response can be characterized as a damped, driven oscillator governed by the equation

\[ I \frac{d^2Q}{dt^2} + c \frac{dQ}{dt} + K Q = T_o e^{iwt}, \]

where \( Q \) is the angular displacement at time \( t \), \( I \) is the moment of inertia of the rod about the linkage, \( c \) is the rotational damping factor, \( K \) is a rotational restoring torque constant, and \( T_o \) is the magnitude of the applied electrical torque. \( w = 2\pi f \), where \( f \) is the frequency of the applied field. The maximum angular displacement is then

\[ Q_o = \frac{T_o}{\sqrt{(K-Iw^2)^2 + c^2w^2}}. \]

The figure illustrates the variation of \( Q_o \) with frequency for an applied electric field amplitude of 10 V/m and reasonable parameter choices for frog mesenteric capillary cells (fm) and hamster cremaster (hc) cells. According to Weinbaum’s model 27 rods form a cluster at each cytoplasmic linkage. The maximum rotational energy, given by \( T_o Q_o \) for one rod, is about \( 10^{-23} \) J for a fm rod cluster and \( 6x10^{-22} \) J for a hc rod cluster. These values are somewhat less than \( kT \sim 4x10^{-21} \) J. However, many clusters are linked in sequence along the actin cortical cytoskeleton so that the overall energy transferred to the cytoskeleton should be well above the \( kT \) limit.


Results. na

Conclusions. na
7-3 PHASE LOCKING OF PEROXIDASE-OXIDASE OSCILLATIONS DURING STIMULATION WITH PULSED LIGHT

Jeffrey J. Carson\textsuperscript{1,2}, Kristy Commerford\textsuperscript{1}, Poonampreet Sekhon\textsuperscript{1}
\textsuperscript{1}Lawson Health Research Institute, London, ON, Canada \textsuperscript{2}University of Western Ontario, London, ON, Canada

\textbf{Objectives.} The peroxidase-oxidase (PO)-NADH oscillator generates dynamical behaviour that is qualitatively similar to oscillatory processes found in biological systems \cite{1}. It is an excellent laboratory model for proof-of-concept experiments on basic questions regarding the interaction of biological systems with their environment. For example, several groups have investigated the response of the PO-NADH oscillator to external stimuli such as modulation of the rate of reactant inflow \cite{2}, exposure to a static magnetic field \cite{3}, illumination with constant light \cite{4}, and illumination with pulsed light \cite{5}. These studies determined that the oscillation amplitude decreased in response to magnetic and photo stimuli. In the case of pulsed illumination, both positive and negative transients in oscillation amplitude and periodicity were observed depending on the initial conditions. The objective of the present study was to extend our previous work with pulsed illumination by measuring the phase-dependent response of periodic PO-NADH oscillations to pulsed light. Specifically, we examined the dependence of the PO-NADH oscillator response on the duty cycle of the pulse waveform.
Methods. Experiments were performed in a quartz cuvette temperature-controlled to 28.0±0.1°C as described previously [4]. With the apparatus, we observed stable periodic oscillations for several hours as periodic variations in the concentration of dissolved oxygen, NADH, horseradish peroxidase and its oxidized forms such as Per$^{6+}$. The cuvette was illuminated with light from a current-controlled red LED (656 nm, FWHM = 20 nm). Light was diffused evenly before reaching the cuvette. The average irradiance was 450 $\mu$W/cm$^2$ as determined with a calibrated detector and meter. During each experiment, the illumination was first held constant at 450 $\mu$W/cm$^2$ for 1000 s, and then the light intensity was modulated ± 430 $\mu$W/cm$^2$ about 450 $\mu$W/cm$^2$ for 3000 s. The modulation waveform was a symmetric biphasic square pulse. The pulse width was specified by a duty cycle parameter, which represented the ratio of the biphasic pulse width to the repetition period. For each experiment, the repetition period was computed from the average oscillator period recorded during the 1000 s of constant illumination. The onset of pulsed illumination was controlled. The rising edge of the first light pulse coincided with the falling edge of the Per$^{6+}$ waveform, which was taken as a phase difference of 0 degrees. By convention, the phase difference was measured as the difference in time between the drop in Per$^{6+}$ and the rising edge of the pulsed light normalized to the average oscillator period obtained under conditions of constant illumination. The phase difference was converted to units of degrees by multiplication by 360.

Results. Fig. 1 summarizes the results from 52 experiments on the average phase difference between the Per$^{6+}$ waveform and the pulsed illumination for a range of duty cycle conditions. The reported average phase difference was computed from the individual phase differences during illumination pulses numbered 10 through 49. For duty cycles over the range from 0.3-1.0, phase-locking of the Per$^{6+}$ waveform to the pulsed illumination was always observed. However, for an intermediate range of values, the final locked phase difference was either positive or negative (0.6-0.8). At low values of duty cycle, (<0.3) phase locking was not observed.

Conclusions. The results demonstrated that pulsed red light could be used to control the timing of PO-NADH oscillations. Phase locking of the PO-NADH oscillations was obtained for a wide range of duty cycles. The disappearance of phase locking at low values of the duty cycle suggested the existence of a threshold where pulsed light was no longer effective at controlling the PO-NADH oscillations. The exact value of the duty cycle threshold was not determined but appeared to be within the range of 0.2-0.3. The identification of a threshold response to a modulated stimulus suggested that the underlying molecular mechanism governing PO-NADH oscillations was sensitive to the duration of the biphasic stimulus. This feature of the PO-NADH oscillator may be useful in uncovering details of the reaction mechanism that are not available through passive spectroscopic measurements.

References:

**Acknowledgements.** This work was supported by the Canadian Institutes of Health Research (CIHR).

**Figure 1.** Dependence of periodic PO-NADH oscillations on duty cycle of a pulsed light stimulus. Each symbol and error bar represents mean ± SD.
LARMOR PRECESSION CAN ACCOUNT FOR FREQUENCY AND AMPLITUDE DEPENDENCIES OF BIOEFFECTS FOR ANY PARALLEL AND/OR PERPENDICULAR COMBINATION OF WEAK AC AND DC MAGNETIC FIELDS.

Arthur A. Pilla\textsuperscript{1,2}, David J. Muehsam\textsuperscript{1}
\textsuperscript{1}Columbia University, New York, NY, USA \textsuperscript{2}Mount Sinai School of Medicine, New York, NY, USA

Objectives. There is significant evidence that both low frequency sinusoidal magnetic fields, which induce electric fields well below the thermal noise threshold, and weak static magnetic fields, for which there is no induced electric field, produce biologically and clinically significant effects. In these cases the stimulus must clearly be the magnetic field, rather than the electric field. We have previously shown that a Larmor precession model (LPM) can describe the effects of weak exogenous magnetic fields on the dynamics of ion binding. Here it is shown that LPM can predict the resonance effects reported to follow both the ion cyclotron and ion parametric resonance models, even in the simultaneous presence of parallel and perpendicular DC magnetic fields.

Methods. Larmor precession describes the effects of exogenous magnetic fields on the dynamics of one state of ion binding, ions already bound, through precession at the Larmor frequency. The angular area swept by the precessing oscillator in the binding site, and thus time required to reach orientations affecting reactivity, will be a complicated function of AC and DC amplitudes, frequencies, and the relative geometric orientation of the fields. The model predicts resonance conditions for combined AC and DC magnetic fields at the Larmor frequency and harmonics, such as the cyclotron frequency. In the simple case of parallel AC/DC field combinations, the results are remarkably similar to reported experimental verifications of IPR, such as those of Koch (2003). However, LPM also makes predictions for combined AC and DC fields in perpendicular orientation. The relative parallel and/or perpendicular orientation of the AC and DC fields is shown to be a critical determinant for the location of resonances and, therefore, the strength and direction of expected bioeffects. The complex resonance behaviors are shown in fig 1. Specific combinations of AC and DC fields can either increase or decrease time required to reach a reactive orientation, and thus the reactivity of the system (see fig 2).

Results. The results for perpendicular and combined parallel/perpendicular field orientations predict experimental frequency dependencies that are not predicted by the Ion Cyclotron Resonance (ICR) or Ion Parametric Resonance (IPR) models. For example, Fitzsimmons (1994) demonstrated a resonance for a parallel AC/DC field combination chosen according to ICR predictions for Ca\textsuperscript{2+}. However, a significant perpendicular DC magnetic field was also present. LPM, as presented here can account for these results. Another study (Diebert, 1994), which showed augmented bone repair in a rabbit model using parallel AC/DC field combinations, according to ICR predictions for Ca\textsuperscript{2+} and Mg\textsuperscript{2+}, was also performed in the presence of a significant perpendicular DC field. Interestingly, this study, which follows LPM predictions, led to a currently available clinical device for recalcitrant fracture repair.
Conclusions. The Larmor precession model suggests a mechanism for extremely weak AC and DC magnetic field effects that explains a wide variety of resonance conditions observed experimentally. The complexity of these resonance conditions is due to the inherent geometrical information encoded in the AC/DC field combination, suggesting that a wide variety of precessing targets may exhibit similar responses to specific applied field combinations. One such result suggests that fields can be configured to actually prohibit the bound oscillator from reaching a reactive position in the binding site. If this possibility is verified by experiment, a non-invasive treatment for pathologies such as ectopic bone formation and malignancies without side effects could emerge.

* 7-5 MICRODOSIMETRY ON CELLS: THE RELEVANCE OF STOCHASTIC DIELECTRIC MODELLING

Caterina Merla, Micaela Liberti, Francesca Apollonio, Guglielmo D’Inzeo
ICEmB at University of Rome ”La Sapienza”, Rome, Italy

Objectives. The evaluation of electromagnetic (EM) field distribution at cellular level is strongly needed in order to get a proper quantification of the exposure, extremely useful both in theoretical studies of interaction mechanisms and in experimental activities. In a previous EM analysis the fundamental role of a proper dielectric modelling of cell structure has been stressed especially in the RF and MW range [1]. Usually the adopted models are extracted from experimental measurements through a non linear least square fitting procedure with reference to Effective Medium Theory (EMT) [2]. This methodology, being based on precise measurements, accurately determines uncertainty of the final estimated dielectric values, evidencing the need of considering the stochastic distribution of the dielectric model parameters inside their uncertainty range. In this work the role of stochastic dielectric modelling in microdosimetric problems has been analyzed using a quasi-static Laplace equation on a multilayered sphere. A statistical analysis of the dielectric properties of cell compartments has been applied considering independent random extraction of the dielectric parameters with normal distributions. The variability of the field strength distribution in...
sub-cellular compartments could be a key point in a realistic evaluation of the EM dose absorbed in microscopic biological structures.

**Methods.** Three-layered spheres, composed by the extra-cellular medium, the membrane and the cytoplasm, model the biological cells. Each layer has been characterized with a Debye modelling to take into account the frequency dependence [1]. To extract the Debye parameters two steps have been followed: first dielectric constant measurements on erythrocyte solutions from different healthy donors have been obtained; secondly a proper formulation of the EMT, taking into account cell morphological parameters, has been applied in inverse way [2]. The Debye parameters have been considered as stochastic variables with normal distribution inside the uncertainty range coming from the estimation procedure. The analysis has been carried out both considering a stochastic dielectric model only for the plasmatic membrane layer and considering a full stochastic dielectric model of the biological cell. Random extractions of the whole cell dielectric model have been performed, and the EM field has been solved with the Laplace equation considering different dielectric properties of cell compartment at different frequencies.

**Results.** In a first step of the study we have determined the optimal realizations number to fully take into account the intrinsic variability of the stochastic variables. The greatest variability of the field values has been obtained in the plasmatic membrane layer, where the E field results to be a random variable with a non Gaussian distribution (fig. 1). A comparison between the E field value obtained with the deterministic cell model and the mean value of the distribution has evidenced some differences. For the stochastic E field it is evident an asymmetric distribution with high values of the kurtosis. The dispersion of the distribution resulted greater at frequencies of about 100 MHz, where a noticeable standard deviation has been observed. This is due to the high variability of the randomly extracted dielectric values of the membrane at a frequency near the mean value of its relaxation frequency \( f_{\text{relmemb}} = 187 \pm 70 \text{ MHz} \). The same kind of analysis has been realized for the fields in the cytoplasm and in the extra-cellular medium. For these layers a lower variability has been observed; this is mainly related to the higher dielectric values of cytoplasm and extra-cellular medium, which imply lower sensitivity of the E field with respect to the dielectric values fluctuations.

**Conclusions.** In this work we focused our the attention on the role of stochastic dielectric modelling of sub cellular compartments in the determination of E field values in such regions. A complete analysis at different frequencies has been realized considering first the stochastic dielectric model of a single layer and later of all the cell layers. Particularly the analysis has been turned to the plasmatic membrane since the E field in this layer has revealed particularly sensitive to permittivity variability. This study suggests that the stochastic analysis in the dielectric modelling of cell compartments can represent an efficient and useful tool in the realistic evaluation of the E field in biological targets.

**References:**


Objectives. The detailed comprehension of interaction mechanisms between electromagnetic (EM) fields and biochemical reactions within molecular structures is of great interest in bioelectromagnetic research, since it may represent the first interaction step of possible induced effects. Nevertheless, the nature and the actual role of the interaction between EM and biochemical systems is still an open problem. Proteins are fluctuating structures, with their own charges, which in principle may couple to an external EM field. In this context, the use of advanced computational chemistry techniques may allow to understand, in a quantitative way, the EM field action on biochemical processes.

Here, we tackled the problem of ligand binding to protein active site in presence of an exogenous microwave (MW) field, by mixed quantum-classical calculations. In particular, the aim was to evaluate if a MW field could alter the energy for binding or unbinding reaction
as catalysts do in enzymatic reactions, or alternatively if it could be able to modify the absorption spectrum of the protein.

**Methods.** Myoglobin (Mb) was chosen as target molecule since it is a well-known protein [1], often used as a model system for studying chemical reactions in proteins. The binding process of carbon monoxide (CO) to Mb was analyzed by a mixed quantum-classical methodology, the Perturbed Matrix Method (PMM) [2, 3]. PMM allows to evaluate the electronic quantum states of a reaction centre interacting with an atomic-molecular environment, via merging standard quantum calculations, with classical molecular dynamics (MD) simulations. In a previous article [4] PMM was used to describe CO-Mb binding/unbinding reaction in water. In the present work we performed the same calculations including the effect of a continuous wave (CW) EM-MW exogenous perturbation.

In order to compare the exposed and unexposed systems we first evaluated the binding and unbinding free energy barriers for CO-Mb reaction. At the same time an in-depth analysis of Mb internal motions by means of essential dynamics (ED) method [5] was performed. ED analysis identifies the relevant modes responsible for most of the conformational fluctuations in the protein. Usually, few number of modes are sufficient to describe the protein internal motions. In Mb the first 10 (essential) modes were used for a comparison between exposed and unexposed systems as they accounted for more than 75% of the total fluctuations. Another parameter used in ED analysis is the root mean squared inner product (RMSIP). RMSIP is an index representing the convergence of the simulated trajectory; it is always ≤1, and the higher the RMSIP, the higher the protein stability. Finally, the CO bound Mb absorption spectrum was evaluated to compare the exposed and unexposed systems.

**Results.** By using different sets of exposed (CW, f=1 GHz and amplitude of $10^3$ and $10^4$ V/m) and unexposed simulations we obtained the mean binding and unbinding free energy barriers of the reaction with the corresponding noise. In Table I we compared such mean values for the exposed and unexposed conditions in order to evaluate if the EM field provides any significant effect on the free energy. A similar procedure was used to compare RMSIP and the mean fluctuations per mode. We used $3\sigma$ (corresponding to a 99.7% confidence) as the limit to identify statistically significant differences. From our data no relevant variation in both the reaction free energy barriers as well as in the conformational fluctuations and modes is observed when an EM field is applied. Finally, we also evaluated the absorption spectra of the exposed ($10^3$ and $10^4$ V/m) and unexposed systems focusing on the Soret band at about 370 nm. No significant absorption changes were induced by the EM field.

**Conclusions.** MW field action on the molecular complex Mb-CO ligand was studied with molecular simulations. Detailed statistical analysis shows that neither ligand binding properties nor conformational fluctuations are significantly altered by MW exposure (1 GHz, $-E-\leq 10^4$ V/m). Binding and unbinding barriers values did not even differ significantly for both longer temporal durations (40 ns) and EM field amplitudes up to $10^7$ V/m, comparable with atomic field intensities. This confirms the extremely high stability of myoglobin with respect to external EM perturbations. The same methodology will be applied to study the EM field effects on other biomolecular processes (e.g. enzymatic reactions).

**References**
7-7 EFFECTS OF RADIOFREQUENCY ELECTROMAGNETIC FIELD ON SURVIVAL OF YEAST CELLS UNDER HEAT TREATMENT

Sachiko Yoshie\textsuperscript{1}, Masateru Ikehata\textsuperscript{1}, Atsushi Saitou\textsuperscript{2}, Saki Hiromoto\textsuperscript{2}, Yukihisa Suzuki\textsuperscript{2}, Toshio Hayakawa\textsuperscript{1}, Masao Taki\textsuperscript{2}
\textsuperscript{1}Railway Technical Research Institute, Tokyo, Japan \textsuperscript{2}Tokyo Metropolitan University, Tokyo, Japan

Objectives. Recent advances in various technologies in wireless communication, transportation and medical devices, etc. increase opportunities for exposure to various electromagnetic fields (EMFs) in general public and working environment. However, since the biological data that related to evaluation of health effects of EMFs have not been sufficient yet, people are growing concerns about possible adverse health effects of EMFs. Against the backdrop of these heightened concerns, WHO conducts ”the International EMF Project” to evaluate scientific findings related to biological effects by EMFs exposure since 1996. Recently, Bisceglia \textit{et al.} (BioEm2005) reported that yeast culture grown under radiofrequency electromagnetic fields (RFs) exposure exhibited the ability to tolerate thermal stress greater than that of unexposed culture. However, relationship of the biological effect and dosimetry of RF has been unclear. In this study, we used cylindrical waveguide-type in vitro exposure apparatus which electromagnetic and thermal dosimetry in exposure space were well characterized by Sonoda \textit{et al.} (IEICE Trans. Commun., E88-B, 3287-3293, 2005) to investigate athermal biological effects of 2.45 GHz RF on survival rate after fatal heat treatment in budding yeast.

Methods. Budding yeast \textit{Saccaromyces cerevisiae} ATCC2601 (wild-type strain) was used as the tester strain. The RF exposure apparatus employed a cylindrical waveguide as a basic structure. This exposure apparatus was designed for exposing 2.45 GHz RF to cells suspended in liquid medium in a petri dish with 90 mm in diameter. Temperature of the bottom of culture dish was strictly controlled by mounting the petri dish on a temperature control unit using the Peltiert element. In this study, continuous wave of 2.45 GHz RF was used for exposure and spatial average of specific absorption rate (SAR) on the bottom surface (where cells were located) of the petri dish was estimated at 50 W/kg. The incubation temperature during RF exposure was examined to minimalize the effect of temperature fluctuation on survival rate of the tester strain following fatal heat treatment. Overnight culture of the tester strain in MRS broth was used for RF exposure experiment. Using an aspirator, $8 \times 10^7$ cells were retained on surface of a membrane filter (Millipore Co., 0.22 $\mu$m}
pore size, 90 mm diameter), which was then placed face down on the bottom of a petri dish. Then, 38.1 ml of fresh MRS broth was poured gently onto the petri dish. It enabled us to hold the cells on the bottom of the dish and to regulate SAR during the RF exposure. Following RF exposure for one hour, aliquot of cell suspension were left on ice for longer than 5 min and then incubated at 45, 46, 47 or 48°C for 5 min using thermal cycler as the heat treatment. After the heat treatment, cell suspension diluted accordingly was poured onto YPD agar plates and then incubated at 30°C. After the incubation for two days, colonies were counted as independent survival cells and the survival rate to non-heated cells was determined.

Results. 1. Effect of incubation temperature before heat treatment on survival rate: Before RF exposure experiment, it was important to investigate how incubation temperature during RF exposure affected to the survival rate by heat treatment in the tester strain. Therefore, survival rates following heat treatment at 47 or 48°C were examined using each culture incubated at 23-37°C. In the temperature range from 23 to 27°C, survival rates after heat treatment were almost same, whereas significant increase in survival rate was observed above 27°C and higher conditions. This result suggested that incubation temperature higher than 27°C before heat treatment led to heat tolerance of the tester strain and even the thermal fluctuation within 0.5°C above 27°C might cause artifact. Consequently, we decided on the temperature during RF exposure as 25°C to avoid artifact by thermal fluctuation and to investigate athermal effects of RF exposure. 2. Effect of RF exposure on heat tolerance of tester strain: The ratios of survival rate in RF-exposed cells to that in unexposed (control) cells after heat treatment were 0.79±0.03, 0.72±0.04, 1.44±0.93 and 1.88±1.29 for heat treatment at 45, 46, 47 and 48°C, respectively. In the heat treatment at 47 and 48°C, survival rate in RF exposed cells was slightly higher than that in unexposed cells occasionally. However, survival rate of cells exposed and unexposed to RF were almost same after lower heat treatment at 45 and 46°C. Considering that only a few percent of cells survived after heat treatment at 47 or 48°C, these thermal conditions were almost fatal for the tester strain. These results suggested that RF exposure might have triggered to increase heat tolerance only under the fatal heat treatment condition. On the other hand, since SAR level exposed in this study was dozens of higher than that of normal environment, which people might be exposed to, it was also suggested that there would be few biological effects of RF exposure in actual environmental exposure condition.

Conclusions. In this study, survival rate of yeast cells after heat treatment at 45-48°C was used as index to examine possible biological effects of RF. The results suggested that exposure to RF (2.45 GHz, SAR 50 W/kg, continuous wave) might have slightly increased heat tolerance of cells under subsequent fatal heat treatment. In the future study, other biological indices such as expression of mRNA and/or proteins related to heat shock protein family should be investigated to understand mechanism of the RF effects on biological systems.
Objectives. Our objective is to measure the conductivity of DNA at microwave frequencies using a doubly-resonant cylindrical cavity and thus avoid the ambiguity of unresolved questions concerning contact effects and charge injection into the DNA helix. Understanding the nature of electronic motion along a DNA double helix is important for the research of a wide range of biological processes such as the repair of damaged bonds in cells, detection of mutations, and protein-DNA interactions. Numerous experimental and theoretical studies of charge transport in DNA have been carried out. However, the electronic properties of DNA remain very controversial. Understanding the conductance of a complicated polyelectrolytic aperiodic system is by itself a major scientific problem. Most of the published work so far reports quasistatic measurements of conductivity obtained at dc to 1 MHz. A reliable microwave frequency measurement of DNA conductivity would serve to test mechanisms of conductivity.

Methods. Resonant cavities are a high sensitivity tool for measuring material properties of biological samples. In cavity perturbation measurements one measures the change in the width of resonance and the resonant frequency which occur due to the introduction of a sample into the resonant structure. If the perturbation is small enough, the material properties of the sample can be determined from the measured changes in the cavity characteristics.

We are using a doubly-resonant cylindrical microwave cavity1, 2 to measure and understand the conductivity of DNA double helix at 900 and 1800 MHz. The cavity is designed to resonate on the TE111 mode at the first frequency (∼890 MHz) and on the TE113 mode at the second frequency (∼1780 MHz). Another important feature of this cavity is that its quality factor $Q (=\text{energy stored/energy dissipated in a signal cycle})$ remains high ($Q>1000$) when it is loaded by the sample. This technique does not require contacts to be attached to the sample. The conductivity (the real part of the complex conductivity) is evaluated from the measured loss of this highly sensitive resonant cavity operating at these two frequencies. The sample is placed in the high electric field region at the center of the cavity and the resulting change in the quality factor $Q$ of the cavity is measured. $Q$ is inversely proportional to the losses in the cavity, and the loss due to DNA sample is evaluated from the change (decrease) of $Q$ upon introducing the sample. The relative dielectric constant is measured by the shift of the resonant frequencies of the cavity. The design of our cavity enables us to test for the nonlinear RF demodulation of the sample simultaneously with the conductivity tests at 900 MHz.

For exposure in a cylindrical cavity, the ideal shape of a sample is a disk with a radius less than one quarter of the radius of the cavity and with thickness very much smaller than the primary cavity dimensions. Typical sample radius is less than 10 mm and typical thickness is below 1 mm in our tests. Therefore we may assume that the samples are exposed to a uniform electric field and the loss is due to the motion of electric charges along the DNA...
strands. The first test samples we measure are samples of randomly oriented (with respect to the direction of the applied electric field) DNA segments. The tests are done on dry DNA samples, DNA in buffer, and buffer alone. Conductivity measurements on oriented DNA samples, parallel and perpendicular to the polarized electric field, offer more insight into the actual charge transfer mechanisms.

**Results.** The results of these measurements will be presented and discussed.

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Session 8: Magnetic Field Effects

8-1 EFFECT OF 100 MT STATIC MAGNETIC FIELD ON [CA$^{2+}$]$_C$ RESPONSE TO ATP IN HL-60 CELLS FOLLOWING GSH DEPLETION

Michelle Belton$^1$, Camilla Rozanski$^{1,2}$, Frank S. Prato$^{1,2}$, Jeffrey J. Carson$^{1,2}$
$^1$Lawson Health Research Institute, London, ON, Canada $^2$University of Western Ontario, London, ON, Canada

Objectives. Calcium is an important ion in all biological systems. Often these systems involve signal transduction cascades in which a molecule such as ATP binds to a receptor on the plasma membrane. This in turn activates second messengers which interact with ion channels on the endoplasmic/sarcoplasmic reticulum resulting in the emptying of the intracellular calcium stores[1]. The influx of calcium ions into the cytosol results in an increase in cytosolic calcium concentration ([Ca$^{2+}$]$_C$). Changes in [Ca$^{2+}$]$_C$ can be influenced by external factors such as a static magnetic field (SMF)[2,3]. One hypothesis suggests that a SMF affects the cell through the radical pair mechanism. Through this mechanism a SMF affects the spin of electrons in free radicals, which may lead to changes in chemical reaction kinetics and possibly alter cellular function[4]. By reducing the number of antioxidant molecules like glutathione (GSH) the proportion of free radicals in the cell is increased and may lead to a greater probability of a biological response to a SMF. The purpose of this study was to determine if the [Ca$^{2+}$]$_C$ response to ATP was affected by depletion of GSH and the absence or presence of a 100 mT SMF.

Methods. Undifferentiated HL-60 cells were loaded with Fura-2 AM. Cytosolic free calcium concentration was measured in real time using a ratiometric fluorescence spectroscopy system with a circulating 37°C water bath and constant stirring. Cells were acclimated in the system for 1200 s at which point 1, 7.5, 10 or 15 mM of diethyl maleate (DEM) was added directly to the cells to deplete GSH. At 2700 s, cells were either sham or field exposed (100 mT) and challenged with 10 $\mu$M ATP at 3000 s. The field was removed at 3480s and a fluorescence calibration was performed by the addition of Br-A23187 followed by EGTA. Statistical analysis was done using a two way ANOVA with replication and a two sample t-test assuming equal variances.

Results. Following the addition of DEM [Ca$^{2+}$]$_C$ rose by 17 - 34% with a greater increase observed at higher [DEM]. The addition of ATP resulted in an immediate increase (peak) in [Ca$^{2+}$]$_C$ followed by a gradual recovery to pre-ATP levels. Two way ANOVA revealed a statistically significant effect of DEM on average [Ca$^{2+}$]$_C$ peak height. The effect of DEM was to decrease the magnitude of the ATP-dependant peak in [Ca$^{2+}$]$_C$ as [DEM] increased (Fig. 1). However, no statistically significant effect of SMF on average [Ca$^{2+}$]$_C$ peak height or interaction between DEM and SMF on average peak height was found. But, examination of the data suggested that an effect of SMF might be present at 10mM DEM (a post-hoc T-test showed statistical significance). Analysis of the full-width-half-maximum (FWHM)
of the ATP-induced peak did not reveal any significant differences or statistical interaction between [DEM] and SMF.

**Conclusions.** The data show that \([\text{Ca}^{2+}]_c\) was elevated following treatment with DEM with greater \([\text{Ca}^{2+}]_c\) at higher [DEM]. The \([\text{Ca}^{2+}]_c\) response to ATP was decreased as the [DEM] increased. This may have been explained by slow emptying of the intracellular stores by DEM. Less \(\text{Ca}^{2+}\) in the stores at the time of ATP addition might explain the smaller \([\text{Ca}^{2+}]_c\) response to ATP following DEM. When the SMF was applied to the cells the average \([\text{Ca}^{2+}]_c\) peak appeared reduced at 10 mM DEM as compared to sham exposed cells and a similar trend was observed at 15 mM (however, the conclusion requires verification by additional experiments). There may be a threshold in the [DEM] at which point enough GSH has been depleted to change the concentration of free radicals in the cell. With more free radicals available to be influenced by the SMF an effect might be observed. It is important to note that this may not be a direct effect on \(\text{Ca}^{2+}\) but may be an indirect effect on one of the many signal transduction cascades which influence \([\text{Ca}^{2+}]_c\). Further work needs to be done to determine the GSH concentration after treatment with different [DEM]. Additionally, although the T-test was significant at 10 mM, the ANOVA was not and so more experiments are required to verify the effect of SMF on \(\text{Ca}^{2+}\).

**References:**

**Acknowledgements.** Supported by funds from the Canadian Institutes of Health Research (CIHR)
Figure 1. Effect of a static magnetic field (SMF) of 100 mT vs. 0 mT on the average peak $[\text{Ca}^{2+}]_c$ in HL-60 cells following treatment with diethyl maleate at 1200 s and activation by ATP at 3000 s. Each bar with error represents the group mean ± S.E.M. Each SMF-exposed and sham exposed group included 3 experiments. Asterisk denotes statistical significance. Cells were exposed or sham exposed for 300 s in the absence of ATP and for 600 s after the addition of ATP.
8-2 EFFECTS OF A STATIC MAGNETIC FIELD ON SEIZURE THRESHOLD IN BLACK SWISS MICE

Qinkun Zhang, Stefan Engstrom, Michael J. McLean
Vanderbilt University, Nashville, TN, USA

Objectives. To determine protective effects of a static magnetic field (SMF) consisting of a strong gradient component perpendicular to the local field vector against audiogenic seizures in Black Swiss mice.

Methods. Black Swiss mice were obtained from Taconic, Hudson, New York USA. These mice have age-dependent audiogenic seizures (AGS) with maximal sound sensitivity at 20-30 days of age. Animals were handled in accordance with standards of the National Institutes of Health and methods approved by the Vanderbilt University Institutional Animal Care and Use Committee. Magnetic field pretreatment was accomplished with a previously described water-cooled, static magnetic field (SMF) exposure device built with commercially available coils around four ferromagnetic cores in a square array. The coils were wired such that polarity alternated. A constant current power supply energized the coils. All mice were kept in perforated tubes prior to experiments. Different groups of mice served as controls or were treated with SMF for 60 min (B=5.27 mT, gradB (perpendicular) = 0.24 T/m; values averaged over head volume) before experiments. For acoustic stimulation, freely moving mice were observed in a closed chamber. A speaker in the lid delivered constant white noise at intensities of 70-120 decibels (dBC). Untreated AGS evolved from wild running (WR), to loss of righting (LOR) and clonic jerks (CLO) in almost all animals. In some, the seizures were more severe and evolved into tonic hindlimb extension (THE) and death (DEA).

Results. SMF pretreatment significantly raised seizure threshold and increased the number of mice with no seizures in response to sound as compared to age-matched controls (p < 0.007; Fisher’s exact test; p < 0.006, Kolmogorov-Smirnov test). Once threshold was reached in treated mice, seizure activity progressed through CLO and did not differ from controls.

Conclusions. SMF pretreatment significantly protects Black Swiss mice against audiogenic seizures. This effect is predominantly elevation of seizure threshold without modifying seizure severity once threshold is reached. Reduction in seizure severity has been observed in two other models in which we have studied effects of similar SMF. This range of anticonvulsant effects supports development of static magnetic devices for the treatment of human epilepsy.
Figure 1. The figure shows cumulative distributions of mice exhibiting clonus at a given sound level (abscissa). The sound levels are reported in amplifier values - they translate to levels in the range 87-115 dBC. "X" denotes animals that did not exhibit clonus at the strongest sound stimulus.

*8-3 A REVIEW OF SEVERAL EXPERIMENTS IN GEOMAGNETIC SHIELDING AND ANALGESIA IN MICE

John A. Robertson\textsuperscript{1,2}, Frank S. Prato\textsuperscript{3,2}, Dawn C. Desjardins Holmes\textsuperscript{1}, Lynn D. Keenliside\textsuperscript{1,3}, Alex W. Thomas\textsuperscript{1,2}

\textsuperscript{1}Lawson Health Research Institute, London, ON, Canada \textsuperscript{2}University of Western Ontario, London, ON, Canada \textsuperscript{3}Lawson Health Research Institute, London, ON, Canada

Objectives. Previously, we have described several experiments in which mice were kept in a Mu Metal box which shielded them from the Earth’s magnetic field. After several consecutive days of this shielding for 1 hour per day, an analgesic effect was observed that peaked on day 5. This abstract will review the overall progress of the last few years in our laboratory.

Methods. Male Swiss CD-1 mice (45-60 days old, Charles River) were kept on 12 hr light/dark cycles with ad libitum access to food and water. Their response latencies were tested before and after exposure with a hotplate at 50°C. The time to an aversive response (foot lift, shake, lick, or escape jump) is recorded as the "latency" – increasing latencies correspond to analgesia (i.e.: decreased sensitivity to noxious heat). Exposure consisted of placing the mice in a variety of different enclosures. All enclosures were lined with Plexiglas on the inside to provide a consistent environment, and mice were kept in standard "shoebox" type acrylic animal cages within the enclosures. Enclosures (33 x 38 x 20 cm)
were either plain Plexiglas (sham condition, no shielding of electric or magnetic fields), Mu Metal (which attenuates both the static and time-varying components of the magnetic field as well as shielding external electric fields), or for some experiments, copper (which shields only the electric and high frequency external fields).

Each enclosure box had eight 2.5 cm diameter ventilation holes, one at each of the four corners (1 cm from edges) on both the top and bottom surfaces. A Mu Metal (or copper, for the non-Mu Metal enclosures) cylinder (2.5 cm high) surrounded each hole, shielding the ambient magnetic field orthogonal to the enclosure surface. For some of the experiments, the enclosures were kept dark, while for others light was delivered via the ventilation holes in the bottom of the boxes with LED arrays and an acrylic reflector/diffuser.

Merrit-like coil inserts (4 rectangular coils per box) were also used in some experiments to reintroduce magnetic fields within the enclosures.

**Results.** Many sets of experiments have been performed investigating the various dimensions of the geomagnetic field shielding-analgesia effect. In its most basic form, we have found that post-exposure latencies were significantly increased (i.e.: significant analgesia) after repeated exposures with Mu Metal enclosures. This effect peaked on day 5 and subsided by day 8.

We have found that the effect is at least partially opioid-mediated, being significantly attenuated by administration of the opioid antagonist naloxone. The analgesia seen on day 5 from Mu Metal shielding alone is equivalent to that seen from a 5 mg/kg i.p. injection of morphine; on day 6 the Mu Metal exposure significantly augmented the analgesic effect of the morphine in combined treatment.

The effect has also been found to be light-dependent. The analgesic effect is not observed when light is present in the Mu Metal enclosures. Interestingly, this effect appears to have a dose-response, with the effect being gradually attenuated by gradually increasing amounts of light. It is also wavelength-dependent, with blue light attenuating the effect while red light does not.

Reintroducing a time-varying magnetic field that mimics the background fields of the laboratory (that is, the time varying geomagnetic field along with a substantial 60 Hz + harmonics component) within the Mu Metal enclosures also attenuates the effect, indicating that it is the shielding of the time varying magnetic fields (as opposed to the static component of the geomagnetic field) that is responsible for the effect. Simply shielding the electric or very high frequency fields with a copper enclosure had no effect. Interestingly, when the reintroduced magnetic fields are at a strength that is substantially higher than what is normally found within the laboratory, the analgesic effect is seen again, indicating that a change in the magnetic field environment of the mice produces the effect, whether this is "hypogeomagnetic" or "hypergeomagnetic".

**Conclusions.** We have found that the "mouse in a box" paradigm is a robust tool for investigating the behavioural effects of magnetic field shielding. It is very interesting that this analgesic effect arises after repeated exposures to a shielded environment, and that it is light-dependent. Furthermore, the light spectrum appears to depend on the visual acuity of the mouse: red light, which the mouse cannot see (or can only see weakly) has no
effect, while blue light does. This indicates that the retina may be involved in the light-dependence, as if it were an interaction with a substance or structure deeper in the brain, then red light would be expected to have the greater effect as it has a greater penetration depth. Also of note is that the reintroduced fields that attenuated the analgesic effect were on the order of 100 nT, very weak compared to the static component (approx. 50 µT).

Acknowledgements. We would like to thank Adrian Koziak and Jennifer Hensel for their assistance with these experiments. We would also like to thank the Canadian Institutes of Health Research, the Ontario Research and Development Challenge Fund, the Lawson Health Research Institute, and the Canadian Natural Sciences and Engineering Research Council for funding.

8-4 EFFECTS OF HIGH MAGNETIC FIELDS AND FIELD GRADIENTS IN THE DEVELOPMENT, STRUCTURE AND SIGNALING OF MICE FOETUS NEURONS

Oscar Céspedes, Osamu Inomoto, Shoichi Kai, Shoogo Ueno
Kyushu University, Fukuoka, Japan

Objectives. We study the effects of static magnetic fields (up to 8 T) and magnetic fields varying in time and space (up to 100 T/m and 100 T/s) in the structure and dynamics of developing and grown neurons from rat’s foetus. Our aim is to identify and separate the effects of ionic displacement and piezoelectric distortion in the axon growth, the structure of the cytosolic membranes and the intercellular communication, in particular the synaptic connectivities between neurons (or junctions to the astrocytes) and the physiological correlation (or synchronization) changes under the field. We also perform luminescence measurements to determine the variations in the apoptosis death rate of the neurons in function of the presence of magnetic fields.

Methods. We use three different setups to distinguish between the Lorentz force on the transported ions and charged molecules (dependent on the amplitude of the field), the magnetic drag force (dependent on the product of magnetic field and magnetic field gradient) and the magnetically induced electrical potentials and piezoelectric effects (dependant on the variations of the magnetic field with time and space).

In the first setup we place samples at different positions in the 70 cm bore of a cryomagnet with 24 cm long superconducting coils. At its center the field is of up to 8 T and the magnetic field gradient negligible, whereas at the edge of the superconducting coils the magnetic field is of 4 T and the gradient is 100 T/m (giving a total maximum product of 400 T²/m) and at 20 cm from the center, where the magnetic field is much smaller but the magnetic gradient is still of order 20 T/m. In the second setup we use an small permanent magnet to create a configuration with relatively high field gradients of up to 3 T/m but an small
product of about 0.05 T^2/m on top of which the cells are cultured for up to two weeks. Finally, we use a magnetic coil and a power generator to create an AC magnetic signal of the order of 1 mT and a temporal gradient of up to 100 T/s.

We study the cell development under the different magnetic fields by real-time optical microscopy and perform statistical analysis on the dynamics of axon length and the formation/deformation of synapses. More detailed studies on the axon thickness and ramification are performed via electron microscopy. For the intracellular events, we observe structural aspects such as the distribution of actin-/microtubulin- filaments and elasticity of cytosolic membranes, and some physiological indexes such as intracellular calcium concentration and molecular conformation studied via Fourier-Transform Infrared Spectroscopy.

**Results.** Preliminary results show that even if high static fields in the Tesla range are required to have an effect in the neural structure, neurons grown under fields of some 50 mT with field gradients of about 1 T/m seem to develop faster, with a comparatively denser net after 10 days of culture. Most of the cells subjected to high magnetic fields die after 24 hours of exposure even if the temperature is kept constant at 37 C. Those who remain alive show thicker and much longer axons, sometimes grown along the magnetic field direction (see Figure 1).
Figure 1. Rat embryo’s neurons grown with 10% serum during 10 days; a) development without magnetic field b) under a magnetic field of 50 mT with a gradient of 2 T/m. c) and d) Images of neurons cultured for 10 days and then submitted to a field of 400 T² m⁻¹ for 30 hours. All images correspond to an area of 0.3 x 0.3 mm. The arrows indicate the field direction.

8-5 SPATIAL GRADIENT EFFECTS OF 120 MT STATIC MAGNETIC FIELD ON ENDOTHELIAL TUBULAR FORMATION IN VITRO

Hideyuki Okano¹,², Naohide Tomita¹, Yoshito Ikada³
¹Kyoto University, Kyoto, Japan ²PIP Tokyo Co., Ltd., Tokyo, Japan ³Nara Medical University, Kashihara, Japan

Objectives. This investigation is designed to investigate the effects of a moderate-intensity gradient static magnetic field (SMF; 120 mT [B_max] with the maximum spatial gradient of 28 mT/mm) on tubular formation by application of the peak gradient to a target site of culture wells.
Methods. Cell Culture:
Endothelial tubular formation was evaluated using an angiogenesis kit (KZ-1000; Kurabo, Osaka, Japan) as described previously [Okano et al., 2006].

Static Magnetic Fields (SMF):
Gradient SMF exposure was carried out using a disc-shaped magnet (NdFeB; Magna, Tokyo, Japan) as described previously [Okano et al., 2006].

For peak gradient exposure in the peripheral part, the maximum magnetic flux density \( B_{\text{max}} \) was 120 mT at the center of the well. The peak gradient value \( G_{\text{max}} \) within a well was 21 mT/mm at the periphery of the well. For peak gradient exposure in the central part, the \( B_{\text{max}} \) was 120 mT at the periphery of the well (Fig.1). The \( G_{\text{max}} \) was 28 mT/mm near the center of the well (shown by an arrow, Fig.2), at which the \( B_{\text{max}} \) was 20 mT.

Uniform SMF exposure at 20 mT or 120 mT was performed using a plate-shaped magnet (NdFeB; Magna, Tokyo, Japan). Sham exposure was performed using sham magnets.

Experimental Procedures:
Five experimental groups of 25 samples each were examined: (1) sham exposure (control); (2) peak gradient exposure in the peripheral part; (3) peak gradient exposure in the central part; (4) uniform exposure to 20 mT; (5) uniform exposure to 120 mT. The SMF or sham exposure was carried out for 10 days. Photomicrographs of tubular cells immunostained with an anti-CD31 antibody were analyzed after culture at 37°C for 10 days as described previously [Okano et al., 2006].

Image Analysis:
As parameters of tubular formation, the mean values of 'the area density', 'the length' and 'the number of bifurcations' were compared between the groups as described previously [Okano et al., 2006]. The measurement area of each well was divided into two parts: the central part and the peripheral part. As a specific case, in the peak gradient exposure in the central area, the peripheral part indicates the overlapping area of the two circles: 'the inner circle of a magnet' and 'the outer circle of a well' (shown by 'P', Fig.1A).

Statistical Analysis:
Two-way ANOVA was performed and Dunnett’s multiple comparison test and Wilcoxon rank sum test were used as post hoc tests. All values are expressed as mean ± SEM. A difference of \( P < 0.05 \) was considered statistically significant.

Results. Effects of Gradient SMF on Tubular Formation:
Applying the peak gradient to a target site of culture wells significantly promoted tubular formation in terms of the area density (Fig.3) and the length of tubules in the peak gradient part of the wells, compared with the sham exposure. However, the gradient did not induce any significant change in the number of bifurcations in any part.

Effects of Uniform SMF on Tubular Formation:
For uniform exposure to 20 mT or 120 mT, the uniform SMF did not induce any significant change in all the parameters of tubular formation in any part.

Conclusions. Gradient SMF significantly promoted tubular formation in the peak gradient part of the wells, whereas uniform SMF did not. These findings suggest that the gradient portion of SMF could be responsible for the observed biological responses.
REFERENCE:

**Figure 1.** Fig. 1. A. A magnet. B. Magnetic flux density.

**Figure 2.** Fig. 2. Magnetic gradient.
8-6 EFFECTS OF MAGNETIC FIELDS ON BIOCHEMICAL REACTIONS

Joergen B. Pedersen, Martin J. Hansen, Nikita N. Lukzen, Aqlexander B. Doktorov
University of Southern Denmark, Odense M, Denmark

Objectives. To determine to what degree magnetic fields and especially rf-fields can influence biochemical and biological reactions and whether such effects can conceivable be hazardous to human health.

Methods. Numerical and analytic solutions of the relevant model equations for the radical pair mechanism.

Results. The RPM is a well established mechanism for magnetic field effects on chemical reactions and it has been used to obtain detailed information on the intermediate radical pair step in such reactions. The good agreement between experimental results and accurate solutions of the model equations proves that model calculations can be used to provide reliable estimates of the effects; In most cases even more accurate than experimental measurements that may be extremely difficult to carry out. This procedure allows us to consider a large range of systems and types of reactions.

Our results for the influence of rf-fields, radiated from mobile phones, on biochemical reactions are divided into four different types of reactions.
1. Reactions in liquids, where the radicals are free to diffuse apart. Such reactions show no measurable effect of the weak rf-field radiated by mobile phones.
2. Reactions on membranes are characterized by a very slow diffusion and a reencounter probability equal to one in the absence of scavengers. These characteristics give rise to
a very large effect of magnetic fields. However, there are several conditions that must be satisfied in order to have an effect of a rf-field. The frequency of the field, i.e. 900 MHz or 1800 MHz, must be in resonance with an electron spin transition. This requires that the radicals have very large hyperfine constant, much larger than the most common values. Another condition is that the lifetime of the radical pair must be long, i.e. scavenging must be slow; Such reactions are rare.

3. Reactions of types 1 or 2 may show an enlarged effect if the reaction scheme includes chain reactions. An example is the lipid peroxidation which is described by a complicated set of reaction steps that include chain reactions. This leads to bifurcations and under some conditions the reaction explodes. We have determined the trigger point and is investigating its dependence on magnetic fields.

4. Enzyme reactions or electron transfer reactions often involves radicals in fixed spatial positions and metal radical ions with large hyperfine constants. Such reactions have the potential to be affected by magnetic fields. The phosphorylation by ATP synthase has been observed to have a very large isotope effect


**Conclusions.** No observable effects of rf-magnetic fields, corresponding to mobile phones, are found for radical pair reactions in liquids or on membranes. Enzyme reactions and chain reactions can show an effect. The phosphorylation by ATP synthase depends strongly on the isotope and the magnetic field.

**Acknowledgements.** This work has been partially supported by a research grant from the Danish Council for Strategic Research under the program, Non-ionizing radiation, and INTAS grant No. 05-100008-8070.
which the perpendicular line through the midpoint of the figure-of-eight coil intersects the surface of cortex, has commonly been defined as the stimulating site in TMS. However, the stimulating site determined in such a way is not supposed to be plausible because electric field induced in TMS is dispersed over the brain vectorially in contrast to the localized stimulation with an electrode in electrical stimulation. Simulation studies with nerve model revealed that the induced electric field parallel to the longitudinal axis of the axon is effective for the stimulation and stimulation occurs at the end of the axon. Pyramidal neurons which are the input and output neurons in the cortex are aligned perpendicular to the cortical surface. On the basis of these understandings, it seems reasonable to suppose that the site on a cortex with a large component of the induced electric field perpendicular to the cortical surface is the stimulating site where nerve excitation readily occurs in TMS. We have proposed the method based on this idea for accurate estimation of the stimulating site in TMS by using the information of the anatomical brain structure obtained from MRI data. The validity of this method has been confirmed with the experiments of TMS which elicited motor evoked potentials.

In this study, we developed a precise locating system using the theory for accurate estimation of the stimulating site in TMS, which includes measurement systems for locations of a brain and a stimulation coil. This system is composed of a multi-articular arm for positioning the stimulation coil and a 3-D scanner for detection of the brain position.

**Methods.** [I. METHOD FOR PRECISE ESTIMATION OF STIMULATING SITE IN TMS]

The basic unit of the cerebral cortex is the cylindrical column containing pyramidal neurons perpendicular to the cortical surface. The simulation studies also showed that the induced electric field parallel to the straight axon like pyramidal neuron is most effective for the nerve excitation. According to these understandings, the relative intensity of nerve stimulation in TMS corresponds to the strength of the component of the induced electrical field perpendicular to the cortical surface. The component of the electric field perpendicular to the cortical surface can be calculated with computation of the dot product of the electric field and the unit vector perpendicular to the cortex surface detected from MRI of a brain.

If the information of the coil position relative to the brain is obtained, the distribution of the induced electric field can be calculated, and the stimulating sites in the cortex can be estimated precisely by finding the sites with large magnitudes of component of the electric field perpendicular to the cortical surface. Therefore, it is necessary to measure the position of the stimulating coil and the brain for accurate estimation of the stimulating sites in TMS.

We developed the precise locating system for the stimulating coil and brain described as the following.

[II. LOCATING SYSTEM FOR TMS]

We used a 3-D scanner (Danae D100, NEC Engineering Corp., Tokyo, Japan) in order to measure the position of the subject’s head. The positional information about the surface of the subject’s face was obtained with the 3-D scanner. The information of the brain position relative to the subject’s head was acquired from the 3-D MR image of the head. The coordinates of 3-D MR image were transformed to the coordinates of the 3-D scanner by minimizing the sum square error of the distance between pixels in the face in 3-D MR image and corresponding points in the face measured with the 3-D scanner. The positional data
of the brain was registered with referring to the face location measured with 3-D scanner. We produced a multi-articular arm system for positioning the stimulation coil. The arm system has seven joints at which the angular positions are measured with rotary encoders. The location and angular information of the stimulation coil was calculated with the angles of the respective joints and lengths of the respective arms in the system.

**Results.** The validity of the system was examined by experiments of TMS which elicited motor evoked potentials (MEPs) at upper limbs. TMS was carried out with a Magstim 200 magnetic stimulator (Magstim, Whitland Dyfed, UK). TMS was delivered through a figure-of-eight coil over the left primary motor cortex. MEPs were recorded from the right first dorsal interosseous (FDI) muscle with Ag/AgCl electrodes. The estimated site with the maximum stimulating intensity lay within the hand area of the primary cortex when the largest amplitude of MEP at FDI was elicited at 20ms post-stimulus.

**Conclusions.** We developed the precise positioning TMS system consist of a 3-D scanner and a multi-articular system. This system enables to estimate stimulating site in the cortex accurately by using the theory that the component of the induced electric field perpendicular to the cortical surface is substantial stimulating intensity.

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**8-8 GENE FROM MAGNETOTACTIC BACTERIA PROVIDES NOVEL MAGNETIC RESONANCE IMAGING (MRI) CONTRAST AGENT**

Frank S. Prato\(^1,2\), Donna Goldhawk\(^1\), Cheryl McCreary\(^4\), Rebecca McGirr\(^1\), Savita Dhanvantari\(^1,2\), David Hill\(^1\), Terry Thompson\(^1,2\), Claude Lemaire\(^3\), Alex W. Thomas\(^1,2\), Robert Z. Stodilka\(^1,2\)

\(^1\)Lawson Health Research Institute, St. Joseph’s Health Care, 268 Grosvenor Street, N6A 4V2, London, ON, Canada \(^2\)University of Western Ontario, 1151 Richmond Street, N6A 5B8, London, ON, Canada \(^3\)University of Waterloo, 200 University Avenue West, N2L 3G1, Waterloo, ON, Canada \(^4\)Hotchkiss Brain Institute, University of Calgary, Suite 2129, 3330 Hospital Drive NW, T2N 4N1, Calgary, AB, Canada

**Objectives.** MRI has been limited as a cellular and molecular imaging technique because it lacks contrast agents known as reporter gene probes (RGP). These are gene constructs that produce a distinctive imaging signal when expressed in a given cell and tissue. Such RGP have been created for optical imaging by co-opting insect genes (firefly luciferase) and for radioisotope imaging by co-opting viral genes (thymidine kinase). The possibility of introducing bacterial genes into cells to create RGP for MRI has been suggested based on the properties of magnetotactic bacteria\(^1\). These fresh water prokaryotes produce iron oxide nano particles, termed magnetosomes, which have a single magnetic domain comparable to super paramagnetic iron oxide (SPIO) particles currently used in MRI. Our goal is to
introduce magnetosome genes into cells and image molecular events associated with the activity of these RGP.

**Methods.** The magnetosome gene MagA was cloned from Magnetospirillum magneticum sp. AMB-1 (American Type Culture Collection) using standard procedures. The 1.3 Kb MagA gene produces an integral membrane protein of approximately 47K molecular weight, with putative iron transporter function. A constitutively expressed EGFP-MagA fusion protein was created by subcloning into the Enhanced Green Fluorescent Protein plasmid (pEGFP). This vector was transfected into mammalian cell lines using Lipofectamine 2000. Protein expression in rat islet cells (INS-1) and mouse neuroblastoma cells (N2A) was evaluated by epifluorescence microscopy. MagA expression was correlated with iron retention using DAB-enhanced Prussian Blue staining. Ultrastructural analysis of transfected cells was conducted using transmission electron microscopy (TEM). Non-invasive imaging of viable cells was performed using a Bruker MRI, equipped with an 11 Tesla magnet.

**Results.** 1. Fluorescence Microscopy of EGFP-MagA Overexpression. Fluorescence microscopy showed cytoplasmic GFP fluorescence, indicating that MagA fusion protein is expressed in each cell type examined.

2. Prussian Blue Staining of N2A Cells. Cells expressing MagA were cultured in media containing 250 µM ferric nitrate. The extent of Prussian Blue staining indicates that MagA expression is correlated with iron retention.

3. TEM of Cells Overexpressing EGFP-MagA. Ultrastructural analysis of transfected cells shows the formation of electron dense, cytoplasmic vesicles in cells overexpressing MagA and cultured under iron-rich conditions.

4. MRI of Cells Overexpressing EGFP-MagA. Cells were sandwiched between layers of gelatin in a Nunc ELISA well. High field MRI was performed at the cell interface (see Figure 1) using a simple gradient echo with a TE of 20ms, and showed some areas of signal loss.

**Conclusions.** The results herein suggest that expression of MagA in mammalian cells is associated with (a) iron retention and the formation of dense core vesicles, and (b) magnetic properties similar to SPIO particles. These data identify the potential use of MagA as a reporter gene probe that will function as an MRI contrast agent. The development of RGP for MRI will permit non-invasive detection of molecular events in cells, tissues and animals. Future applications in human medicine include tracking stem cells as they are transplanted for the treatment of heart disease or diabetes, localizing cancer cells during metastasis, and identifying specific gene expression, such as the activation of heat shock proteins.

The bioelectromagnetics community now has a significant opportunity to introduce magnetic sensitivity into biological systems through the application of magnetosome-derived genes. Further elucidation of other genes from magnetotactic bacteria that affect magnetic sensitivity is expected to enhance iron biomineralization and its detection in mammalian cells by MRI.

**References:**

Acknowledgements. This research was supported in part by the Canadian Institutes of Health Research (CIHR) and in part by the Ontario Research and Development Challenge Fund (ORDCF).

**Figure 1.** MagA gene expression in mammalian cells alters MRI contrast. N2A cells were transfected with MagA and placed under selection in iron-supplemented media. MRI was performed on cells mounted in a gelatin mold using an 11 Tesla magnet and simple gradient echo with a TE of 20ms. Positive (A,B) and negative (A’,B’) images show areas of signal loss in two adjacent planes. A human hair marks the plane of focus. The image resolution is 65x65x125 µm³.
HUMAN EXPOSURE STANDARDS AND HEALTH CONSIDERATIONS

Maila Hietanen
FIOH, Helsinki, Finland

Objectives. Electromagnetic field (EMF) standards are used to specify either limits for emission from a device or limits for human exposure to EMF in a living or working environment. Exposure standards generally refer to maximum levels to which whole or partial body is permitted to be exposed from EMF emitting sources. In addition to international standards, developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronic Engineers (IEEE), several countries have published their own national or local standards. The International EMF Project of the World Health Organization (WHO) has compiled a database which contains worldwide standards limiting exposure to EMF (EMF World Wide Standards Database).

Exposure standards are based on studies from various disciplines of health sciences, including biology, epidemiology and medicine, as well as physics and engineering. Especially important are studies that provide information on biological effects caused by EMF, physical characteristics of sources, human exposure levels, and people at risk. For an effect to be established as a health effect, the evidence from the epidemiological, human volunteer, animal and cellular studies should indicate that an effect occurs. A health hazard is defined as a biological effect that has health consequences detrimental to health or well-being. Annoyance or discomforts caused by EMF exposure may not be pathological but can affect the physical and mental well being of a person, so that the resultant effect may be considered as a health hazard.

It has been recognized that different groups in a population may have differences in their ability to tolerate a particular EMF exposure. Therefore it has been necessary to develop separate guideline levels for different population groups. This has been accomplished by the use of larger safety factors for population groups that have an increased sensitivity to EMF when determining guideline limits. A general approach is to distinguish between members of the general public and working population. In addition, some standards indicate provisions for pregnant women who are occupationally exposed to EMF.

References. ICNIRP. Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics 74(4), 494-522, 1998.
IEEE. C95.1, IEEE standard for safety levels with respect to human exposure to radio

EPIDEMIOLOGY OF MOBILE PHONE AND HEALTH
Naohito Yamaguchi¹, Toru Takebayashi², Suminori Akiba³, Yuriko Kikuchi², Masao Taki⁴, Kanako Wake⁵, Soichi Watanabe⁵, Nadege Varsier⁴, Noriko Kojimahara¹, Satoru Shimizu¹, Ikuko Kato¹, Yasuto Sato¹, Osami Kubo¹, Shigeru Sokejima⁶
¹Tokyo Women’s Medical University, Tokyo, Japan ²Keio University School of Medicine, Tokyo, Japan ³Kagoshima University Graduate School of Medical and Dental Sciences, Kagoshima, Japan ⁴Tokyo Metropolitan University, Tokyo, Japan ⁵National Institute of Information and Communications Technology, Tokyo, Japan ⁶National Institute of Public Health, Wako, Japan

Objectives. The INTERPHONE STUDY aimed at examining the safety of radio-frequency electromagnetic field (EMF) used by mobile phones by epidemiological methods. The study focused on the potential biological effects on the head and neck area, especially on the carcinogenic effects as brain tumors (gliomas and meningioma, in particular), and acoustic neuroma.

Methods. The case-control study was adopted as the study design, in which the association between mobile phone use and disease risk was examined by comparing the past history of mobile phone use between the case and control groups. The cases were those patients, who were identified in the collaborating hospitals and who agreed to participate in the study by written informed consent. In Japan, twenty-four hospitals located in Tokyo and neighboring prefectures consisted of the collaborating hospitals. The case group consisted of patients of age 30-69 and of residents of Tokyo and surrounding areas, who were newly diagnosed as having primary brain tumors or acoustic neuroma during the period of December 2000 to March 2004. One or more controls were selected for each brain tumor case and two or more control for each acoustic neuroma case from disease-free residents by individually matching to each case with regard to sex, age (within 5 years) and residential area (ward or city). The method of control selection varied by country, and the random digit dialing (RDD) method was used in Japan. The participation rate by this RDD method was 53% for face-to-face interview and 75% if controls who agreed to have telephone interview instead of face-to-face interview were included.
The same face-to-face interview was administered to cases and controls. The questionnaire was based on the common core protocol of INTERPHONE STUDY. The record of mobile phone use was obtained from network operators and used for validation of interview data,
if the participant agreed by informed consent. Clinical Information was collected from participating hospitals.

**Results.** In the study of Japan [Takebayashi et al Occupational and Environmental Medicine, 2006;63:802-807], the number of cases and controls who agreed to participate was 88 cases and 169 matched controls for gliomas, 132 cases and 236 controls for meningioma, and 97 cases and 320 controls for acoustic neuroma. Here, the results for acoustic neuroma were presented. The analysis for gliomas and meningioma will be presented in the meeting. The odds ratio (OR) for regular mobile phone use and acoustic neuroma was 0.73 with the 95% confidence interval (CI) of 0.43-1.23. When the reference date was set at 5 years, the OR was 1.09 with a 95% CI of 0.58-2.06, suggesting again that mobile phone use was not likely to increase the risk. There was no increasing trend in ORs in association with cumulative years of use or cumulative call time. The OR for using both analogue and digital phones was 1.19 with 95%CI of 0.37-3.79 as compared to digital-only users, indicating no increased risk among users of both analogue and digital phones. As compared to non-users, the odds ratio was estimated at 0.75 with the 95% CI of 0.39-1.46 for the use of mobile phone on the same side as affected ear. By the case-only analysis, the OR was estimated at 0.72, again indicating no association for laterality.

The results of national case-control studies of acoustic neuroma conducted within the INTERPHONE STUDY have been published for Denmark and Sweden. In the Danish study [Christensen et al, Am J Epidemiol 2004;159:277-83], the odds ratio was estimated at 0.9, indicating no increase in risk among mobile phone users. Further analysis did not show any increased risk for mobile phone users with 10 or more years of use, nor any increased risk of disease on the same side of ear as mobile phone use. In the Swedish study [Lonn et al, Epidemiology 2004;15:653-9], on the other hand, 148 cases diagnosed with acoustic neuroma during 1999-2002 were compared with 604 resident controls, and an increased risk was observed for those who had used mobile phone for 10 years or longer. Further, if the comparison was restricted to those who used their mobile phones on the same side of tumor location, the odds ratio was found to increase up to 3.9 with 95%CI of 1.6-9.5. The results of combined analysis of data from Denmark, Finland, Norway, Sweden and the United Kingdom (two study sites) were further reported [Schoemaker et al, Br J Cancer 2005;93:842-8]. The total numbers of acoustic neuroma cases and controls were 678 and 3,553, respectively. No increased risk was observed for regular mobile phone use (odds ratio: 1.0). No increasing trend was identified for increasing cumulative years of use nor cumulative call hours. For those with mobile phone use of 10 years or longer, however, a statistically significant increase in risk was observed for the same side of affected ear in comparison with short-term users; odds ratio was 1.8 with 95% CI of 1.1-3.1.

**Conclusions.** In conclusion, no increase risk was observed for mobile phone use in the case-control study of Japan. The case-control studies overseas reported inconsistent results; some reported increased risk, whereas other not. The overall results of INTERPHONE Study are awaited for further evaluation. In light of the increased risk identified for long-term mobile phone users with experience of 10 year or longer in Sweden, continuing efforts are necessary to examine the risk of long-term mobile phone users, because, in Japan, there have been very few users with the experience of 10 years or loner. In addition, further
studies are needed to examine the possibility of distortion of observed risk caused by recall bias among affected cases as well as differential participation of mobile phone users in cases and control.

THE IMPACT OF MEASUREMENT ERROR AND SELECTION BIAS ON INTERPHONE STUDY RESULTS.

Martine Vrijheid, Elisabeth Cardis, Isabelle Deltour
International Agency for Research on Cancer (IARC), Lyon, France

Objectives. Widespread and increasing use of mobile phones over the past decade has raised concerns about possible health effects of radio frequency fields used in mobile telephony. This has prompted a series of epidemiological studies, particularly focusing on the risk of brain tumours related to mobile phone use. Studies of brain cancer risk related to mobile phone use have used mainly the case-control approach. INTERPHONE is an international collaborative case-control study investigating whether mobile telephone use (specifically radio-frequency field exposure resulting from this use) is related to risk of tumours of the brain and salivary glands (Cardis & Kilkenny, 2000; protocol available at: http://www.iarc.fr/ENG/Units/INTERPHONEStudyProtocol.pdf). Thirteen countries participate in INTERPHONE following a common protocol, making this the largest study of its kind.

Exposure assessments in most case-control studies of mobile phone use and cancer, including INTERPHONE, have relied on participants’ self-reports of phone use, as it is usually impossible to obtain long-term independent records of phone use. Recall errors may arise from errors in such self-reports, in particular from errors in the cumulative amount of phone use reported. In addition, case-control studies may be subject to selection bias when selection of cases and controls into the study is related to the exposure, in the present context to the use of mobile phones. Because the impact of radiofrequency exposure from mobile phones is expected to be small (if it exists) at the individual level, potential recall and selection biases could invalidate or complicate the interpretation of the results.

Extensive validation studies were therefore carried out as part of INTERPHONE to validate phone use reported through standardised personal interviews (Vrijheid et al, 2006a). Further, sensitivity analyses were carried out to investigate the potential impact of recall errors and selection bias on tumour risk estimates (Vrijheid et al 2006b).

Methods. Validation studies
In volunteer validation studies, mobile phone use of 672 volunteers in 11 countries was recorded by operators or through the use of software modified phones, and compared to use recalled 6 months later using the INTERPHONE study questionnaire (Vrijheid et al 2006a). Further validation studies were carried out to address questions regarding long-term recall errors and differences in recall between INTERPHONE cases and controls; these studies
were limited to the few countries where it was possible to collect long-term billing records for cases and controls, but they give important additional information to the short-term volunteer studies.

**Sensitivity analyses**
The impact of recall errors and selection bias on tumour risk estimates was then assessed through Monte-Carlo simulations (Vrijheid et al 2006b). Simulations used exposure distributions based on existing INTERPHONE data and assumed varying levels of the true risk of brain cancer related to mobile phone use. Recall error scenarios simulated plausible values (based on the validation studies) of random and systematic, non-differential and differential recall errors in amount of mobile phone use. Selection bias scenarios assumed varying selection probabilities for cases and controls, mobile phone users and non-users. Where possible these selection probabilities were based on existing information from non-respondents in INTERPHONE.

**Results. Validation Studies**
On average, volunteers underestimated the number of calls per month (geometric mean ratio of recalled to actual use=0.92, 95%CI=0.85-0.99), whereas duration of calls was overestimated (geometric mean ratio=1.42, 95%CI=1.29-1.56). Inter-individual variation was large, and increased with level of use. These studies concluded that volunteer subjects recalled their recent phone use with moderate systematic error and substantial random error. Analyses of the long-term case-control validation studies, focusing on trends in recall errors over time and on differences in recall errors between cases and controls, are underway and will be presented.

**Sensitivity Analyses**
The simulation studies showed that when random errors were large (of the level found in these validation studies) they had a large impact biasing risk estimates for continuous exposure towards a null effect. Further, random errors had a larger impact on the risk estimates than did systematic errors, even when relatively extreme systematic errors were modelled and when the systematic errors simulated differed between cases and controls. Selection bias resulting from under-selection of unexposed controls led to J-shaped exposure-response patterns, with risk apparently decreasing at low to moderate exposure levels.

**Conclusions.** The results of these validation and simulation studies will play an important role in the interpretation of existing and future case-control studies of mobile phone use and cancer risk, including the INTERPHONE study.
Session 9: EMF Exposure and Standards II

9-1 MEASUREMENT OF PHYSIOLOGICAL CHANGES CAUSED BY LOCAL EXPOSURE OF ELF ELECTRIC FIELD.

Masaji Yamashita, Kazuo Ohsaki, Koichi Shimizu

1Hokkaido Institute of Technology, Sapporo, Japan 2Hakuju Institute for Health Science Co.Ltd., Tokyo, Japan 3Hokkaido University, Sapporo, Japan

Objectives. We have studied the biological effects of ELF electric field exposed to a human body using a therapeutic device. In a past study, the effects on a vigilance level and on an autonomic nerve activity were suggested. In this study, the skin temperature and the surface blood flow was measured in the field exposure to clearly identify the effects on an autonomic nervous system.

Methods. A 50 Hz electric field was generated between circular plane parallel electrodes (50 cm dia., 13 cm separation) by applying high voltage (10 kV AC) from the power source of a therapeutic device. In the experiment, the hand and the forearm of the subject were inserted between the horizontal electrodes and kept on the lower electrode. The field strength on the hand and the forearm is estimated from 100 kV/m to 155 kV/m. This strength is in the similar level to that a patient experience with the therapeutic device.

CONDITIONS
Experiments were carried out from 1 p.m. to 6 p.m. in a controlled environment. The room temperature and the humidity were 22-24.5 degrees C and 15-35 %, respectively. The subjects were 21-23 years old healthy male volunteers. The surface body temperature and the blood flow were measured in the following conditions.

Next three experimental conditions were introduced in this study.
Eyes-Closed: 13 subjects were instructed to close their eyes throughout the experiment.
Eyes-Opened: 9 subjects kept their eyes opened in the experiment to sustain a vigilance level.
Body Hair Removed: When the electric field was applied on the body surface, the body hair moved and caused the perception. To eliminate this effect on the measuring parameters, the body hair in the exposure area was removed by applying the hair-remover cream 30 minutes before the measurement in 8 subjects.

MEASUREMENT
The sensor parts of a thermometer and a laser Doppler flow-meter were placed on the dorsum of the left hand with electrical shielding. The electrodes of impedance flow-meter were also set on the left wrist and the left upper arm. A sensor part of a thermometer was placed on the right hand, as well.

Prior to the experiment, the purpose, the possible risks and the procedure of the experiment were explained to each subject, and the consent was obtained. The experiments were carried out in the double-blind method. The time course of the experiment consisted of three sessions, i.e. 15 minutes rest, 30 minutes field exposure and 20 minutes rest periods.
A subject sat on the chair of the therapeutic device. The electric field was applied without any noticeable cue following the rest period. Then the electric field was switched off without any cue, as well. The temporal changes of the temperature and the blood flow were measured in 200 Hz sampling rate. The data were divided into 7 analyzing sections (rest 1, rest 2, expo.1, expo.2, expo.3, rest 3, rest 4) of 5.5 minutes period.

**Results.** Figure 1 shows the temporal variation of the hand skin temperature in the eye-closed condition. Each value was normalized as the difference from the datum value at the onset of the field exposure. A noticeable difference was observed between the exposed and the sham exposed cases. Since the subjects were forced to keep the same posture on the chair, the body temperature naturally decreased in the sham case. This result suggests that the temperature decrease is suppressed by the field exposure.

Similar changes were observed in the eye-opened condition. In both conditions, the temporal changes of the peripheral blood flow and the blood volume agree with these changes. Similar changes were also observed at the right arm, as well. When the body hair was removed from the hand and the forearm, the temporal changes of the exposed case became almost the same as the sham-exposed case.

**Conclusions.** When an electric field around 100 kV/m was exposed to locally to the hand and the forearm, the natural decrease of skin temperature was suppressed with statistical significance. The difference in vigilance level did not alter this effect. Since this effect disappeared in the hair-removed cases, the field perception due to the hair movement can be involved in this effect. Similar temporal change of temperature was observed in another unexposed arm. This suggested the involvement of autonomic nervous system.

![Figure 1. Temporal change of peripheral skin temperatures.](image)
9-2 NATURAL KILLER ACTIVITY IN PERIPHERAL BLOOD LYMPHOCYTES OF WORKERS EXPOSED TO DIFFERENT LEVELS OF ELF-MF

Fabriziomaria Gobba¹, Annalisa Bargellini², Meri Scaringi¹, Giulia Bravo¹, Paola Borella²

¹University of Modena and Reggio Emilia, Modena (MO), Italy ²University of Modena and Reggio Emilia, Modena (MO), Italy

Objectives. Extremely Low Frequency-Magnetic Fields (ELF-MF) are considered possible carcinogenic to humans (Group 2B IARC). Some evidence exists that they can act as promoters or progressors. Since Natural Killer cells (NK cells) play a primary role in inhibiting tumour growth, an effect of ELF-MF on NK activity has been hypothesized. Nevertheless results of research are largely inconclusive: in experimental studies in animals both an increase and a reduction in the number of circulating NK cells have been reported. In humans, occupational and environmental exposures have been linked either to a reduction or to an increase in NK cells count. In a preliminary study we observed a decrease in NK cytotoxic activity in peripheral blood lymphocytes (PBL) of a group of workers exposed to ELF-MF TWA levels exceeding 1 µT. This study was performed to confirm these preliminary results.

Methods. Sixty-nine workers (43 men and 26 women) aged 39.1 ± 8.0 years (mean ± S.D.), engaged in various occupations were studied. Criteria for eligibility to the study were: no known occupational or avocational exposure to chemicals or other factors interfering with the immune system, no current acute or chronic diseases and/or pharmaceutical drugs consumption that might influence immune function. Occupational ELF-MF exposure was evaluated during two complete work-shifts using personal dosimeters (EMDEX LITE) worn on the hip in a belted pouch. MF levels were sampled every 10 seconds, resulting in more than 5,600 measures for each worker. Personal monitoring results were expressed as Time-Weighted Average (TWA), calculated as the arithmetic mean of all measurements throughout the sampled work-shifts. Environmental (non occupational) exposure was also monitored. NK cell cytotoxic activity in PBL was measured using a non radioactive method. NK activity was evaluated both as % of lysis at different ratios between effector vs. target cells (E:T ratios) and as number of Lytic Units (L.U.) per 10⁷ lymphocytes.

Results. In the whole group median TWA exposure to ELF-MF resulted 0.15 µT; the 5°-95° percentiles were 0.03 – 3.89 µT respectively. Environmental exposure resulted much lower, in the order of less than 1/10, compared to the occupational one, and was not further considered. According to the occupational exposure, subjects were divided into two groups: Low Exposed (no. 36; ELF-MF level up to 0.2 µT), and High Exposed (no. 33; ELF-MF level > 0.2 µT). NK activity resulted decreased in High Exposed workers, but the difference was not statistically significant. Then we selected the subgroup of workers exposed to ELF levels ≥ 1 µT (Higher Exposed; no. 12 subjects), and compared NK activity to the whole
group of Low Exposed. Considering L.U., mean values resulted 21.4 (S.E. 3.7) vs. 51.2 (S.E. 7.6) respectively: the difference is statistically significant (p<0.01). The results were similar expressing NK activity as % of lysis at different E:T ratios (Fig.1). Furthermore, the results were also confirmed after correction of NK activity for gender and smoking habit.

**Conclusions.** Our data show a reduced NK activity in workers exposed to higher TWA levels of ELF-MF, and suggest that 1 µT may represent a threshold for this effect. These results are in agreement with our preliminary observation in a smaller group of workers. The biological significance of our results is still to be elucidated, but NK cells are part of the first line of the innate defence system that acts against various types of target cells, such as tumour or virus-infected cells. ELF are considered possible carcinogenic to humans, and some available data suggest that they could act as promoters rather than as initiators: the effect of ELF-MF exposure on NK activity observed in this study is in agreement with this hypothesis.

![Figure 1](image.png)

**Figure 1.** NK activity, expressed as % of lysis at different E:T ratio, in Peripheral Blood Lymphocytes of 36 Lower Exposed workers (ELF-MF levels up to 0.2 µT) vs. 12 Higher Exposed workers (ELF-MF levels ≥ 1 µT); * Significance of the difference: p < 0.01.
* 9-3 STUDY ON SUBJECTIVE SYMPTOMS AND EMITTING EXPOSURE CHARACTERISTICS OF EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS FOR ELEMENTARY SCHOOL STUDENTS

Sungho Choi¹, Yoon-Shin Kim¹, Ju-Hyun Song¹, Chul min Lee¹, Young man Roh¹, Hyun-Ju Park², Seung-Cheol Hong²
¹Hanyang University, Seoul, South Korea ²Inje University, Kimhae, South Korea

Objectives. This study proposed to analyze the relativity of emitting exposure of extremely low frequency electromagnetic fields and subjective symptoms of elementary school students.

Methods. This research carried out personal measurement and assessment of 60 Hz magnetic field and questionnaire between elementary school students near by 154Kv power line and elementary school students away from 154Kv power line. Personal measurement and assessment of 60 Hz magnetic field was investigated as collecting the bag of EMDEX lite(Enertech) with which volunteers carry for 24hr. This study get filled up volunteers about headache, fatigue, dizziness, failure of memory, A drop of power of concentration, Occurrence of subjective symptoms to survey their health subjective symptoms for 1 week. Therefore, to compare the social and economic standard of volunteers under environment of near by power line and away from power line, this study make an investigation into gross earnings of volunteers’s home for a year.

Results. Table 1 is the result of group’s subjective symptom about elementary school students living in environment near by power line and away from power line. As a result, the complaint rate of dizziness and failure of memory of elementary school students near by power line is significantly higher than that of elementary school students away from power line(p-value: 0.0150, 0.0047).

Conclusions. Further study of this study have to advance because these result remark that EMF may affect change of children’s neurobehavior.
9-4 REFLECTION UPON COST 281; ITS ACTIVITIES AND ITS RESULTS

Gerd Friedrich
FGF, Bonn, Germany

Objectives. To present my thoughts on the outcomes resulting from Cost 281

Results. The Action COST 281 “Potential Health Implications from Mobile Communication Systems” was carried out between September 2001 and September 2006 in response to continued public concerns about possible adverse health effects of electromagnetic fields in connection with mobile communication systems. Thematically, the Action was designed as continuation of the Actions COST 244 and 244bis in the field of RF. Whereas the predecessor actions (title of both actions: Biomedical Effects of Electromagnetic Fields) were intended to deal with electric, magnetic or electromagnetic fields of extremely low frequencies, intermediate frequencies and high frequencies or radio frequencies, the Action COST 281 focused exclusively on radio frequencies (RF). Due to the rapid development and deployment of mobile telecommunication the focus of public interest had shifted towards RF already during the course of Action 244bis. Accordingly, the research in the field of EMF concentrated on RF. Action COST 281 accommodated to this development.

Based on the Memorandum of Understanding of Action COST 281 (MoU) the main objective of the Action was ”to obtain a better understanding of possible health impacts of emerging technologies, especially related to communication and information technologies, that may result in exposure to electromagnetic fields”.

COST Action 281 gave priority to the co-ordination of research, as well as the evaluation and discussion of research results. Facing the increase of both national and international research projects to the subject EMF (e.g. REFLEX, INTERPHONE) it was of high importance to enlarge the already existing networks and to accelerate the exchange of scientists. Therefore, COST 281 aimed at giving scientists from all member countries (at last 26) a platform for the exchange of research results and discussions and has contributed to establish a worldwide network of information, amongst others by cooperation with WHO, EBEA, ICES, EMF-NET and further COST-Actions.

COST 281 has acquired several fields of knowledge through Workshops and meetings. The Action has organized 13 workshops on its own and was co-organizer of several meetings, workshops and seminars.

Six Working Groups dealt with special fields of interest, e.g. Dosimetry, Epidemiology and Base Station Monitoring. These Working Groups were initiated by the Management Committee of COST Action 281 after identifying the needs for a closer look on special topics. During the course of COST Action 281 substantial advances in the state of knowledge in research and health aspects related to electromagnetic field exposure were achieved. COST 281 made a contribution to improvements in statistics and dosimetry in research as well as in epidemiological research. Main topics of the Action’s work were: Base Station, Behaviour, Blood-Brain-Barrier, Brain, Calculation of Field and Measurement Methods, Cancer, Children, Dosimetry, Emerging Technologies, Epidemiology, Exposure Assessment, Genotoxicity, Human Reproduction, Mechanisms, Methods, Proteins, Statistics (in alphabetical order).

COST Action 281 addressed to the public with several publications, e.g. with the COST
281 Newsletter and through its website. Stakeholders and decision makers in policy were addressed in two Watchdog Reports, which informed about past research activities and the state of knowledge. Also a recommendation on an Internationally Co-ordinated Research on Genotoxic Effects of Electromagnetic Radiation from Mobile Communication Systems and two comments on Research projects got an official hearing.

As working results COST 281 has achieved several state of the arts at the workshops. Ongoing attention is given to the issues COST Action 281 dealt with.

Results of COST Action's 281 work have been presented to the public as statements or documentations.

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9-5 BORDEAUX-MOSCOW PROJECT: CONFIRMATION STUDIES OF THE RUSSIAN DATA ON IMMUNOLOGICAL EFFECTS OF MICROWAVES

Bernard Veyret\textsuperscript{1,2}, Bernard Billaudel\textsuperscript{1}, Sébastien Duleu\textsuperscript{3}, Michel Geffard\textsuperscript{2,3}, Emmanuelle Haro\textsuperscript{1}, Anabelle Hurtier\textsuperscript{1}, Isabelle Lagroye\textsuperscript{1,2}, Florence Poulletier de Gannes\textsuperscript{1}, Gilles Ruffié\textsuperscript{1}, Murielle Taxile\textsuperscript{1}

\textsuperscript{1}University of Bordeaux 1, IMS laboratory, ENSCPB, Pessac, France \textsuperscript{2}EPHE Bioelectromagnetics laboratory, ENSCPB, Pessac, France \textsuperscript{3}GemacBio, Cenon, France

\textbf{Objectives.} In a series of Russian and Ukrainian papers published in 1975-1986, dealing with immune-system effects on rats exposed to CW RF at 2375 MHz (0.1 to 10 W/m\textsuperscript{2}), it was reported that microwave exposure disrupted the antigenic structure of rat brain tissue (e.g., Vinogradov and 1986; reviewed by Grigoriev et al. 2002). Experimental results revealed that semi-chronic exposure at 5 W/m\textsuperscript{2} evoked a pronounced autoimmune response. Moreover, using a teratology approach, with serum of exposed rats injected into pregnant rats, significantly higher offspring mortality was noticed at the end of the first month of life.

These effect were found at ca. 5 W/m\textsuperscript{2} incident power which corresponds to a whole-body SAR of approximately 0.6 W/kg.

Since the results of these studies have served in part as the basis for the setting of exposure limits in the USSR, it was deemed necessary to perform replication studies in two independent laboratories using modern dosimetric and biological methods. Under the coordination of WHO, the two laboratories (i) IMS at Bordeaux University (contact: bernard.veyret@ims-bordeaux.fr) and (ii) the State Research Centre - Institute of Biophysics, Moscow, Russia (Contact: Oleg Grigoriev o.grigoriev@mtu-net.ru) engaged into a one-year project.

\textbf{Methods.} RF exposure: The RF source is a Russian-made magnetron generator "Luch-11". The working frequency is 2450 MHz. The antenna is a cylindrical horn antenna with elliptic polarization. Sixteen male Wistar rats are placed in an annular set of 16 plastic cages, underneath the antenna, in two anechoic chambers (exposed and sham). Animals
are free to move and exposed at 5 W/m² for 7 hours per day, 5 days per week for 30 days. Cage-control rats are kept in the animal facilities during the whole experiment. Dosimetry of the exposure system is performed independently by the XLIM laboratory in Limoges, France (contact: P. Lévêque philippe.leveque@unilim.fr).

Immunology: circulating antibodies (Ab) will be assayed in blood samples using ELISA. Increase in Ab titers is related to damage of the nervous tissues and auto-immunity. Immunoglobulin of A, M and G isotypes will be evaluated for 16 neo-antigens (e.g., NO-cysteine, cysteiny1 catecholamines).

Teratology: sera from cage-control, RF exposed and sham-exposed rats will be injected into pregnant rats. A standard battery of teratological tests will be performed using coded samples by the EVIC company (Blanquefort, France).

Results. Exposure is in progress and results from the immunological and teratological approaches will be available at the time of the meeting. By then, data obtained in Bordeaux will have been confronted with those of the Russian laboratory.

Acknowledgements. This project is being supported by the CNRS, the French Foundation ”health and radiofrequency”, the MMF and the GSM Association, and coordinated by WHO’s EMF International Project.

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9-6 IS ELECTROMAGNETIC HYPERSENSITIVITY INCREASING AMONG GENERAL POPULATION - A CROSS SECTIONAL REPRESENTATIVE SURVEY IN AUSTRIA

Joerg Schroettner, Norbert Leitgeb
University of Technology Graz, Graz, Austria

Objectives. An increasing number of persons suffer from non-specific health symptoms like headache, sleep disturbances and take refuge to the assumption, that electromagnetic pollution is the cause for their problems. The discussion, whether electromagnetic fields could cause adverse health effects is still ongoing.

In 1994 Leitgeb first estimated the electromagnetic hypersensitive (EHS) subgroup to about 2% of the general population. A population-based survey in Sweden (Hillert et.al., 2002) resulted in 1.5 percent, Levallois et. al. (2002) reported 3.2 percent in California and Schreier et. al. (2006) found a prevalence of 5% for EHS in Switzerland.

To get actual information of the perspective of the general population in regard to the perception of electromagnetic pollution and risk assessment an investigation of a cross section sample of the Austrians population was performed.
Methods. A statistical cross-sample with regard to age, gender and region was investigated. The survey was performed by telephone interviews involving a total number of 526 persons. For this, a two page questionnaire was developed comprising 25 questions addressing health status and lifestyle, EMF risk assessment, avoidance behaviour, the suspected EMF sources, EMF related symptoms and personal data.

Results. This survey showed, that 3.5% of the investigated people are suffering from EHS. 70% of the sample think that electromagnetic pollution could be a risk factor for health. More than 30% of the sample declares to some degree or completely, that they feel disturbed in their well being near mobile phone base stations or power transmission lines. Despite this high risk perception only 10% of the responders were actively looking for information for the issue of electromagnetic pollution. In 24% of the cases media were said to have triggered the EMF hypothesis. The most frequently identified health-relevant EMF sources were power lines (79%), mobile phone base stations (77%) and video display units (50%). Mobile phones (46%) were on place four followed by computers (41%). (Fig. 1)

Conclusions. This survey showed that a considerable amount of persons is convinced that electromagnetic pollution is a potential health risk factor. This is in clear contradiction to the established scientific knowledge. In every fourth case media triggered the EMF hypothesis. The percentage of people suffering from EHS is 3.5%, in comparison to results from a former study in 1994 it turned out, that the percentage of hypersensitive persons almost doubled within the last 10 years.

![Figure 1](image-url)

**Figure 1.** Response to the question: Which sources do you consider as responsible for electromagnetic pollution?
9-7 STUDYING THE EFFECTS OF DISCRETIZATION IN FDTD ANALYSIS OF HUMAN EXPOSURE TO EM FIELDS

Tero M. Uusitupa¹, Sami Ilvonen¹, Ilkka Laakso¹, Kimmo Kärkkäinen², Keijo Nikoskinen¹

¹Helsinki University of Technology, Espoo, Finland ²Nokia, Espoo, Finland

Objectives. Standardized computational and measurement methods for the evaluation of human exposure from mobile telephone base stations are currently under development in IEC project team 62232. Part of the standard is dedicated for full wave numerical SAR evaluation. To support the development of the standard, the basic requirements and principles needed to perform a successful SAR evaluation are studied using a parallel FDTD code. This study concentrates mainly on two issues. Firstly, the effect of FDTD resolution on SAR is examined. Secondly, it is studied how the positioning of body-model material voxels (in E cells vs. in H cells) affects SAR values.

Methods. Parallel-FDTD solver is used in field computation with CPML ABC. So called packed coefficient tables are used: the 3D FDTD coefficient tables are integer type instead of float type, which saves memory. Each integer number (index) in space tells which effective conductivity and permittivity value to use at an E-field point. Different body models are used. The material voxels are associated with E cells or with H cells. If using E cells (H cells), a material voxel is surrounded by 12 E-field (H-field) components. Which method is chosen affects the (packed) coefficient tables and the SAR computation routines. Using H cells is desirable because this produces less material-interface combinations than using E cells.

When computing point SAR in postprocessing with H cells, every E and J component is spatially interpolated to the center of a material cube at two time instants (two E and J values are used per interpolation per coordinate direction per time instant). Then using a so-called T/4 method, one obtains amplitudes Ex, Ey, Ez, Jx, Jy, Jz at the cube center. These amplitudes are used in point SAR computation. When computing SAR with E cells, E-field amplitude at the material-cube center is obtained from the surrounding 12 E-field components and by using the T/4 method. Finally, the computation codes have been verified with lossy-sphere simulations.

Results. Example SAR results are shown here for two distinct human-body models, which were exposed to vertically-polarized plane wave (amplitude 1 V/m, r.m.s.). The first body model is based on voxel data of Zubal model (Zubal et al., Computerized three-dimensional segmented human anatomy, Medical Physics, 21(2):299-302, 1994.). It consists of 3.6 mm cubical voxels, has length 1.76 m, and mass 81.85 kg. The voxels (material cubes) were associated with the Yee’s grid H cells. The effect of FDTD cell size on WBASAR was studied: cell size was 3.6mm (which equals to the voxel size) and 1.8mm (double resolution in FDTD). WBASAR results at f=900MHz and f=1800MHz are shown in the Table 1.

The two WBASAR values in each case have been computed as SAR1 = total loss power / mass, and SAR2 = the average value of point SAR. Unit is μW/kg.

The second body model is based on voxel data of Norman model (Dimbylow, 1997, FDTD calculations of the whole-body averaged SAR in an anatomically realistic voxel model of the
human body from 1 MHz to 1 GHz, Phys. Med. Biol. 42, pp. 479-490). It consists of 2 mm cubical voxels, has length 1.74 m, and mass 70.62 kg. The effect of positioning of the material cubes was studied (H cells vs. E cells). WBASAR results at f=900MHz and f=1800MHz are shown in the Table 2.

Conclusions. The cell size used in FDTD computation does not seem to have a remarkable effect on whole-body averaged SAR, but of course, the cell size affects more in higher frequencies. Using H-cell method seems to give somewhat higher WBASAR values, especially with the higher frequencies.

Acknowledgements. This study was funded by TEKES and Nokia Corporation.

* 9-8 ANALYTICAL COMPUTATION OF NEAR FIELD EXPOSURE FROM A FINITE DIPOLE ANTENNA IN THIN LAYER DIELECTRICS

Teddy Kurniawan1,2, Andrew W. Wood1,2, Robert L. McIntosh2, Steve Iskra2
1Swinburne University of Technology, Melbourne, VIC, Australia 2Australian Centre for Radiofrequency Bioeffects Research, Melbourne, VIC, Australia

Objectives. This paper aims to present and show the accuracy of near field computations based on an analytical approach in tissue-like objects due to RF exposure from a finite length dipole. Here we present a novel approach in using the quasi-static nature of the near field of an RF source, with the development of an analytic methodology and simulation tools in MATLAB (R).

Methods. This study is performed using:

(i) a finite length, infinitely thin dipole is chosen to represent the mobile phone antenna as extensively found in literature [1],
(ii) the formulas to compute the electric and magnetic fields in the free space surrounding a finite length dipole are determined based on [2], which are extended into a possible 3D analysis in Cartesian and cylindrical coordinate system,
(iii) the interaction mechanism of electric and magnetic fields with object(s) in the near field of exposure is represented as quasi-static [3, 4], and
(iv) the formulas and the interaction mechanism described, are developed into simulation tools built in the MATLAB (R) platform.

The simulations performed in MATLAB (R) consider free space and layers of dielectrics, exposed to a 0.4 wavelength dipole of 900 MHz, driven at its centre by 0.1 ampere (peak) antenna current. Fig. 1 and Table 1 detail the simulation conditions of the near field exposure.
Results. The free space simulation results in MATLAB (R) for both electric and magnetic (near) fields, are in very good agreement with results from FEKO (R) and XFDTD (R) (not shown due to space limitations). For layers of dielectrics, the results for both total electric and magnetic fields along the y direction, at x=0 and z=10 mm are shown in Fig. 2a and 2b. The value of z=10 mm is chosen, to show the near field interaction mechanism for layers of dielectrics for both y- and z-directed electric field component (Ey and Ez), instead of only Ez component at z=0.

Overall, the matlab results have shown good agreement with FEKO (R) and XFDTD (R). Nevertheless, differences which occur in the range of 3 mm < y < 5 mm in Fig. 2a, has highlighted the inherited differences among numerical methods used by FEKO (R) (finite element method), XFDTD (R) (finite difference time domain), and also due to assumptions that are used in the analytical approach. These assumptions are: infinitely thin wire dipole, sinusoidal current distribution for dipole length less than a wavelength, infinitesimal dipole feed point, and the focus on dipole current instead of radiating power that takes into account the dynamic change in dipole impedance in the presence of near field object(s). On the other hand, differences for the magnetic (near) field as seen in Fig. 2b, may be accounted for by noting that the analytical solution does not require conductivity values to be specified, while these values must be specified in FEKO (R) and XFDTD (R).

Interestingly, Fig. 3a and 3b confirm the quasi-static approach taken in the analysis and modelling. Fig. 3a shows that the normal electric field component (Ey) within the layers of dielectrics (in the near field) depends on the relative permittivity ($\epsilon_r$) values. Therefore, there exists a situation where lower $\epsilon_r$ at medium II gives significant rises in the electric fields even though its distance is further from the centre of radiation. Fig. 3b shows that the tangential component (Ez) of electric fields within the layers of dielectrics is uninfluenced by the presence of dielectric object(s).

Conclusions. Results from analytical near field computations in layers of dielectrics exposed to a finite length dipole have been presented. The results show the utility and fine accuracy of a quasi-static analytic approach to estimate the near (electric) field exposure in layers of dielectrics, with further benefits of: reducing simulation time and resource for a focused investigation, a very fine resolution, and improved insight into system analysis. Nevertheless, further simulations and investigation are still required to provide a more inclusive knowledge on the benefits and limitations of this analytical approach for computation of near field exposure.

REFERENCES


![Figure 1](image1.png)

**Figure 1.** Geometrical conditions of the finite length dipole and layers of dielectrics in the Cartesian System (the x axis is directed into the paper). The layers are infinite in extent in the x z directions.

![Figure 2](image2.png)

**Figure 2.** Total electric fields vs distance along y direction in layers of dielectrics exposed at z = 0 and z = 10 mm.

![Figure 3](image3.png)

**Figure 3.** y-directed component of electric fields (Ey) vs distance along y direction on layers of dielectrics exposed at z = 0 and z = 10 mm.
Session 10: EMF Effects on Animal Systems

10-1 EFFECTS ON BRAIN DARK NEURONS OF WISTAR-HAN RATS EXPOSED HEAD-ONLY TO GSM-1800 OR UMTS SIGNALS.

Bernard Billaudel¹, Murielle Taxile¹, Laetitia Mayeur¹, Elodie Ladeveze¹, Muriel Laclau¹, Emmanuelle Haro¹, Philippe Leveque², Gilles Ruffie¹, Florence Pouletier de Gannes¹, Isabelle Lagroye¹, Bernard Veyret¹

¹ENSCPB, Pessac, France ²XLIM, Limoges, France

Objectives. The Swedish group of Leif Salford in Lund reported the occurrence of brain damage (permeability of the blood-brain barrier and presence of dark neurons), 50 days after a single 2-hour exposure of rats to a mobile telephony GSM-900 signal (Salford L.G., Brun A. E., Eberhardt J.L., Malmgren L., Persson B.R.R. Environmnental Health Perspectives, (2003), 111:881-883) . However, new signals for mobile communication signals are being developed and their health effects have to be assessed. As part of the German Federal Ministry for Environment, Nature Protection and Reactor Safety project (BfS project), it was therefore planned to study the effects of GSM-1800 and UMTS signals on the blood-brain barrier and dark neurons in rats. In this specific study, we described the influence of a single 2-hour exposure to these two signals on rat brain and assessed the occurrence of dark neurons.

Methods. Exposure and dosimetry: the characterization of the brain averaged SAR (BASAR) had been performed at 900 MHz using the loop antenna (Leveque P., Dale C., Veyret B., and Wiart J.. IEEE MTT (2004) 52: 2067-2075). The same approach, experimental measurements and numerical simulations (FDTD), was used as part of the project at 1800 MHz and UMTS frequency.

Biological system and experiments: Male Wistar rats were housed under controlled temperature (22 C) and lighting conditions, and supplied with water and food ad libitum. After a one-week acclimation period, rats were randomly distributed in each experimental group and progressively trained to the rocket-type exposure setup during one week. 10 weeks old rats (300-325 g) were exposed once during 2 hours at 12 weeks. Four SAR levels were used: 0.026, 0.26, 2.6, and 13 W/kg. Sham-exposed rats (0 W/kg, restrained in a rocket), cage controls, and positive controls were included in the protocol. Injection of kainate was used as a positive control. The tested time-points were: immediately, 1 hour, 1, 7, and 50 days after exposure. To ensure the blinding of the experiments, rats were coded before exposure and brains were then recoded before slicing and analysis. Rats were euthanized using isoflurane inhalation (5% in air). The rat brains were fixed by intracardiac perfusion using a paraformaldehyde solution and frozen. Serial 10-µm-thick brain sections were prepared from 3 different brain regions (between bregma -0.80 and -1.20 mm; -4.00 and -4.80 mm; -8.00 mm and -8.80 mm).

Biological parameters: The dark neurons, assumed to be markers of neuronal degenerescence were identified using (a) Cresyl-violet staining applied on the tissue sections (1-5 min)
and rinsed with distilled water and (b) Fluoro-Jade staining for a more specific detection of dark neurons (Schmued L.C., Albertson C., and Slikker W. Jr. Brain Research, (1997), 751, 37-46). Briefly, tissue slices were treated with successive baths (1% NaOH and 80% ethanol, 5 min; 70% ethanol, 2 min; 0.06% potassium permanganate, 10 min), rinsed and stained using a 0.001% Fluoro-jade solution (30 min, gentle agitation). Slices were then rinsed in distilled water and immersed in xylene. After various staining conditions, coverslips were mounted on slides before microscopy observation, and analysis performed using the Aphelion image software (ADCIS SA, France).

Statistics: For each exposure condition, groups of 16 rats were used allowing the detection of a significant variation (p < 0.05) for an arbitrary average error of 35% (worse case arbitrary value considering variability usually reported for biological tests). Two successive series of 8 rats per exposure condition (n = 16) were performed. Statistical analysis was made using the Student t-test and STATEXACT tests.

Results. The proposed program is being performed over a 3-year period (beginning in 2004 and ending in 2007). All rat exposures and brain perfusion are completed. 80% of the brains are sliced, almost 50% of the slices are stained. So, final experimental results will be presented at the meeting.

Acknowledgements. This work is supported by the German Federal Ministry for Environment, Nature Protection and Reactor Safety, the Aquitaine Council for Research, and the CNRS.

10-2 MORPHOMETRY ON THE INJURY EFFECTS OF THREE KINDS OF BAND ELECTROMAGNETIC RADIATIONS ON HIPPOCAMPUS AND THE EXPRESSION OF INJURY-RELATED PROTEINS IN WISTAR RATS

Hongyan Zuo, Dewen Wang, Rui-yun Peng, Shui-ming Wang, Chen Juan
Academy of Military Medical Science, Beijing, China

Objectives. To explore the pathologic alterations of hippocampus and the expression of injury related proteins in Wistar rats model which was wholly irradiated with three kinds of band electromagnetic radiations.

Methods. Hippocampal sections with HE and TB Staining were observed for pathologic changes under lightmicroscopy. The expression of GFAP[IL-1β]nNOS proteins were detected with SP immunohistochemistry and image analysis.
Results. Decrease of Nissel bodies and pyknosis of hippocampus neurons were observed which revealed degeneration of neurons after three kinds of band electromagnetic radiation irradiated. The injury grades are X > S > EMP. Under the electromicroscopy, hippocampus neurons showed different degree ischemic changes after irradiation 6h. The injury extent of 3d is bigger than that of 6h. The expression level of GFAP protein down-regulated (P<0.05) at 6h, 1d, 3d after radiation. The expression level of IL-1β protein rise strongly (P<0.01) at 6h, 1d after radiation and rise (P<0.05) at 3d after S group was radiation. The expression level of nNOS protein rise (P<0.05) at 6h, 1d, 3d, 7d after radiation.

Conclusions. In the experiment, three kinds of band electromagnetic radiations can at different extents damage hippocampal neurons in rats and GFAP[IL-1β][nNOS proteins expression be partly responsible for the injury and repair mechanism.

10-3 COMPARATIVE PROTEOME ANALYSIS OF THE HIPPOCAMPUS INJURED BY ELECTROMAGNETIC RADIATION

Hongyan Zuo¹, Dewen Wang¹, Rui-yun Peng¹, Shui-ming Wang¹, Ya-Bing Gao¹, Wen-hua Hu¹, Juan Chen¹, Kai-hua Wei², Hong-li Wang², Bing-yu Lui²
¹Academy of Military Medical Science, Beijing, China
²National Center of Biomedical Analysis, Beijing, China

Objectives. To investigate the difference of hippocampus proteome maps after radiation by three electromagnetic waves of different frequency.

Methods. Comparative proteomic approach based on two dimensional gel electrophoresis (2-DE), mass-spectrum identification and bioinformatics analysis was used to study the difference of hippocampus total protein at 6h after electromagnetic radiation exposure. Western blot and RT-PCR technique was applied to detect the differential protein for further verification on the level of protein and gene respectively.

Results. The three kind of electromagnetic radiation changed the hippocampus proteome map similarly. 45 differential protein spots were found by image analysis, among of which 26 spots were identified initially. For raf kinase inhibitor protein (RKIP), which was one of the differential proteins and correlated with signal transduction, Western blot and RT-PCR results further verified 2-DE results. The expression of RKIP protein and mRNA was down regulated significantly at 6h after radiation, and no significant difference was observed between any radiation groups.
Conclusions. The injury mechanisms of hippocampus by the three kind of electromagnetic radiation possessed similarity, and the degree of injury showed frequency dependence. RKIP may play an important role in the hippocampus injury by radiation.

10-4 EFFECT OF RADIOFREQUENCY FIELDS EXPOSURE ON HEAT SHOCK PROTEIN (HSP) EXPRESSION IN BRAINS OF RATS OF DIFFERENT AGES

Isabelle Lagroye\textsuperscript{2,1}, Muriel Laclau\textsuperscript{1}, Gilles Ruffie\textsuperscript{1}, Bernard Billaudel\textsuperscript{1}, Murielle Taxile\textsuperscript{1}, Bernard Veyret\textsuperscript{1,2}

\textsuperscript{1}University of Bordeaux 1, IMS site ENSCPB, Pessac, France \textsuperscript{2}EPHE bioelectromagnetics laboratory, ENSCPB, Pessac, France

Objectives. We previously showed that repeated exposure (2 hours/day; 5 days / week; 4 weeks) of 12 week-old rats to UMTS signals (1960 MHz, 2.6 brain-averaged specific absorption rate, BASAR) enhanced the expression of HSP25 and HSP70 in their brains. These proteins are classically induced in the brain under stressful conditions. Elderly rats, which are usually less responsive to stress, were also found much less responsive to RFR exposure. In the present work, we studied the effect of UMTS on the expression of HSP70 and HSP25 in the brains of 12-week (young adult) and 17-month (elderly) male Wistar rats.

Methods. Groups of 8 animals were exposed or sham-exposed. Exposures were performed using a loop antenna at a BASAR of 2.6 W/kg. Rats were submitted to a single 2-hour exposure, after habituation to the exposure setup (rockets) over two weeks to avoid stress. A sham-exposed group was included. Positive controls were obtained by induction of a status epilepticus using a subcutaneous injection of kainic acid (10 mg/kg). At the end of exposure, rats were anesthetized with isofuran and perfused via the heart with 4% paraformaldehyde in phosphate buffer (0.1 M). Brains were kept in the fixative solution overnight at 4°C and then cryo-preserved in 20 % sucrose in phosphate buffer for 48 h at 4°C. The brains were removed and placed in fixative solution for 24 hours prior freezing in isopentane. Sections (10 µm thick) were prepared on slides in 3 separated zones taken approximately at −0.8, −3.8, and −8 mm posterior to bregma (zone 1, 2, and 3, respectively).

Brain samples were coded and the analysis was performed in a blind manner. The sections were stained with antibodies raised in rabbits against Hsp25 or the inducible form of Hsp70. The qualitative analyses were done on the cerebral cortex of the three zones, in the hippocampus in zone 2 and in the substantia nigra in zone 3. A score of zero to four (no Hsp expression, high Hsp expression) was given to each brain sub-region. Data were then expressed as arbitrary units corresponding to the percentage of the maximum possible score. Due to the loss of some slices, the data of 5 to 8 animals/group are available. The significance of differences between groups was evaluated using the Kruskal-Wallis test for independent samples.
**Results.** No significant difference was found in HSPs expression in cage control and sham-exposed rats. Kainate induced a significant increase in Hsp70 in young adult animals while elderly rats were found not responsive to the treatment. A mild effect was observed on Hsp25.

UMTS induced no significant alteration in Hsp25 and Hsp70 labeling in the rat brain except for an increase in Hsp25 expression in one sub-region of the cortex (motor cortex) of elderly rats.

**Conclusions.** Our data show no substantial effects of a single exposure to UMTS on Hsp25 and Hsp70 proteins in the brains of young-adult and elderly rats. However, our results after kainate injection are in agreement with an altered reaction to stress, usually found in elderly animals.

Overall, our results suggest that only repeated exposures to UMTS seem able to increase HSP expression. According to the experimental evidence of the co-carcinogen potential of low-level RFR, such an increase in HSP expression is unlikely to be linked to cancer. As Hsp expression is reported to be induced after radical stress, we are currently investigating this parameter in the brains of rats exposed repetitively to UMTS.

**Acknowledgements.** The French Ministry for Research and New Technologies (contract ACI-RTM0004) and Bouygues Telecom supported this work.

![Figure 1](image.png)

**Figure 1.** Effects of a single UMTS exposure on HSP expression in the hippocampus on young adult and elderly rats
DOES 50 HZ MAGNETIC FIELD EXPOSURE SPEED UP THE PROGRESSION OF AMYOTROPHIC LATERAL SCLEROSIS (ALS) IN MICE?

Florence Poulletier de Gannes¹, Murielle Taxile¹, Sébastien Duleu³, Emmanuelle Haro¹, Gilles Ruffi¹, Bernard Billandel¹, Renaud Charlet de Sauvage¹, Michel Geffard¹, Bernard Veyret¹,², Isabelle Lagroye¹,²
¹IMS laboratory, Pessac, France ²EPHE Bioelectromagnetics laboratory, Pessac, France ³GemacBio, Cenon, France

Objectives. Amyotrophic Lateral Sclerosis (ALS) is a neurodegenerative disease of unknown etiology. Motor neurons are the target tissue and death occurs on average in two to five years following diagnosis and is due, in a large majority of cases, to respiratory disorder. Epidemiological data have suggested that occupational exposure to EMF is associated with ALS (Gunnarsson et al 1991; Davanipour et al 1997; Savitz et al 1998a, 1998b; Johansen & Olsen 1998, Hakansson et al, 2003). However, further epidemiological studies and confirmatory results of specifically-designed biological studies would be valuable. The objective of our study was to evaluate, for the first time, whether exposure of an ALS animal model (SOD-1 mice) to 50 Hz magnetic fields (MF) is able to alter development of the disease.

Methods. SOD-1 mice were purchased from Jackson Laboratories (USA). Eight mice per group were exposed to 50 Hz MF in Merritt coils at two levels (100 and 1000 µT). Exposures began before the onset of ALS clinical signs at 10 weeks. Exposure lasted 2 hours/day, 5 days/week for 7 weeks. Sham-exposed mice (placed in inactive Merritt coils) and cage-control mice (maintained in the animal room) were included in this protocol. Body weight, survival and motor coordination using the Rotarod test (15 rpm, 180 s) were followed. Blood samples were taken once a week, beginning on week 10 until death, and coded. Mice were killed when they were unable to roll over within 30 sec after being pushed on their side, and this time point was recorded as the time of death. Mice were perfused transcardially with PBS, followed by 4 % paraformaldehyde in PBS. The brain and the spinal cord were dissected, cryoprotected in 30 % sucrose and kept at −80°C until immunolabelling. Radical stress markers were searched in mice sera by ELISA Tests and by immunohistochemistry in brain and spinal cord sections.

Results. In a first series of experiments on 3 mice/group, no significant differences were measured on the following parameters: weight, rotarod test and survival. ELISA and immunohistochemistry tests are in progress.

Conclusions. Complete results on 8 animals/group will be presented at the meeting. Our data will complement those from epidemiological studies related to risk assessment of neurodegenerative diseases in populations occupationally exposed to MF. Further research in our laboratory will test the effects of electric shocks on SOD1 mice, since they are another suspected factor for ALS risk in professional exposure.

Acknowledgements. This work is supported by the Agence Nationale de la Recherche (ANR), France, under grant n°05 9 89/ ANR 05 SEST 007-01.

We thank RTE, and especially I. Magne and J.P. Gernez for lending the exposure setup.
Objectives. One of our research objectives is to identify microwave exposure parameters in the 0.75-1 GHz frequency range that can elicit non-thermal effects on skeletal muscle contraction. To eliminate heating as a variable and allow us to distinguish between thermal versus non-thermal effects, this study was undertaken to begin assessing how heating the tissue above physiological values affects contractile force.

Methods. The muscle used, flexor digitorum brevis (FDB), was dissected from the hind-foot of 8-12 week old male C57B mice using a stereoscopic zoom microscope. Non-absorbable braided silk suture (4-0) was tied to both ends of each FDB muscle at the tendons, and the distal end suture fixed to a glass hook at the bottom of the inner chamber of a glass organ bath. The muscle was suspended vertically within the chamber by attaching the proximal end suture to a force transducer to register muscle contraction. Oxygenated Tyrode solution, continuously perfused at a rate of 1 ml/min, bathed the muscle. The temperature of the Tyrode solution was monitored continuously by a fluoroptic temperature probe placed along side the muscle, and maintained at the desired temperature by controlling the temperature of the water circulating in the outer chamber of the organ bath via a circulation water bath. Square voltage pulses (width 0.5 ms and 40 V) of varying frequency, ranging from 1 to 100 Hz to elicit single (unfused) twitches and fused twitches (tetani), were applied for 1000 msec to a pair of platinum ring electrodes located above and below the muscle using a stimulator. The signal from the force transducer was sent through an amplifier to an analog to digital converter, whose output was logged and recorded using Chart Version 5.3 software. At the start of experiments, resting tension was set at 1 ± 0.02 g. Each experiment consisted of stimulating the muscle to contract from low to high frequency (1, 5, 10, 20, 30, 40, 50, 75 and 100 Hz) starting at a temperature of 35°C that approximates the temperature of this muscle in vivo. The length of time for the low to high frequency series of electrical stimulations was around 60 seconds. The temperature was then increased in 1°C increments, up to a final temperature of 45°C, and a low to high frequency series of electrical stimulations carried out at each temperature. Approximately 3-4 minutes elapsed before the temperature stabilized at each new value. After the last series of electrical stimulations at 45°C, the muscle was returned to 35°C and subjected to a final series of electrical stimulations at low to high frequency.
Results. Under constant temperature conditions (35°C), the amount of force generated at each stimulation frequency varied very little over the course of multiple low to high frequency series of electrical stimulations applied to the muscle. For example, at 5 Hz and at 50 Hz, the force generated was 0.28 ± 0.028g and 1.0861 ± 0.065g, respectively, for 19 repetitive low to high frequency stimulations. As the temperature of the Tyrode solution increased from 35°C to 40°C in 1°C increments, there was a very slight decrease in the magnitude of the force elicited at each stimulation frequency that did not reach statistical significance over this 5°C temperature range (P ≥ 0.99; n = 16). As the temperature was increased above 40°C in 1°C increments, the decrease in contractile force at each stimulation frequency and at each temperature became more pronounced and reached statistical significance (P ≥ 0.00001; n = 16). At 45°C, almost all contractile force was lost and returning the muscle to 35°C did not restore contractile activity.

Conclusions. When examining the effects of microwave fields on contractile force, any changes that we observe where the temperature is within the range of 35°C to 40°C would suggest that the effect is non-thermal in nature. More experiments assessing the effects of heating on contractile force are underway to verify this.

Acknowledgements. This research was supported by the Air Force Office of Scientific Research grants F49620-03-1-0262, FA9550-04-1-0194 and FA9550-05-1-0308.

* 10-7 A CONTINUED INVESTIGATION OF SPECIFIC PULSED MAGNETIC FIELD EFFECTS ON CIRCULATORY AND MICROCIRCULATORY PARAMETERS

Julia C. McKay1,2, Karel Tyml2, Frank S. Prato1,2, Alex W. Thomas1,2
1Lawson Health Research Institute, St. Joseph’s Hospital, 268 Grosvenor St., N6A 4V2, London, ON, Canada 2The University of Western Ontario, 1151 Richmond St., N6A 5B8, London, ON, Canada

Objectives. The circulatory and microcirculatory systems are important for the maintenance of proper health and conversely they are often implicated in various disease states. The ability to locally or systemically manipulate blood flow and blood pressure would be advantageous in controlling a variety of medical problems, including wound healing, re-perfusion-ischemia, hypertension, and others. The effects of magnetic fields of various intensities and forms on blood flow and blood pressure have been investigated, although results are mixed. The objective of the current research is to expand upon our previous findings to determine how exposure to a particular pulsed electromagnetic field alters certain microcirculatory and circulatory parameters (e.g. blood flow, blood pressure).
**Methods.** Male Sprague-Dawley rats \( (n = 93) \) were anesthetized and surgery was performed on the left hind-limb to expose the extensor digitorum longus (EDL) muscle. Individual rats were then placed within a set of Helmholtz-like coils and a laser Doppler flow meter probe was lowered directly on top of the EDL. Specifics of the coils and MF (complex neuroelectromagnetic pulse - CNP) are as follows: 1.2 m diameter for the coil that generates the vertical low frequency \(< 1000 \text{ Hz}\) MF with a 200 \( \mu \text{T} \) peak (400 mT/s), and the sequence consists of 5 pulse segments (each 853 ms) with an average frequency of 72 Hz each separated by an increasingly long refractory period (110-1200 ms).

A 'Time 0' blood flow measurement was taken prior to turning on the CNP. After 30 min had elapsed from the end of the Time 0 recording, a second measurement ('Time 30') was taken. After 60 min had elapsed from the end of the Time 0 recording, a final ('Time 60') measurement was again made. For each recording, the same procedure was followed: a 20 sec recording of un-stimulated blood flow was recorded to obtain a baseline and then acetylcholine (Ach) was dropped directly on the EDL. Three different concentrations of Ach were used: 0.1, 1, and 10 mM. At the end of the experiment, rats were euthanized. The Time 30 and Time 60 peak blood flow values were normalized to the Time 0 peak values and the results were analyzed using SPSS 12.0.

In our next set of experiments, blood pressure will be measured simultaneously to blood flow. A carotid artery will be cannulated and a pressure transducer will be used to monitor any changes in blood pressure after exposure to the CNP for 30 and 60 min. Body temperature will be carefully controlled to minimize any variation between subjects.

**Results.** There was a significant difference in peak blood flow response across the 3 tested time points \( (F(2, 179) = 18.15, p < 0.001) \). The Time 60 values were lower that the Time 30 values. Also, as expected, there was a significant interaction between injection type \((0.1, 1, \text{ or } 10 \text{ mM Ach})\), our positive control, and time of exposure \( (F(4, 184) = 3.92, p < 0.05) \). The interaction between time and exposure type is approaching significance at the 0.1 mM Ach concentration (Figure 1). Indications from our previous experiments that a pulsed magnetic field can induce effects through subtle changes in blood flow and more pronounced effects through endogenous opioids lead us to investigate any changes in blood pressure. These results will be discussed.

**Conclusions.** In light of the present results, it would appear that after 60 min of CNP exposure, the rats that received 0.1 mM Ach showed a modest increase (12 %) in peak microvascular blood flow response compared to sham-exposed animals. Circulatory blood pressure data is pending. These findings help clarify the specific effects of the CNP and contribute to the larger pool of data, which is inconsistent, involving the effects of magnetic fields on circulation and microcirculation.

**Acknowledgements.** The Lawson Health Research Institute Internal Research Fund, Natural Sciences and Engineering Research Council of Canada (NSERC), Canadian Institutes of Health Research (CIHR), the Ontario Research and Development Challenge Fund (OR-DCF), Canada Foundation for Innovation (CFI), and the Ontario Innovation Trust (OIT). Special thanks to Mr. Lynn Keenliside and Ms. Fuyan Li for their technical assistance.
**Figure 1.** Change in microvascular blood flow after 30 and 60 min of exposure to the CNP relative to pre-exposure blood flow baseline. The line of reference at point 0 represents ‘no change’ from the Time 0 blood flow values. The most noted difference in peak blood flow response between the sham- and CNP-exposed animals occurs at the lowest concentration of Ach (0.1 mM) after 60 min of exposure. Within each of the sham and CNP cells, the left hand points and error bars refer to the Time 30 measurements and the right hand points and error bars refer to the Time 60 measurements.

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**10-8 ASSESSMENT OF THE IMPACT OF POST-TRAUMATIC STRESS DISORDER ON BRAIN FUNCTION IN ELECTRICALLY INJURED PATIENTS**

Elena N. Bodnar¹, Alia N. Ammar², Joseph W. Fink¹, Kathleen M. Kelley², Neil H. Pliskin², Raphael C. Lee¹

¹The University of Chicago, Chicago, IL, USA ²University of Illinois College of Medicine, Chicago, IL, USA

**Objectives.** There are numerous physical, cognitive and emotional sequelae which can result from electrical injury (EI). Memory problems have been a frequent complaint following EI and memory impairment has been identified as a core area of deficit by some studies. However, many of these studies did not control for the presence of psychiatric disorders
in their samples such as Post-Traumatic Stress Disorder (PTSD), and PTSD itself is associated with impaired cognitive performance. In this study, we investigated the impact of PTSD upon memory functioning by evaluating performance on the California Verbal Learning Test in 165 EI survivors with and without PTSD diagnosed via structured psychiatric interview. We found that EI patients with PTSD performed more poorly on tasks of immediate recall ($p = .004$) and delayed recall ($p = .02$) as compared with EI patients without PTSD. EI-PTSD patients demonstrated a greater susceptibility to proactive interference. Additionally, 20 repeat subjects who were given neuropsychological examinations over a period of time following their injury were selected for a longitudinal study. Among the 20 subjects, 6 subjects show an improvement in their neurocognitive function between their initial and repeated neuropsychological evaluation, 11 subjects maintained a consistent level of neurocognitive function, and 3 subjects experienced a decline in neurocognitive function after their initial evaluation. In general, patients with little to no PTSD symptoms tended to improve their neurocognitive function over time, while those with the strongest PTSD symptoms tended to exhibit a decline in neurocognitive function over time. These results suggest that psychiatric condition indeed plays an important role with regard to neuropsychological status, and the significance of these findings as it relates to the pathophysiology of EI is discussed.

Methods. The present study utilized the data of 165 EI patients derived from a convenience sample of 212 treatment-seeking EI patients who received comprehensive neuropsychological and psychiatric evaluations following accidental electrical injury. The EI group was further dichotomized into EI participants with PTSD (EI-PTSD; $N = 31$) and those without PTSD symptomatology (EI-No PTSD; $N = 134$) on the basis of an independent psychiatric evaluation by a board certified psychiatrist that included: a) an interview with the patient (and his/her family if available); b) a review of any prior psychiatric evaluations; and c) the administration of the Structured Clinical Interview for the Diagnostic and Statistical Manual of Mental Disorders- Third Edition Revised, Axis 1, McLean version (SCID-1-MAC). The source of electrical injury in this sample was limited to domestic and commercial power sources. EI patients who had a history of closed head injury were excluded from the study. The two groups were matched for age and education. Procedures: All participants successfully passed symptom validity testing to be included in the study, and were administered the California Verbal Learning Test (CVLT) as part of a standard neuropsychological battery. The CVLT measures the capacity to learn and retain a 16-item word list with five repeated exposures to the material. A second intervening word list is introduced to examine susceptibility to distraction and source memory confusion. We examined specific CVLT indices related to immediate (Short Delayed Free Recall) and delayed (Long Delayed Free Recall) recall and retention of information (Recognition Hits). Source memory confusion and susceptibility to distraction and initial encoding of information were also examined. Two sets of analyses were conducted using multivariate analysis of variance on select CVLT indices to determine if EI-PTSD patients demonstrate overall greater impairment in memory functions and if EI-PTSD patients produce a higher rate of memory errors compared to EI-No PTSD patients. Three categories were used to characterize the overall cognitive shift within the longitudinal study patients: improved cognitive function; maintenance of a consistent level of cognitive
function and a decline in cognitive function between initial and follow-up neuropsychological evaluations. This characterization process was administered based on the opinion of the neuropsychological evaluator after the completion of a full battery of tests.

Results. Neuropsychological studies indicate that EI patients with PTSD demonstrated overall greater impairments of memory than EI patients who did not suffer from PTSD \([F (3, 140) = 2.74, p < .05]\).

EI participants with PTSD were observed to perform more poorly upon tasks of immediate recall \([F (1, 142) = 7.17, p = .004]\) and delayed recall \([F (1, 142) = 4.29, p = .02]\) as compared with EI-without PTSD. Additionally, EI -PTSD patients demonstrated an overall higher rate of memory errors as compared to the EI-No PTSD group \([F (4, 338) = 1.99, p = .048]\), accounted for primarily by a greater susceptibility to proactive interference as reflected by fewer items recalled on list B relative to the number of items recalled on trial 1 \([F (2, 169) = 4.02, p = .01]\).

Among the 20 longitudinal study subjects, 6 showed an improvement in their neurocognitive function between their initial and repeated neuropsychological evaluation, 11 subjects maintained a consistent level of neuropsychological function, and 3 subjects experienced a decline in neurocognitive function after their initial evaluation. In general, patients with little to no PTSD symptoms tended to improve their neurocognitive function over time, while those with the strongest PTSD symptoms tended to exhibit a decline in neurocognitive function over time.

Conclusions. The results of this study indicate that EI patients diagnosed with PTSD performed more poorly on a standard verbal memory task requiring learning and spontaneous recall of new verbal information compared to EI patients with no PTSD. Moreover, EI patients with PTSD tended to be more distractible compared to a group of EI patients with no PTSD. Results suggest that psychiatric condition plays an important role with regard to neuropsychological status in EI.

It is not yet well understood by which mechanisms electrical injury causes neuropsychological damage, nor how these changes progress over time. To address this, the incorporation of newer technologies such as functional neuroimaging to advance our knowledge regarding the effects of electrical exposure on brain function will be important. Both of the studies herein suggest that early recognition and treatment of severe emotional disturbance may decrease neurocognitive morbidity in electrically injured patients and improve the chances of successful rehabilitation.
GROWTH CONE GUIDANCE BY PHYSIOLOGICAL DC ELECTRIC FIELDS

Ann M. Rajnicek
University of Aberdeen, Aberdeen, United Kingdom

Objectives. Proper nervous system function requires developing neurons to make appropriate synaptic contact with target cells that are often very distant. At the tip of each growing neuronal process (neurite) is a dynamic structure, the growth cone, which is responsible for sensing and integrating directional cues present in the extracellular environment and translating them into appropriately directed migration. Since neurons within the developing central nervous system (CNS) differentiate and extend neurites within a naturally occurring DC voltage gradient it has been proposed that the resulting electric field (EF) in embryonic tissues provides a directional cue that directs growth cones toward their targets. Although several key molecules have been identified, the cellular mechanism by which growth cones detect and are guided by an EF is not yet clear.

The aims of my research are to identify the receptors and intracellular signalling cascades involved in directional growth cone steering by EFs of a physiological magnitude and to explore the cross talk between these pathways, including the consequences for regional cytoskeletal dynamics, which underpin directed migration.

Methods. Xenopus laevis neural tube (developing spinal cord) cells were dissociated and plated in chambers made from standard 100 mm diameter tissue culture dishes. (Fig 1) The chamber design incorporated agar-salt bridges to isolate the cells from potentially cytotoxic electrode products. The voltage source was a DC electrophoresis power supply in series with a variable resistor. Neurons were exposed to an EF of 150 mV/mm for 3 to 5h and time-lapse images were analysed to correlate the angle of growth cone orientation and rate of growth cone advance relative to the EF vector. Signalling pathways were studied by adding specific pharmacological inhibitors to the culture medium during EF exposure. In some cases time-lapse video images were used to correlate growth cone morphology with directional movement.

Results. In the absence of any inhibitors Xenopus spinal neuron growth cones grew preferentially toward the cathode and were deflected away from the anode. Growth cone migration rates were also increased toward the cathode and decreased toward the anode. Pharmacological studies revealed essential, but distinct roles for the small GTPases rac, rho and cdc42 in cathodal turning. Confocal microscopy indicated that rho immunofluorescence was increased anodally. Since rho stimulates growth cone collapse and since anodal rho elevation correlated spatially and temporally with collapse of filopodia and lamellipodia on
the anodal sides of growth cones a model is proposed whereby rho elevation on the anode-facing sides of growth cones underpins anodal repulsion and that conversely, rac and cdc42, which stimulate lamellipodial and filopodial extension respectively, are elevated cathodally, leading to growth cone extension and turning toward the cathode. It is not yet clear how a physiological EF modulates small GTPase activity locally but it is likely that it involves interaction of lipids and proteins very near the membrane.

**Conclusions.** Recent in vivo studies suggest that rho inhibition improves recovery from spinal cord injury in rats and clinical trials suggest that a DC EF applied to the injured human spinal cord is a promising future therapy. Therefore improved understanding of the mechanism for growth cone steering by EFs has the potential to suggest novel combined pharmacological and electrical strategies to treat CNS injury.

**Acknowledgements.** I am grateful to Louise E Foubister and Colin McCaig, who contributed to these studies and to The Wellcome Trust for funding.

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**Figure 1.** Set up for DC electric field application in vitro. A) Overhead view of chamber. B) Side view of chamber. Not drawn to scale.
NANOSECOND PULSED ELECTRIC FIELD EFFECTS ON ION CHANNELS AND MEMBRANE PERMEABILITY

Andrei G. Pakhomov, Juergen F. Kolb, Jody A. White, Rachael Shevin, Ravindra P. Joshi, Shu Xiao, Karl H. Schoenbach

1 General Dynamics - Advanced Information Systems, San Antonio, TX, USA 2 Old Dominion University, Norfolk, VA, USA 3 Old Dominion University, Norfolk, VA, USA

Objectives. Nanosecond duration, high voltage electric field pulses (nsEPs) can cause profound bioeffects, including intracellular Ca\(^{2+}\) bursts, phosphatidylserine externalization, necrotic and apoptotic cell death. In contrast to cell electroporation by µs- and ms- range pulses, nsEP-exposed cells typically remain impermeable to Trypan Blue and propidium iodide dyes, suggesting that the membrane integrity has not been violated. This observation, however, does not exclude possible membrane permeabilization to smaller ions, the mechanism that has recently been predicted by several in silico models. The present study was the first attempt to employ the whole-cell patch clamp technique to explore plasma membrane electrical properties and voltage-gated transmembrane ion currents in nsEP-exposed cells.

Methods. All experiments were performed in cultured mammalian cells (GH3, PC12, Jurkat, and HeLa) attached to poly-l-lysine-treated glass cover slips. NsEPs generated by a Blumlein line were delivered to individual cells via a pair of tungsten wire electrodes (125-µm diameter, 310-µm gap), which were positioned next to the selected cell by means of a micromanipulator. Shortly after exposure to a single pulse (60 ns width, 12 kV/cm) or a brief train of pulses, a glass micropipette was brought in contact with the exposed cell. Following gigaseal formation, the membrane was ruptured by applying slight negative pressure, and a whole-cell patch clamp recording configuration was established. The data were collected in voltage or current clamp mode, using MultiClamp 700B amplifier, Digi-data 1340 digitizer, and pCLAMP-10 data acquisition software. Randomly chosen parallel control cells were sham exposed.

Results. Exposure to a single nsEP caused about 3-fold decrease in the passive membrane resistance and partial loss of membrane potential (by 20-30%) in all tested cell lines except HeLa. These effects were markedly enhanced by applying multiple pulses. Recovery of the membrane properties was gradual and took some 10-15 min. Membrane pores opened by nsEPs showed little selectivity to small anions and cations, but were not permeable to propidium iodide (FW 668) or Trypan Blue (FW 961). Within studied limits, membrane permeabilization did not depend on the presence of ion channel blockers ruthenium red, amiloride, 4-aminopyridine, or tetraethylammonium. The increased membrane conductance after nsEP exposure could be markedly attenuated by lanthanide ions, but the block was still partial even at millimolar concentrations of Gd\(^{3+}\) and La\(^{3+}\). Exposure to nsEP also inhibited transmembrane transport via voltage-gated ion channels, Na\(^{+}\) current being the most vulnerable and the transient K\(^{+}\) current being the least affected.

Conclusions. These experiments unambiguously established that even relatively low amplitude nsEP cause multiple, profound, and long-lasting effects on cell plasma membrane. These effects are well-reproducible, dose-dependent, and apparently non-thermal in nature (heating is < 0.1°C/pulse). Observed changes in the passive permeability of the plasma
membrane were generally consistent with *in silico* models. However, nsEP effects on voltage-gated ion channels were neither expected nor predicted by modeling. The data suggest that known nsEP effects, including cell death, may be at least in part mediated by the membrane permeabilization and dependent on the composition of the extracellular medium. Plasma membrane effects of nsEP could lead to new applications in medicine and technology; they can also be employed as a criterion or guidance for science-based safety limits in exposure to ultra-short, high voltage E-field pulses.

**Acknowledgements.** The study was supported in part by internal funding from the Frank Reidy Research Center for Bioelectrics, and by the Air Force Research Laboratory under U.S. Air Force Contract (F41624-01-C-7002), awarded to General Dynamics Advanced Information Systems, Brooks City-Base, San Antonio, TX.

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**DESIGNING THE WAVEFORM OF THE ELECTRONIC CONTROL DEVICE TO REPLACE THE POLICE CLUB**

Mark W. Kroll  
University of Minnesota, Crystal Bay, MN, USA

**Objectives.** Replace the stone-age club. The specific goal: How does one take a violent and paranoid person dying of a stimulant drug overdose into custody so that they can be treated? Most people would be surprised to learn that the main methods police officers use, in such a situation, all rely on causing pain or breaking body parts. These include: wrist twists and other forms of joint distortion, pepper spray, and of course that stone-age technique—clubbing. Also, many illegal drugs are painkillers, and thus these standard techniques are ineffective at bringing a drug addict to heel and can instead lead to their serious injury. Even worse, many of the dangerously drug-addled exhibit superhuman stamina and strength. There are numerous accounts of drug abusers throwing five or six police officers around. Here are the specifications of the ideal arrest tool: First, it must temporarily freeze the largest, most determined, and drug anesthetized individual. Second, it must cause no serious injury to the suspect or the police officer. Third, it cannot rely on causing pain. Fourth, it must work reliably on both hot days and cold. Finally, it must be usable over a safe standoff distance (at least 5 meters) so an arresting officer need not come into range of a suspect’s rage.

**Methods.** Many approaches have been suggested and tested to meet these five criteria. Some that came close include throwable nets (which still require the officer to come into contact with a thrashing suspect) and projected body glues (which can entangle officers and cause enormous cleanup problems). What does seem to work is the Thomas A. Swift Electric Rifle or TASER (R) Electronic Control Device or ECD. It is an air gun, powered
by two lithium camera cells, that fires twin barbed electrodes. The electrodes are attached
by wire to a waveform generator that delivers muscle-locking current pulses into the person
hit by the barbs. The majority of law enforcement agencies in the United States, Canada,
and the United Kingdom have adopted the ECD. In the five years from 2002 to 2006 the
daily usage grew from about 60 to 650 for an astounding compound annual growth rate of
63%.

When the trigger of an ECD is pulled, a blast of compressed nitrogen launches two barbs
to a speed of 55 mps with a 9 mm tip that helps them penetrate clothing and the insulating
outer skin layer. A whisper-thin wire trails behind for up to 9 meters—forming a connection
to the ECD.

Because the barbs fail to penetrate clothing about 30% of the time, the ECD generates a
brief arcing pulse—ionizing the intervening air to establish a conductive path for the current
that will do the real work. This arcing phase has an open circuit peak voltage of 50 kV.
The body never sees the 50 kV. The TASER X26 is only capable of delivering a peak pulse
of about 3 amperes, and with the typical body resistance of 400 Ω the peak voltage the
subject experiences is about 1200 V. The average pulse voltage is 400 V.

Once the barbs establish a circuit the ECD generates a series of 100-µs pulses at the rate
of 19 per second. Each pulse comprises 100 µC of charge so the average current is just 1.9
mA. It seems a small jolt, but it’s just the right amount and at the right frequency to cause
regional skeletal muscle contractions.

Basically, an ECD works because the electric pulse it generates is just right for locking
up skeletal muscles without electrocuting (inducing ventricular fibrillation). That required
designing a signal that takes advantage of the difference in the electrical characteristics
between heart muscle and the ”motor” nerves which control skeletal muscle.

The skeletal muscle contraction force is roughly proportional to the stimulation rate up
to about 70 pps. At that point, called tetanus, contractions are continuous and can be
dangerously strong. The TASER ECDs operate far from the tetanus region at a ”clonic”
19 pps. At that point the muscles contract continuously but not so strongly as to cause any
damage.

The ECD takes advantage of two ingrained protections against electrocution. The
first—anatomy—is so obvious that it is typically overlooked. The skeletal muscles are on the
outer shell of the body; the heart is deep inside. In the upper body, the skeletal muscles
are arranged in bands surrounding the rib cage. Because of the muscle fiber’s tendency to
conduct current along its length (anisotropy), current injected into skeletal muscle tends to
follow the muscle grain around the chest rather than penetrate inwards toward the heart.

The second protection obtains from the different timing requirements of the motor nerves
and of the heart. It is the same protection that keeps one from dying from the 100-
nanosecond 30-ampere strong static shocks that can be felt in a dry winter climate.
The heart’s chronaxie is about 3 ms, or about 30 times longer than the chronaxie of motor
nerves and the pulses from an ECD. The current required to electrocute someone (induce
ventricular fibrillation) by directly pulsing the most electrically sensitive part of the heartbeat (the T-wave) using 3-ms pulses is about 20 A, and it requires 60 mC of charge. Because
the TASER X-26 100-µs pulses are so much shorter than the heart’s chronaxie, it would
take about 600 A to do the same thing. The TASER X26’s average pulse current is 1 A.
Since the ECD barbs are likely to land in current-shunting skeletal muscle away from the heart the average electrocution safety margin is about 100:1. Obviously, for barbs deeply inserted directly towards the heart the safety margin is less, but it still appears to be higher than that of some very popular headache remedies.

**Results.** In the USA, about 300 people die each year fighting with police during restraint procedures. ECDs were used during about 30% of these in-custody-deaths. As more police departments adopt these weapons that percentage will increase while the total number of deaths should decrease. (Crossover comparisons, done in large cities, have always demonstrated a reduction in serious injury after adoption of ECDs.)

Although ECDs are temporally associated with these deaths, medical examiners have only cited the devices as the primary cause of death in three cases to date. Three cases (out of over 600 000 uses) would give the devices a death rate of 1 in 200 000, making a death far less likely than one’s risk of being struck by lightning (1 in 3000). And, even those three cases are suspect. In one case, the individual had his pulse and respiration verified by Chicago paramedics after the ECD was used. He later died with a lethal level of methamphetamine in his system. The medical examiner still ruled the TASER ECD as the primary cause of death even though that directly contradicted the paramedics’ findings.

**Conclusions.** Electronic control devices are rapidly and successfully replacing the club.
Session 11: EMF Effects on the Genome and Proteomics

11-1 HUMAN LYMPHOBLASTOID CELL EXPOSURE TO EXTREMELY HIGH PEAK POWER 10 NS PULSED EMF SIGNALS IS NOT ASSOCIATES WITH DIRECT DNA STRAND BREAKAGE

Martin L. Meltz¹, Cynthia Galindo¹, Bijaya Nayak¹, Susan Weintraub², Kevin Hakala², Karl H. Schoenbach³
¹Univ. of Texas Health Science Center, San Antonio, TX, USA ²Univ. of Texas Health Science Center, San Antonio, TX, USA ³Old Dominion University, Norfolk, VA, USA

Objectives. To examine the relationship between pulsed EMF exposure, viability and direct DNA breakage, human lymphoblastoid 244B cells were exposed to extremely high average peak power 10 ns pulses (20 MV/m), which has resulted in cell toxicity, and also to 0.78 ns UWB high peak power pulses (1 kV/m), which did not result in cell killing. The total number of 10 ns pulses was 25 - 100, while the exposure to the shorter pulses was at 250 pulses per second for 30 or 90 minutes (intermittent 30 min on, 30 min off). The cell viability was measured at 2 hr and 24 hr post-exposure using the trypan blue dye exclusion assay. The cell killing varied with the number of pulses at a given average peak power.

Methods. For DNA single strand break analysis, the cells were exposed at room temperature, using the same exposure protocol as for the viability studies. They were then immediately chilled in a slush ice bath. The cells were analyzed for DNA single strand breaks using a standard comet assay technique. Slides were examined at 250X magnification using a Zeiss Fluorescent Microscope equipped with a 515-560 nm barrier filter. Image analysis was done using a CCD Pulnix Camera and scored using Komet 5.5 Software. A total of 100 cells per sample (50 cells from two different slides) were examined for DNA migration (tail length in microns), Olive Tail Moment, and % DNA Tail.

Results. For the specific exposure of 25 total 10 ns pulses, at an average peak pulse height of 200 kV/cm (20 MV/m), the cell viabilities at 2 hr and 24 hr were 73 % and 92 %, respectively.

Conclusions. The results of these studies demonstrated a total absence of evidence for DNA single strand breaks immediately after exposure to these unique 10 ns PEMF signals; any toxicity from such exposures must therefore cause cell killing through a different mechanism.

Acknowledgements. This research was supported by two grants from the Air Force Office of Scientific Research, AFOSR No. F49620-01-10349 and AFOSR No. F49620-02-10320 (through Old Dominion University).
11-2 GENE EXPRESSION CHANGES IN RAT SKIN FOLLOWING PROLONGED 35-GHZ MILLIMETER WAVE EXPOSURE

Walter G. Hubert\textsuperscript{1}, Nancy J. Millenbaugh\textsuperscript{1}, Caleb C. Roth\textsuperscript{1}, Roza Sypniewska\textsuperscript{1}, Victor Chan\textsuperscript{2}, Jeffrey S. Eggers\textsuperscript{3}, Robert V. Blystone\textsuperscript{4}, Johnathan L. Kiel\textsuperscript{5}, Patrick A. Mason\textsuperscript{6}  
\textsuperscript{1}AFRL, Brooks City-Base, TX, USA \textsuperscript{2}AFRL, Wright-Patterson AFB, OH, USA \textsuperscript{3}AFRL, Brooks City-Base, TX, USA \textsuperscript{4}Trinity University, San Antonio, TX, USA \textsuperscript{5}AFRL, Brooks City-Base, TX, USA \textsuperscript{6}AFRL, Wright-Patterson AFB, OH, USA

Objectives. Prolonged exposure to millimeter waves (MMW) leads to hyperthermia in laboratory rats. While this response has been well characterized physiologically, the underlying regulation is not well understood at the molecular level.

Methods. In an effort to identify MMW-specific biomarker candidates in the target organ of energy deposition, gene expression in skin biopsies from non-lethally irradiated animals was compared to sham- and environmental heat-controls by microarray analysis. RNA levels of genes exhibiting significant changes were further quantified by real-time polymerase chain reaction.

Results. Among the 15866 genes and expressed sequence tags sampled by the microarray, 43 genes were found to be up- and 13 down-regulated at 6 h post-MMW exposure, while at 24 h, 27 were up- and 31 down-regulated. The observation that only 8 of these genes were regulated similarly at both time points is consistent with the notion of a biphasic biological response. Genes involved in cellular transcription, protein folding, tissue matrix turnover, as well as oxidative stress- and immune responses were regulated differentially at 6 and 24 h. At the later time point, fewer heat-shock protein genes remained up-regulated and gene expression was altered for more extracellular matrix components as well as regulators of chemokine activity and cell adhesion.

Conclusions. Prolonged exposure to 35-GHz MMW primarily up-regulates the expression of factors in the skin which indicate thermal stress and tissue injury and which participate in inflammation and repair processes.

Acknowledgements. This work was supported by a grant from the Air Force Office of Scientific Research and institutional funds of the Air Force Research Laboratory, Radiofrequency Radiation Branch.
11-3 GENE REGULATION IN ESCHERICHIA COLI AS A RESPONSE TO NANOSECOND PULSED ELECTRIC FIELDS

Michael A. Gealt¹, Zheng-Ming Wang², Howard L. Gerber³, Karl H. Schoenbach⁴, Charles C. Tseng²
¹University of Arkansas at Little Rock, Little Rock, AR, USA ²Purdue University Calumet, Hammond, IN, USA ³Purdue University Calumet, Hammond, IN, USA ⁴Old Dominion University, Norfolk, VA, USA

Objectives. Escherichia coli was used as a model system to determine how bacterial genes respond to nsPEF and for comparisons of this response to that observed in eukaryotic systems. A whole genome DNA microarray was used to determine the effect of the nsPEF on the gene expression at the mRNA level. In previous reports we described the genes that with enhanced expression following 25 pulses with a length of 10 ns. We now report on the genes that showed decreased expression following 25 pulses with a length of 10 ns. We now report on the

Methods. E. coli grown at 37 C in Luria broth to approximately 10E9 cells/ml in 30 ml was resuspended in Hanks BSS before being treated with 25 10 ns pulses at 270 kV/cm. Following this treatment the cells were incubated for an additional 10 minutes at 37 C to allow gene expression. Following this incubation, cellular RNA was extracted and RT-PCR was used to create cDNA with incorporated cyanine-3-dCTP or cyanine-5-dCTP. Hybridization of the labeled cDNA to oligonucleotide probes specific for the E. coli genes was performed with the MWG DNA Array for E. coli K12-V2. Following washing of the hybridized nucleic acids, the microarray was scanned in GenePix 4000B Microarray Scanner. Genes identified as being down-regulated were determined and the sequences obtained from EcoGene. Primers were generated from these sequences and RT-PCR was used to confirm the reduced expression.

Results. After 25 pulses, the viability was always 70% or greater. Following 25 pulses, 20 genes were identified as being down regulated (synthesizing no more than 50% of the amount of RNA synthesized before treatment). The sequences from these identified genes were obtained and used to generate PCR primers. The primers were used in RT-PCR to obtain confirmation of the down regulation. At least 12 of the identified genes were confirmed as being down regulated. These genes were not in a single operon, but were located throughout the E. coli genome. The confirmed down-regulated genes are: yadE (polysaccharide deacetylase-like protein), yahH (unknown function, may be lipoprotein-like), gltI (periplasmic glutamate-aspartate binding protein), ybIB (function unknown), grxB (glutaredoxin 2), sra (ribosome-associated protein), osmE (osmotically inducible, contains signal peptide sequence), manZ (mannose permease), glgS (glycogene synthesis regulator), glmM (phosphoglucosaminemutase), hdeB (periplasmic chaperone), and fsaB (fructose-6-phosphate aldolase B).

Conclusions. Previous work indicated that genes involved with DNA repair were up-regulated (enhanced gene expression). The down-regulated genes appear to be involved primarily with cell membrane and cell wall structures (permeases, sugar transport, lipoproteins), or are located in the periplasmic space between outer membranes. This suggests that E. coli cells are decreasing the energy utilized for wall and membrane synthesis while
putting cellular energy into repair of the genome. E. coli is more resistant to ns PEF than human Jurkat cells used in another study, suggesting that the coordinated effort of DNA repair and decreased structural efforts help cells repair damage resulting from exposure to pulsed electric fields.

**Acknowledgements.** This research is supported by two AFOSR DOD MURI grants.

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**11-4 GLOBAL GENE RESPONSE TO EMF IN SACCHAROMYCES CEREVISIAE**

Zhengping Xu, Guangdi Chen, Lingli Wang, Deqiang Lu, Huai Chiang
Bioelectromagnetics Laboratory, Hangzhou, China

**Objectives.** To investigate the global change of gene expression pattern induced by 50 Hz magnetic fields (MF) or 1800 MHz radiofrequency electromagnetic fields (RF EMF) in Saccharomyces Cerevisiae, and identify key EMF-responsive genes in the yeast cells.

**Methods.** The yeast cells were exposed to 0.4 mT 50 Hz MF, or 1800 MHz RF EMF at a time-averaged SAR of 3.5 W/kg for 6 hours. Total RNA was isolated by hot phenol assay and then purified using QIAGEN’s RNeasy mini Kit. Affymetrix Yeast Genome S98 gene chips (2 chips for control and 2 for exposure) were applied to detect the gene expression pattern following the manufacturer’s instruction. Data was analyzed by Affymetrix Genechip Operating Software version 1.0 (GCOS 1.0) and Affymetrix Data Mining Tool 3.0 (DMT 3.0). And the quantitative real-time reverse transcription polymerase chain reaction (RT-PCR) analysis was conducted to confirm the results of Genechip assay.

**Results.** The GOCS software analysis showed that there were a number of differentially expressed genes in single pair-wise comparison after exposure to the MF or RF EMF. The reproducible and consistent analyses with DMT software revealed that three genes were affected by 50 Hz MF exposure with 100% consistency in 4 pairwise comparisons, i.e. Self-glucosylating initiator of glycogen synthesis (GLG2), Regulatory subunit of protein phosphatase 1 (GLC8), and a gene with unknown function.

The same procedure was applied to analyze genes affected by RF EMF, and 40 differentially expressed genes were screened with 100% consistency after DMT software analysis, including 13 down-regulated genes and 27 up-regulated genes.

However, all these differentially expressed genes responding to both EMF exposure were not confirmed by the quantitative real-time RT-PCR method, indicating they were false positives.

**Conclusions.** Our study demonstrated that the EMF exposure did not induce differential gene expression in Saccharomyces Cerevisiae. The applicability of HTST in EMF research needs to be discussed.
**Acknowledgements.** This study was supported by the National Natural Science Foundation of China (No. 50137030), the Key Project of the Chinese Ministry of Education (No. 104092), the Excellent Young Teachers Program of MOE, P.R.C., and Zhejiang Provincial Natural Science Foundation (No. M303807).

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**11-5 GENE EXPRESSION OF CELLS EXPOSED TO 2-GHZ BAND W-CDMA MODULATED RADIOFREQUENCY FIELDS IN TRANSFORMATION ASSAY.**

Hideki Hirose¹, Kohei Inoue¹, Takeshi Suhara¹, Koji Nakayama¹, Masaru Sekijima¹, Toshio Nojima², Junji Miyakoshi³

¹Mitsubishi Chemical Safety Institute Ltd., Kamisu, Japan ²Hokkaido University, Sapporo, Japan ³Hirosaki University, Hirosaki, Japan

**Objectives.** The objective was to investigate any signs of a carcinogenic process induced by radiofrequency (RF) fields. We studied altered gene expression in BALB/3T3 cells exposed to RF radiation in the transformation assay. In order to assess carcinogenic potential on the low level RF, which corresponds to the limit of the average whole body SAR for general public exposure defined as a basic restriction in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [1], in vitro BALB/3T3 cell transformation assay was employed using a large-scale in vitro exposure system [2].

**Methods.** We used the in vitro exposure system with a horn antenna and dielectric lens in an anechoic chamber, which allows simultaneous exposure of 49 (7x7 array) 35 mm dishes [2]. In this study, we performed the experiments accurately employing two pairs (exposure and sham) of this exposure system [3]. Exponentially growing BALB/3T3 A31-1-1 cells were seeded at 5000 cells/35-mm dish in 20 replicates. Non-, 100 ng/ml 3-methylcholanthrene (MCA)-, or 100 ng/ml MCA plus 30 ng/ml 12-O-tetradecanoylphorbol-13-acetate (TPA)-treated cells were exposed to W-CDMA RF field at average SAR of 80 or 800 mW/kg for 6 weeks, to confirm its initiation, promotion, or combination activities. The RF field exposures dishes were processed in a blind manner. The frequency was 2.1425 GHz, which corresponded to the middle frequency allocated to the downlink band of the IMT-2000 from mobile radio base stations. The medium was changed twice a week for the duration of the assay. Total RNA was isolated from cells harvested from dishes 2 and 4 weeks after starting the culture. Data were analyzed using Affymetrix (R) Microarray Suite 5.0 (MAS 5.0) software. Genes were considered to be differentially expressed if (i) the expression changed at least twofold in the independent experiments performed with triplicate RNA samples, and (ii) the mRNAs were assigned a "present" detection call by the Affymetrix software. The multiplicity problem was controlled by the Benjamini and Hochberg false discovery rate [4]. A p-value of less than 0.05 was considered statistically significant.
Results. We evaluated whether or not there were biological effects of exposure to W-CDMA RF field at SAR of 80 or 800 mW/kg on the gene expression profile in the non-, 100 ng/ml MCA-, and 100 ng/ml MCA plus 30 ng/ml TPA-treated cells during a cultivation period of two and four weeks. In the RF field exposure experiments, 22,418-23,306 genes were “present” or “marginal” in BALB/3T3 cells, of 45,101 gene probe sets. There was no statistically significant difference observed between any of the RF field (80 or 800 mW/kg) exposure groups and the sham exposed controls in gene expression profile, including cyclin and proto-oncogenes. On the contrary, treatment of BALB/3T3 cells with 100 ng/ml MCA plus 30 ng/ml TPA resulted in a significant changes at least twofold in 322 gene expressions, including cyclin and proto-oncogene expressions, in a cultivation period of two weeks, compared to non-treated cells. Our experimental results suggest that long-term exposure to W-CDMA at 2.1425GHz does not affect the gene expression profile at the limit of the average whole-body SAR level (80 mW/kg) as defined by the ICNIRP guidelines.


Acknowledgements. This work was supported by NTT DoCoMo Inc.

11-6 PREDICTION ALGORITHM FOR EXPOSURE TO RADIOFREQUENCY RADIATION USING GENE EXPRESSION PROFILES

Woong-Yang Park, Jeong-Sun Seo, Tai-Qin Huang
Seoul National University, Seoul, South Korea

Objectives. General concerns about possible health effect upon RF radiation have been raised in the public as well as health care providers. Carcinogenic effect has been studied during last decades, but the relationship between cancer and RF radiation seems to be not so evident. At the molecular levels, the effects of RF radiation on DNA damage, chromatin conformation (Belyaev et al., 2006), permeability of blood-brain barrier (BBB) (Persson et al., 1997), the concentration of zinc ions (Aksen et al., 2004), and the activities of ornithine decarboxylase (ODC) (Paulraj et al., 2002) were reported to be not proven. In our previous reports on stress responses, 1763MHz RF radiation did not induce the expression of heat shock proteins nor activate MAPKs in whole-body exposed mice (Lee et al., 2005). However, the molecular effect of RF radiation is still debated by several reports on the same targets.
A high throughput analysis on genome using microarray can provide powerful information on the molecular characteristics of certain physiological and pathological conditions. A number of investigators observed gene expression profiles in ionizing radiation (IR) (Park et al., 2002) to find IR-specific genes. In this study, we tried to find biomarkers to predict the RF-exposed cells from shame-exposed one using gene expression profiles.

**Methods.** Jurkat cells were exposed to 10 W/kg of 1763 MHz RF radiation for one hour or one hour a day for 7 days. Cells were harvested immediately as R0 groups like sham (SR0) and PCS-exposed (PR0), and cells were incubated for 5 hours to recover from acute response as R5 groups like sham R5 (SR5) and PCS-exposed (PR5). We repeated sets of experiment five times to collect biological triplicates in every sample.

**Results.** We have designed the microarray experiments to identify the genes, which were differentially expressed among the three groups – sham, PR0, and PR5. By the statistical analysis (p < 0.05), we selected 68 differentially expressed genes, among which 45 genes were fully annotated. Even though the numbers of genes listed here were quite small, we could suggest that cells suffered transcriptional changes upon RF-radiation. Using the GO analysis, we could characterize the biological responses to RF radiation in Jurkat T cells. Cellular responses require the changes in the expression of transcription factors and kinase enzymes. Especially those genes were related to apoptosis and cellular metabolism.

Finally we have developed an algorithm to predict the exposure to RF radiation using those 68 genes based on SVM algorithm. We estimated the prediction error with accuracy, TP rate, FP rate, precision and F-measure using 10-fold cross validation. While one dataset from PR5 class was misclassified as a sham class, our prediction model could find the correct target class of 19 among 20 examples exactly (95% accuracy).

**Conclusions.** Using in vitro and in vivo models, we have investigated biological responses to radiofrequency (RF) radiation. For the levels of heat shock proteins and the activation of mitogen activated protein kinases (MAPKs), we could not detect any alteration. In this study, we tried to find the molecular responses to RF radiations using gene expression profiling. Jurkat T cells were exposed to 1763 MHz RF radiation at an average specific absorption rate (SAR) of 10 W/kg for an hour and harvested immediately (R0) or after five hours (R5). From the profiles of 30,000 genes on the microarray, we could select differentially expressed genes using a random-variance F-test method. We designed prediction model using 68 genes to discriminate three groups using support vector machine (SVM) algorithm. This prediction model could predict the target class of 19 among 20 examples exactly. From these data, we could suggest biomarkers to predict the RF radiation exposure with high accuracy, which might need to be validated in in vivo models as well as volunteers.

**Acknowledgements.** This work was supported by a grant from The Ministry of Information and Communication of Korea (2006-P20-60) to J.-S. Seo.
DOSE-DEPENDENT DNA DAMAGING EFFECTS OF EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC FIELDS (UMTS; 1950 MHZ) IN HUMAN FIBROBLASTS IN VITRO

Elisabeth Kratochvil¹, Claudia Schwarz¹, Alexander Pilger¹, Franz Adlkofер², Niels Kuster³, Hugo W. Rüdiger¹
¹Medical University of Vienna, Vienna, Austria ²Foundation for Behaviour and Environment, Munich, Germany ³Swiss Federal Institute of Technology, Zurich, Switzerland

Objectives. UMTS (Universal Mobile Telecommunication System) is the recently introduced mobile communication standard in Europe. No information about biological effects and genotoxic properties of these particular signals is available so far. Secure use of this new technology needs knowledge about the lowest biological effective dose. Exposure to RF-Emf induces DNA strand breaks in vitro as demonstrated in diploid human fibroblasts in our laboratory using different GSM signals. Therefore we tested whether RF-EMFs generated by UMTS signals have genotoxic properties as well.

Methods. We investigated if exposures to signals simulating the 3rd generation mobile system UMTS affects the frequency of DNA strand breaks and micronuclei in cultured human fibroblasts. DNA strand breaks were determined with the alkaline comet assay, the frequency of micronuclei by means of the cytokinesis-blocked micronucleus assay.

An exposure apparatus for uniform exposures of cell monolayers with bandwidths of larger than 5 MHz at 1950 MHz was developed and provided by the ITIS-foundation (Foundation for Information Technologies in Society, Zurich, Switzerland; www.itis.ethz.ch). The setup was based on two short-circuited R18 rectangular waveguides, both of which were placed inside a commercial incubator (BBD 6220, Kendro, Vienna, Austria) to ensure constant environmental conditions for cultured cells (37 °C, 5 % CO2, 95 % humidity). Two sets with six 35 mm diameter Petri dishes each were exposed simultaneously per waveguide chamber (one set exposed and the other sham-exposed). For loading the setup, the short cut could easily be removed and the cell dish holder could be placed inside positioning the Petri dishes in the H-field maxima ensured by the appropriate insets for the Petri-dish holders. Exposition was controlled by field sensors, temperature sensors for the air environment, and by an optimized air-flow system based on ventilators with a common inlet for both waveguides. The signal unit was designed for generation of the UMTS test signal. The system could be used for exposure of cell monolayers up to 17 W/kg with less than 26 % non-uniformity of the specific absorption rate (SAR). The system allowed for exposure with a temperature load of the medium less than 0.03 °C / (W/kg). The temperature difference between the waveguides did not exceed 0.1 °C. To enable blind experimentation, a computer randomly determined which of the two waveguides was exposed. Therefore, the experimenter did not know which cells had been actually exposed. This information was stored in an encoded file and uncovered by the ITIS foundation in Zurich via e-mail in exchange with the transmission of results.

Dose dependency - Continuous exposure for 24 hours was performed in all experiments with SAR values between 0.05 and 2.0 W/kg. Each experiment was conducted in quadruplicate.

Time dependency - Continuous exposure at a SAR value of 0.1 W/kg was performed in all experiments with exposure durations between 4 and 48 hours. Each experiment was
conducted in triplicate. Intermittency - Different intermittency schemes were tested using exposure conditions proved to be optimal in the previous tests (16 hours and 0.1 W/kg). Each experiment was conducted in triplicate.

**Results.** Continuous exposure of cultured human fibroblasts to UMTS test signal (carrier frequency 1950 MHz) at SAR values of 1.0 and 2.0 W/kg resulted in a 2-fold increase of DNA strand breaks compared to sham-treated controls at exposure durations of 16 and 24 hours (p < 0.001). An increased frequency of micronuclei in exposed human fibroblasts was observed after an exposure duration of 16 hours at a SAR value of 1.0 and 2.0 W/kg which was significant with the one-sided $\chi^2$-test. This increase was twofold compared to the basal level after 24 hours and reached significance using the $\chi^2$-test (p < 0.05) with both SAR values tested (1.0 and 2.0 W/kg). The dose dependency of UMTS-related DNA strand breaks was investigated after continuous exposure for 24 hours. An increased comet tail factor was detected with field intensities between 0.01 and 2.0 W/kg, being significant (p < 0.001) at all SAR values investigated. A threefold increase compared to sham-exposed cells was detected at a SAR value of 0.1 W/kg, whereas 0.05 W/kg, 1.0 and 2.0 W/kg all yielded only a twofold increase. Again, no significant differences could be demonstrated between 1.0 and 2.0 W/kg. Time dependency of UMTS-related genotoxic effects was evaluated using a SAR of 0.1 W/kg, because this value has proved to be most effective in the alkaline comet assay. An increased response in exposed human fibroblasts compared to sham-treated controls could be detected after 8 hours of exposure (p < 0.05) or longer (p < 0.001). Comet tail factors of exposed cells increased until a plateau was reached after an exposure duration of 20 hours. Intermittent exposure for 16 hours at a SAR of 0.1 W/kg generated slightly but significantly more DNA strand breaks in human fibroblasts compared to continuous exposure.

**Conclusions.** Our detailed comet assay data point to a genotoxic effect of UMTS in vitro which is confirmed by an induction of micronuclei at SAR values of 1.0 and 2.0 W/kg.

**Acknowledgements.** This study was supported in part by the Austrian Workers Compensation Board, Vienna, Austria, the Verum Foundation, Munich, Germany, and the Austrian Science Fund FWF (project number P18984-B09). The authors gratefully acknowledge the valuable assistance of Marietta Weninger and Petra Hartbauer.

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**11-8 EFFECT OF MOBILE PHONE RADIATION ON PROTEIN EXPRESSION IN SKIN OF HUMAN VOLUNTEERS: A FEASIBILITY STUDY**

Dariusz Leszczynski, Anu Karinen
STUK-Radiation and Nuclear Safety Authority, Helsinki, Finland
Objectives. Our previous in vitro studies have shown that changes in protein expression and in protein activity (phosphorylation) appeared when human endothelial cell line EA.hy926 was exposed for 1 hour to 900 MHz GSM signal [1, 2, 3]. These effects, however, do not automatically prove that similar changes will happen in mobile phone users. Therefore, the study was undertaken to determine whether the local exposure of skin of human volunteers to 900 MHz GSM signal will induce changes in protein expression and whether it will be possible to find any common protein(s) responding to mobile phone radiation among the different volunteers.

Methods. The present study was composed of two parts. In the first part, the extent of the variability of protein expression in skin, among 20 different people, was examined. Comparison of these 20 different protein expression profiles gave an estimate about the variability of protein expression pattern between different donors. This information was then used to set-up a baseline of protein expression variability that was used in the evaluation and validation of the results obtained from the mobile phone radiation exposed volunteers. In the second part of the project a small skin area of forearm of 10 volunteers was irradiated for 1 hour with 900 MHz GSM signal at a specific absorption rate (SAR) of ≤2.0 W/kg. Immediately after the exposure, a punch biopsy of the exposed area of skin (experimental sample) was taken by a physician. Another punch biopsy was taken from the non-exposed skin of the other, non-exposed, forearm (sham sample). In this experimental set-up each volunteer acted as own sham control. Both exposed and non-exposed skin samples of all volunteers were frozen immediately and stored before extraction of proteins.

Proteins were extracted with TRIzol (R) Reagent (Invitrogen) and separated using 2-dimensional gel electrophoresis (2-DE) with pH gradient range of 4-7 in the first dimension and 9% SDS-PAGE gel in the second dimension. Proteins in the gels were detected by silver staining and distribution pattern was analyzed using PDQuest 7.2 software. Proteins showing statistically significant changes in expression in response to mobile phone radiation were identified by MALDI-TOF mass spectrometry.

Results. The PDQuest software analysis of the protein expression changes using 2-DE and the Maldi-ToF identification of proteins is still ongoing.

Conclusions. Results and final conclusions will be presented at the meeting.

12-1 ACCURATE AND FAST ESTIMATION OF VOLUMETRIC SAR FROM PLANAR SCANS FROM 30 MHZ TO 6 GHZ

Mark Douglas, Chung-Kwang Chou
Motorola Labs, Ft. Lauderdale, FL, USA

Objectives. An accurate algorithm is developed for the estimation of 1-gram and 10-gram averaged SAR in a homogeneous phantom from a wireless handset using two-dimensional scans, saving as much as 70% of the three-dimensional scan measurement time. This study extends the frequency range of a previous algorithm to the entire 30 MHz − 6 GHz spectrum covered by new SAR measurement standards.

Methods. The algorithm requires only the measurement of a coarse two-dimensional scan and knowledge of the penetration depth (see Kanda et al., IEEE Trans. Microwave Theory and Techniques, vol. 52, no. 8, pp. 2013-2020, 2004). A linear equation estimating the penetration depth \( \delta \) as a function of frequency \( f \) was previously determined in Kanda et al.:

\[
\delta \text{ [mm]} = -10.7 \ f \text{ [GHz]} + 40.4 \ (1)
\]

This equation was developed for 150 − 2450 MHz by analyzing dozens of wireless products. There is a strong demand to extend the frequency range of this algorithm to 30 MHz − 6 GHz. There is not yet a sufficiently large portfolio of products at these frequencies to conduct a study in the same manner as was done previously. In addition, measurements at very low and very high frequencies can be difficult and are still being standardized. Therefore, numerical simulations of canonical antennas were performed.

The present study consists of four steps. First, a Method of Moments (MoM) code was used to simulate the SAR distributions in a flat phantom from half-wavelength dipole antennas. The parameters of the phantom are consistent with IEEE 1528 and IEC 62209-1 standards. The dipole antennas are fed at frequencies from 150 − 2450 MHz, and they are located at different distances \( d \) from the phantom. Second, the distance having penetration depths closest to those of real wireless products in Kanda et al. was found. This effective distance \( (d_e) \) accounts for the difference between the concentrated current distribution on a thin dipole antenna and the more spread current distribution on a typically rectangular wireless handset. Third, MoM simulations were run from 30 MHz − 6 GHz using half-wavelength dipole antennas at a distance \( d_e \) from the flat phantom. Fourth, the penetration depths were calculated and a polynomial function was found that gives the best fit over the 30 MHz − 6 GHz range.
**Results.** MoM simulations of half-wavelength dipole antennas at a distance $d$ below a flat phantom were performed, where $d$ varies from 10 mm to 50 mm. Figure 1 shows the resulting penetration depths for $d = 10, 25$ and 50 mm at frequencies from 150 $\text{–} 2450\text{ MHz}$. The effective distance was found to be $d_e = 25\text{ mm}$. The root-mean-squared (rms) error between the SAR values calculated from the dipole data and from the product data is not sensitive to this distance, which indicates that the use of the effective distance can be extended to other frequencies without concern of large errors.

MoM simulations were run at frequencies from 30 MHz $\text{–} 6\text{ GHz}$ using half-wavelength dipole antennas 25 mm below the flat phantom. The resulting penetration depths are shown in Fig. 2. A least-squares polynomial through the dipole antenna data is obtained, having the form:

$$\ln (\delta [\text{mm}]) = -0.00814 <\text{it}>x</it>^4 - 0.0698 <\text{it}>x</it>^3 - 0.168 <\text{it}>x</it>^2 - 0.345 <\text{it}>x</it> + 3.31 \text{ (2)}$$

where $x = \ln(f [\text{GHz}])$. It is observed that the linear fit of Equation (1) deviates significantly from the product data outside the 150 $\text{–} 2450\text{ MHz}$ range. The polynomial fit of Equation (2) fits the dipole penetration depth data well, with an rms error of 4.1%. Within the 150 $\text{–} 2450\text{ MHz}$ frequency range, the rms deviation between Equations (1) and (2) is 0.5% and 1.7% for the 1-gram and 10-gram averaged SAR, respectively. This indicates that switching to Equation (2) does not have a significant impact on the SAR estimate within this range.

**Conclusions.** A new algorithm has been developed to quickly and accurately estimate the 1-gram and 10-gram averaged SAR from two-dimensional scans. The new algorithm extends the frequency range of a previous algorithm to 30 MHz $\text{–} 6\text{ GHz}$.
Figure 1: Penetration depths vs. frequency in the 150 – 2450 MHz range.

Figure 2: Penetration depths vs. frequency at 30 MHz – 6 GHz showing the new polynomial fit.
12-2 FAST SAR COMPLIANCE ASSESSMENT USING OPTICAL TECHNIQUES

Vildana Hodzic, Robert W. Gammon, Quirino Balzano, Christopher C. Davis

1University of Maryland, College Park, MD, USA  
2University of Maryland, College Park, MD, USA

Objectives. To develop fast SAR compliance assessment optical techniques for wireless devices.

Methods. We have developed a very sensitive system for a rapid SAR measurement which provides the assessment of the SAR produced by a cell phone in a test phantom in less than one minute. It combines a Jamin interferometer and a beam deflection measurement using a position sensitive detector (PSD). A photograph of the current lab version is shown in Fig. 1. The laser beam is divided into two vertically-displaced parallel-beams by the first Jamin etalon. The top beam is a probe beam and the lower one is a reference beam. The two beams recombine upon reflections at the second Jamin flat. We are testing thermal excitation by near-field RF exposures produced by a radiating antenna placed near the upper phantom surface. The probe beam experiences an optical path-length change caused by the thermal variation of the refractive index of the phantom liquid. Our optical system allows probing of the sample at different depths below the antenna, as well as at different orientations (parallel and perpendicular to dipole) and at different lateral distances from the antenna. Beam deflections were measured by replacing a photodiode (D in Fig. 1) by a mirror, folding the output beam and using a PSD.

Results. We have performed tests with two microstrip tapered balun printed dipole reference antennas (900MHz and 1800MHz) at two power inputs (325 mW and 10 mW). The phantom liquid used is 0.1 M solution of NaCl in water. Results of the tests done with the interferometer are summarized in Fig. 2. We plotted phase difference as well as temperature rise versus time (from ”RF on”) for 900 MHz and 1800 MHz antenna fed by 325 mW (resonantly tuned to phantom load, 882.5 MHz and 1760 MHz respectively). For comparison we plotted on the same graph a temperature rise that corresponds to the currently specified maximum specific absorption rate (SAR) averaged over 1 g of tissue. This shows that for the 900 MHz antenna there is a linear temperature rise of 15.8 mK/min within the first minute of exposure. For the 1800 MHz antenna the initial response is faster, a linear temperature rise of 25.2 mK/min occurs in the first 30 seconds. Figure 3. shows thermally induced angular deflection of the upper Jamin beam as a function of time (from ”RF on”) for the 1800 MHz antenna fed by 325 mW. The right hand axis on this graph represents a derived temperature rise versus time from turning the antenna ON. The initial slope for deflection was -28.1 µrad/min and the derived temperature slope was 28.4 mK/min. Beam deflection measurements done on the lower Jamin beam show no angular deflection.

Conclusions. The work done so far shows that we have two optical methods that complement each other and provide adequate detection of the SAR temperature distribution in the phantom. Either could be used in the design of an instrument for fast SAR compliance assessment. Further development of the system would include simultaneous monitoring of the SAR with several beams to assess a 3D temperature distribution in the phantom.
Acknowledgements. This research has been supported by the Mobile Manufacturers Forum (MMF).

Figure 1. A photograph of the SAR measurement setup
A Jamin interferometer flats
B Double-walled flat phantom
C He-Ne laser
D Photodiode in interferometer configuration; Mirror in beam deflection measurement
E Antenna
Figure 2. a) Phase difference and temperature rise as a function of time from turning antenna ON measured with Jamin interferometer. Probe laser beam directly below (∼6 mm into phantom liquid) and parallel to the dipole. Input power is 325 mW. (green) 900 MHz antenna, initial slope = 15.8 mK/min; (red) 1800 MHz antenna, initial slope = 25.2 mK/min; (blue) 1 g SAR limit temperature slope = 22.8 mK/min. b) Same as a) except input power is 10 mW at 1800 MHz. (green) measurement; (black) linear fit of the initial one minute response gives the initial slope of 1.36 mK/min.
Figure 3. Angular deflection of the upper beam measured with a PSD 2.08 m away from output Jamin flat. Probe laser beam directly below (≈6 mm into phantom liquid) and parallel to the dipole. Input power 325 mW at 1800 MHz. Right hand axis represents a derived temperature rise. (blue) measurement; (red) exponential fit: initial slope = -28.1 µrad/min (28.4 mK/min).
12-3 SAR MEASUREMENT VALUE VARIATIONS BY THE TEST POSITIONS OF MOBILE PHONES

Yoon-Myoung Gimm$^{1,2}$, Young-Ho Jang$^1$, Seung-Bae Lee$^2$, Kyung-Jin Yeo$^3$, Hak-Tae Oh$^3$

$^1$Dankook University, Hannam-dong, Yongsangu, South Korea $^2$EMF Safety Inc., Hannam-dong, Yongsangu, South Korea $^3$Radio Research Laboratory, Wonhyoro-3 ga, Youngsangu, South Korea

Objectives. Checking the SAR value variations by the test positions of the mobile handsets for suggesting the additional standard test position giving more SAR values than at the existing test positions to avoid the under evaluation of the nominal SAR of the handsets.

Methods. IEEE std 1528-2003 recommends two kinds of handset test positions against the head phantom - the ”cheek or touch” position and the ”15° tilt” position. While maintaining the cheek position, test phones were revolved 10° up from the mouth to the nose and 10°, 20° down from the mouth to the neck. SAR values were measured at 4 different touch positions and at a tilt position with 12 phone models. All of the test phones were manufactured by Samsung Electronics and all of them were for operating in the CDMA (850 MHz band) network in S. Korea. SAR values were measured by ESSAY-III system of EMF Safety Inc..

Results. For the most of the test phones 20° down revolutions from the mouth of 0° touch position to the neck gave more SAR values than at the existing standard positions. We can consider to add this phone position to the standard SAR test positions. Instead tilt position gave much smaller SAR values which can be deleted from the standard test positions.

12-4 RF EXPOSURE ANALYSIS OF MULTI-BAND, MULTI-SYSTEM MOBILE PHONES IN REAL NETWORKS

Sven Kühn$^1$, Valentin Keller$^1$, Christoph Sulzer$^2$, Denis Spät$^1$, Niels Kuster$^1$

$^1$ETH Zurich, Zurich, Switzerland $^2$SPEAG, Zurich, Switzerland

Objectives. The cumulative exposure dose of cellular phones during usage in a network is a function of the SAR strength and distribution (SARdistr) at maximum power level (PWCmax), the average power control level (PWCavg) depending on the corresponding transmission mode and the duration of the exposure (t). The total dose for a phone continuously operated at the same position at the head can be assessed as follows:

\[ \text{Dose} = \text{SARdistr} \times \frac{\text{PWC(avg)}}{\text{PWC(max)}} \times t \]
The SAR strength and distribution are highly dependent on the phone design and the communication system. The cumulative dose may also be affected by the radiation effectiveness of the phone, network coverage, environmental and user factors, as well as the communication network’s power control implementation.

The objective of this study was to evaluate the power control behavior of GSM900, GSM1800, and UMTS mobile phones in real networks in various environments in single as well as multi-band and multi-system operation.

**Methods.** The phones were evaluated using the SYstem NEtwork and HAndset (SYNEHA) Analyzer. The SYNEHA analyzer compares the power control of up to four handsets simultaneously in different environments and networks. The phones were mounted on the SAM phantom, and the relative PWC was measured locally with a SAR sensor behind the ear. The communication systems and frequency bands of the phones were recorded and evaluated in parallel using a frequency selective receiver in each SAM head.

The system specifications were:
- **sampling rate:** > 3000 samples/s (rise time < 0.1s)
- **dynamic range:** > 40dB
- **linearity:** < 0.2dB
- **noise:** < 1mW/kg
- **temperature range:** 10-40 °C (< 1dB)
- **frequency discrimination:** EU / US communication bands
- **humidity:** 0 - 90%
- **relative position accuracy (head/phone/probe):** < 1mm
- battery and AC operated

**Results.** For the GSM system, the exposure is dominated by the SAR level at maximum power level. For the UMTS system phones, the cumulative dose is much lower than for GSM phones. The power control in UMTS is more efficient than in GSM, and hence the power control of UMTS is also dependent on the phone’s radiation effectiveness and the environment. The exposure from multi-system phones was dominated by the exposure during GSM communication backup.

**Conclusions.** For GSM phones the spatial peak SAR determined during compliance testing is an accurate indicator of the relative average exposure of the user by a particular phone compared to other phones. The average exposure dose due to UMTS system phones is much lower than from GSM phones.

**Acknowledgements.** Support of SPEAG, Zurich and Cellular Telephone and Internet Association (CTIA).
**12-5 FINAL REPORT ON THE INTERNATIONAL INTERCOMPARISON OF SAR MEASUREMENTS ON CELLULAR TELEPHONES**

Christopher C. Davis, Quirino Balzano  
University of Maryland, College Park, MD, USA

**Objectives.** To be compliant with national and international regulations, cellular telephones must be tested to verify that the maximum volume-averaged specific absorption rates (SARs) that they produce within an anthropomorphic phantom are below specified values. The testing procedure is specified in detail in IEEE Standard 1528 [1]. To determine whether compliance laboratories can perform such SAR measurements precisely, an international intercomparison has been carried involving 17 different laboratories to assess the variability of standard SAR measurements over many laboratories who are involved with the compliance testing of wireless phones with respect to human exposure limits. This study follows a previous intercomparison study in which 15 laboratories made SAR measurements in a standard flat phantom placed in the near-field of custom 900MHz and 1800MHz dipole antennas [2].

**Methods.** SAR Measurements are made inside an anthropomorphic phantom with two different wireless phones placed close to the ear of the phantom to determine the peak spatial SAR averaged over 1-gram and 10-grams of tissue at 900 and 1800 MHz. These measurements follow the testing procedures in the IEEE 1528 Standard, but with limits on the number of frequencies that will be tested. Two cellular telephones, a Motorola Model V290 and a Nokia Model 6310i were circulated around 17 international testing laboratories in Canada, China, Denmark, Finland, France, Japan, Korea, Sweden, Switzerland, and the USA. Each laboratory participating in the SAR intercomparison had to supply its own anthropomorphic phantom, dielectric simulant fluids for operation at 900MHz and 1800MHz, and SAR measurement equipment. Typical SAR measurement systems consist of an electric probe that is scanned inside the phantom by a robotic scanning system. The IEEE 1528 standard specifies the composition of the simulant fluids to be used, probe calibration procedures, and methods of data analysis. Specifically, each laboratory has measured the 1g and 10g average SAR at one frequency in the center of each band to be tested – 900MHz and 1800MHz, for both the "cheek" and "tilt" positions, and for both the left and right ear regions of the anthropomorphic phantom. Therefore, each participating laboratory has reported sixteen (16) SAR values for each of the two phones tested. Specifically:

1. 900MHz, ”cheek,” left ear, 1g average SAR
2. 900MHz, ”tilt,” left ear, 1g average SAR
3. 900MHz, ”cheek,” right ear, 1g average SAR
4. 900MHz, ”tilt,” right ear, 1g average SAR
5. 1800MHz, ”cheek,” left ear, 1g average SAR
6. 1800MHz, ”tilt,” left ear, 1g average SAR
7. 1800MHz, ”cheek,” right ear, 1g average SAR
8. 1800MHz, ”tilt,” right ear, 1g average SAR

And the same eight measurements for the 10g average SAR.

For these 16 measurements for each phone, all participating laboratories have submitted a data sheet detailing the values obtained, estimated standard deviations for each value (as
described in Annex E of IEEE 1528), the simulant fluid temperature, density, and the measured dielectric properties of the phantom simulant fluid used at 900MHz and 1800MHz. Each participating laboratory also reports the technique used for dielectric measurements, and the procedure used for calibration of their E-field probe, whether this was performed in-house, or whether manufacturers’ calibration values were used. Each participating laboratory specifies the SAR measurement system(s) that are used at their location for compliance testing. Each company was permitted to use knowledge obtained from previous internal interlaboratory comparisons to select a SAR measurement system to test for the MMF interlaboratory comparison.

**Results.** All participating laboratories have completed their measurements. These measurements have been communicated to the University of Maryland where data analysis has been carried out. Some example results are shown in Figures (1) and (2). Results are generally consistent across many laboratories, with a few outliers, as might be expected from such a study.

**Conclusions.** The cell phone SAR intercomparison is complete and the overall findings of the study will be reported at the meeting.

**Acknowledgements.** This research has been supported by the Mobile Manufacturers Form (MMF).

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**Figure 1.** Fig.(1) 1g SAR results for the Motorola phone at 900MHz, right cheek position.
Figure 2. Fig. (3) 1g SAR results for Nokia phone at 1800MHz, right tilt position.

12-6 CHARACTERIZATION OF THE ELECTROMAGNETIC ENERGY ABSORPTION OF THE HUMAN BODY EXPOSED TO THE RADIATION OF BASE STATION ANTENNAS

Andreas Christ\textsuperscript{1}, Marie-Christine Gosselin\textsuperscript{1}, Sven Kühn\textsuperscript{1,2}, Wayne Jennings\textsuperscript{3}, Niels Kuster\textsuperscript{1,2}
\textsuperscript{1}IT’IS Foundation, Zurich, Switzerland \textsuperscript{2}Swiss Federal Institute of Technology, Zurich, Switzerland \textsuperscript{3}Schmid and Partner Engineering AG, Zurich, Switzerland

Objectives. Current safety limits for the exposure of the human body to electromagnetic radiation from base station antennas were derived assuming far-field conditions and highly simplified mathematical models of the human body. These models generally do not consider antenna parameters, such as half power beam width, polarization, etc., or effects of individual anatomical features, such as tissue distribution. Technicians or maintenance personnel who are required to work in close proximity to the antennas may be exposed to very high power levels. The uncertainty of the simplified models to determine occupational safety distances may therefore not be sufficient to prevent the violation of current exposure limits. The objective of this study therefore is the development of compliance criteria for workers conducting service and maintenance tasks in the vicinity of antennas. In detail this includes:
- to assess worst-case configurations with respect to tissue distribution, body mass and height using generic and anatomically correct models of the human body
- to determine the absorption for typical base station antenna designs with different frequencies, opening angles, dimensions, etc.
- to compare the local exposure (peak spatial average SAR) against the whole-body SAR with respect to the basic restrictions on absorption in the body

**Methods.** The whole-body and spatial average SAR are simulated for different generic (layered and homogeneous) and anatomical whole-body models (53kg – 90kg, 1.60m – 1.80m) exposed to typical generic and commercial base station designs in the frequency range from 450MHz to 2200MHz. Particular care was taken to assert the anatomically correct representation of the tissue layers at the surface of the body (skin, fat and muscle tissue) when discretizing the anatomical models in the simulation mesh. The simulations were carried out using the FDTD simulation platform SEMCAD X. The antenna models were validated by measurements of their near-field distribution using the dosimetric assessment system DASY5NEO.

**Results.** The 10g peak spatial average SAR and the whole-body SAR have been evaluated for different distances and postures of the body models and different horizontal beam widths and polarizations. The comparison of these results to generic body models (prolate spheroids with layered and homogeneous tissue distributions) allows the assessment of the impact of individual anatomical differences on the absorption. The conditions under which the local SAR or the whole-body SAR is the limiting factor for compliance with the safety guidelines have been identified, and the uncertainty of the simulations with respect to the numerical parameters and the variability of the exposure for different individuals have been considered for the proposal of minimum safety distances.

**Conclusions.** The study shows the impact of anatomical features and antenna parameters on the worst-case absorption and assesses the range of applicability of the currently used simplified models. It identifies the conditions under which the basic restrictions for SAR can be violated for workers in the close environment of base station antennas and proposes criteria for determining the permissible occupational safety distance to base station antennas.

**Acknowledgements.** This study was greatly supported by the Forschungsgemeinschaft Funk e. V., Bonn, Germany
12-7 SYSTEMATIC ANALYSIS OF GENERAL PUBLIC EMF EXPOSURE AROUND GSM AND UMTS BASE STATIONS

Christian Bornkessel\textsuperscript{1}, Markus Schubert\textsuperscript{1}, Matthias Wuschek\textsuperscript{2}, Peter Schmidt\textsuperscript{3}
\textsuperscript{1}IMST GmbH, Kamp-Lintfort, Germany \textsuperscript{2}Deggendorf University of Applied Sciences, Deggendorf, Germany \textsuperscript{3}EM-Institut GmbH, Regensburg, Germany

Objectives. Precise determination of the general public exposure around RF transmitters is extremely important for check of regulatory exposure guidelines observance, risk communication, scientific purposes and biological studies.

This presentation summarizes two comprehensive dosimetric studies, in which measurement and calculation methods for determination of the general public exposure around GSM and UMTS base stations has been developed.

The measurement techniques were applied to determine the exposure distribution around different types of base stations in several scenarios (microcell/macrocell, indoor/outdoor coverage, high/low mounted stations in urban/rural environment, ...). From the results, important factors which influence the exposure were investigated. The exposure of GSM and UMTS stations were compared systematically.

Numerical software packages, which state of themselves to be able to predict the exposure around base stations accurately, were investigated in their applicability. Methods for including topography as well as buildings into the simulation were developed. The software tools were applied to different real scenarios, and the simulation results were compared to the measurements.

Methods. The fields around base stations show small and large scale space and time variations, which are due to fast fading effects (space) and traffic load as well as DTX (time). Because exposure guidelines demand for local maximum exposure search and extrapolation to highest operational state, techniques for space and time maximization must be included. For space maximization the ”sweeping method” has been proven to give accurate results in a reasonable time. Concerning time maximization, the exposure to special time constant signalization channels (BCCH for GSM, P-CPICH for UMTS) has to be measured and extrapolated to the maximum possible station’s transmit power.

While very often spectrum analyzers are used, the correct settings for detector, resolution and video bandwidth as well as sweep time are of utmost importance, as they can cause measurement errors of at least 10 dB. In the investigations, reference signals from a signal generator were fed by cable into the analyzer to study the setting’s influence. For frequency selective UMTS measurements e.g., the RMS detector is necessary, which requires minimum sweep times of at least 100 ms. Presently available code selective UMTS measurement devices have been proven to be well suited as well, if some preconditions are met.

The developed methods were investigated concerning accuracy, sensitivity, measurement uncertainty and repeatability in different basic scenarios.

Concerning numerical exposure prediction, ray optical, FDTD, hybrid as well as free space calculation tools have been investigated. Different operation and mounting conditions of the base station’s antenna were accounted for with a synthetic radiation pattern, which represents an envelope over the different patterns concerning frequency and downtilt changes. Also methods to include topography and buildings in the simulation have been developed.
The tools were applied to generic as well as real scenarios to compare with the measurements.

**Results.** Extensive measurements around stations with both GSM and UMTS systems show exposures between 0.01 % and more than 10 % of the field strength limit. It has been found, that from the cell size or the transmit power no conclusion can be drawn on the resulting exposure. The highest exposure were measured in microcell scenarios, which were operated with smaller transmit power than typical roof or mast installations, but use antennas mounted under the ceiling, that result in small distance to persons. Further analysis shows, that whereas the distance from the station is not a main influencing factor, the orientation to the main lobe and the sight conditions have large influence on exposure. GSM dominates exposure at about 85 % of all measurement points, which is due to higher installed transmit power, broader main lobe and smaller exposure limits compared to UMTS.

Concerning the simulation tools it was shown, that in scenarios with LOS all packages gave good exposure forecast for the majority of the investigated examples. Even simple free space models fit well in these scenarios. In NLOS scenarios, however, simple free space models overestimate real exposure by 10-60 dB, whereas ray optical methods partially exhibit good predictions up to the borders of the coverage area, if buildings and other obstacles are included accordingly. Transmission through buildings often plays a secondary role and can then be neglected.

**Conclusions.** GSM and UMTS measurements under on site conditions are possible with low measurement uncertainty (+/-3.3 dB) and high repeatability (+/-1.8 dB), but require a high degree of RF skills and quality awareness of the measurement personnel. They shall be considered even for epidemiological studies with large population groups, because simple distance based formulas have been proven to give wrong estimation of the real exposure.

Numerical simulation is a possible way of predicting the exposure without the help of on site measurements, although the consideration of topography and buildings tends to make the simulation complicated very quickly. Simple free space approaches are practical in worst case investigations or in the direct vicinity of the station. But they overestimate real exposure by several 10 dB in NLOS scenarios, which limits they applicability in epidemiological studies.

The work was funded by the German Federal Office for Radiation Protection and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety within the German Mobile Telecommunication Research Program.
UNCERTAINTY ESTIMATIONS FOR COMPLIANCE ZONE
ASSESSMENT AROUND BASE STATION PANEL AND OMNIDIRECTIONAL
ANTENNAS

Frans J. Meyer, Francois D. du Plessis
EMSS Consulting, Stellenbosch, South Africa

Objectives. The assessment of radiation intensity around cellular base station antennas is necessary for the prevention of overexposure to the general public and RF-trained personnel. To perform the assessment, a computational tool has been developed for determining the field values, as well as the non-compliance zones, in terms of ICNIRP public and occupational guidelines.

Methods. Panel and omnidirectional antennas are modeled using linear arrays of point sources with 3-D radiation patterns for each element. The 3-D patterns are created using available measured horizontal and vertical far-field antenna radiation patterns. The E-fields are calculated on a number of grid points surrounding the antennas, and are used to determine the compliance boundaries.

The calculation of compliance boundaries using computer simulations has a degree of uncertainty that affects the accuracy of the assessment. In this piece of work uncertainty parameters such as variation on input power, signal loss, reflection and scattering and antenna model uncertainty are identified, and uniform uncertainty distributions are quantified for each. The uncertainty distributions are combined to form near-field and far-field distributions for the actual power density. The power density distributions are used to determine the accuracy in predicting the zone boundaries.

Results. By integrating the surfaces of the power density uncertainty distribution functions, it was found that there is a 5% chance for the actual near-field power density to exceed the simulated power density with more than 2.5 dB, and a 5% chance for the actual far-field power density to exceed the simulated power density with more than 1.9 dB.

Conclusions. The maximum impact of the errors in power density within 95% certainty was investigated in terms of the compliance region boundaries. A distance error of 3m was determined in the far-field region for tri-band panel antennas that transmit typical macro base station power. It was found that the distance error decreases when closer to the antenna, but reaches a minimum of 1m for panel and omnidirectional antennas due to the emerging of hotspots near antennas.
ACUPUNCTURE: THE EVIDENCE FOR A BIOELECTRICAL MECHANISM

Andrew C. Ahn\textsuperscript{1,2}
\textsuperscript{1}Harvard Medical School, Boston, MA, USA \textsuperscript{2}MIT, Cambridge, MA, USA

Objectives. Main objective is to review literature on acupuncture and its relationship with bioelectric fields.

Results. Acupuncture originated in China approximately 2,500 years ago and is one of the oldest medical procedures in the world. It has been shown to be effective for various medical conditions (particularly, nausea, postoperative dental pain, knee osteoarthritis), although the lack of an inclusive physiological mechanism has led many to doubt its promise as a therapeutic intervention as a whole. While multiple physiologic models have been proposed, the bioelectric effects of acupuncture may be an important part in explaining how acupuncture operates, for several reasons: (1) The tools used by acupuncturists - for instance, metal needles, electrical stimulation, magnets, and low-intensity near-infrared laser - point to a common electromagnetic mechanism through which these tools can influence the body; (2) Electrical stimulation of acupuncture needles induces endorphin release at spinal and supraspinal levels through well described nervous pathways. "Low frequency" (2-4 Hz) electroacupuncture mobilizes enkephalin, \(\beta\)-endorphin, and endomorphin at the spinal cord, midbrain, and pituitary/hypothalamus, while "high frequency" (100 Hz) electroacupuncture induces only dynorphin at the spinal level; and (3) Acupuncture points and meridians, the fundamental anatomical structures of Chinese medical theory, reportedly have distinct electrical characteristics. For example, measurements at acupuncture points show decreased electrical impedance, increased electrical capacitance, and higher electrical potential (as high as 100mV) compared to adjacent non-acupoint controls. These topics will be discussed in detail with critical evaluation of past studies and with emphasis of their relevance to the field of bioelectromagnetism.

Acknowledgements. Dr. Ahn is funded by an NIH National Center for Complementary Alternative Medicine grant, 5K23AT003238.
MAGNETIC STIMULATION OF THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM: IMPLEMENTATION AND CLINICAL APPLICATIONS

Anthony T. Barker
Royal Hallamshire Hospital, Sheffield, United Kingdom

Objectives. Since the work of Galvani and Volta in the 1790’s it has been known that nerves and muscles can be electrically stimulated. Electrical stimulation, whereby excitable membranes are depolarised using current injected into the body via surface or implanted electrodes, is today widely used in both diagnosis and therapy. Examples of the former include measuring the speed of conduction of nerve action potentials in health and disease, and of the latter the stimulation of muscles whose neural connections have been compromised to produce functionally useful contractions. Typical pulse parameters used to stimulate superficial nerves via surface electrodes are of the order of 20mA for 100µsec, with up to 250 volts needed to drive this current through the relatively high electrical resistance of the skin. Whilst very effective in many applications, electrical stimulation has some disadvantages. It can sometimes be painful, it is difficult to non-invasively stimulate deep structures, and the human brain is relatively inaccessible because of the high electrical resistance of the surrounding bone.

Methods. An alternative approach is to induce current in the body using time-varying magnetic fields. Whilst the underlying principles of electromagnetic induction were first discovered by Michael Faraday in 1831 it was not until 1985 that so-called ‘magnetic stimulation’ generated widespread attention with the first demonstration of transcranial magnetic stimulation (TMS). Interest in the technique has grown rapidly since then. Today several thousand stimulators are in use world-wide for basic research, diagnosis and therapy. This presentation charts the progress of the technique from the discovery of the underlying scientific principles in the nineteenth century up to the present day and summarises its clinical and research applications in both therapy and diagnosis. Magnetic stimulation uses a brief but intense magnetic field pulse to induce currents in the body. If these currents are of appropriate amplitude, duration and orientation they will stimulate excitable structures by exactly the same mechanism as currents injected into the body using needle or surface electrodes. Hence ‘magnetic’ stimulation is something of a misnomer - the mechanism is in fact electrical — but it is a convenient shorthand to describe the method. Typical parameters of the magnetic field pulse required to depolarise nerves include a rise time of order 100µsec, a peak field of order 1 Tesla (depending on a number of factors including local anatomy and the stimulating coil geometry) and magnetic field energy of several hundred joules.

Results. Magnetic stimulation has the major advantage of being able to readily stimulate the human brain and deep peripheral nerves. The skull presents no barrier because the magnetic fields pass through it without attenuation. Stimulation is painless because current does not pass through the skin, where most of the sensory nerve fibre endings are located, and the relatively high current density underneath the electrodes used for electrical stimulation does not occur. This lack of discomfort enables the technique to be readily used on both patients and volunteers alike.
The construction of practical stimulators presents some engineering challenges, with voltages of up to 4kV and currents of up to 8kA being delivered to the stimulating coil. Continuing technical advances have addressed some of the limitations of the early hardware, such as stimulus repetition rate, and modern stimulators which can run at tens of stimuli per second are now widely used. However, there is scope for more development, particularly in the areas of coil cooling, electrical efficiency and the use of ferromagnetic materials in coil construction.

The basic physics of magnetic stimulation appears to preclude the holy grail of selective stimulation of a small volume of tissue at depth, the induced current paths being quite diffuse and field strengths decreasing with distance from the stimulating coil. However coil geometry can have some influence over the induced current paths and a figure-of-eight coil can produce more focal stimuli than those obtained from circular coils.

An important recent development is the delivery of stimuli in short trains (‘theta bursts’) rather than at a uniform repetition rate. By varying these stimuli patterns cortical excitation can be either facilitated or inhibited without changing the physical position of the stimulating coil, and the effects are longer-lasting than those produced by traditional protocols.

Magnetic stimulation is being used, or evaluated, in a plethora of applications. These include areas as diverse as creating ‘virtual lesions’ in psychology to investigate signal processing within the human brain; treatment of depression and schizophrenia in psychiatry using stimuli at either convulsive or sub-convulsive levels; aiding the diagnosis and charting the progress of disease or mechanical damage in central and peripheral nerve pathways; stimulating cortical plasticity; and functional stimulation applications such as the treatment of incontinence, artificial respiration and the induction of speech arrest. Particularly active areas at present are investigating whether magnetic stimulation can be used as an alternative to electroconvulsive therapy (ECT) to treat severe depression and stimulation of the motor cortex using novel pulse paradigms to encourage plasticity as an adjunct to post-stroke rehabilitation.

Conclusions. Since the advent of TMS in 1985 some 4000 papers have been published studying or using the technique. It seems likely that the range of clinical and research applications will continue to grow as more biologically potent delivery regimens are developed and stimulator hardware continues to improve.
EFFECTS OF ULTRA-HIGH STATIC MAGNETIC FIELDS AND PULSED MAGNETIC FIELDS ON SCIATIC NERVE REGENERATION AND FUNCTIONS OF NEURONS IN HIPPOCAMPUS AND SUBSTANTIA NIGRA

Shoogo Ueno$^{1,2}$

$^1$University of Tokyo, Tokyo, Japan $^2$Kyushu University, Fukuoka, Japan

Objectives. We have investigated the possible medical applications of ultra-high magnetic fields for nerve regeneration and functioning of neurons in hippocampus and substantia nigra in rats. Our research has two parts. In part 1, we studied the effects of ultra-high static magnetic fields (8T) on the orientation and regeneration of sciatic nerves in rats. In part 2, we studied the effects of pulsed magnetic fields (1T, 238 us) in functions of hippocampus neurons such as long-term potentiation and ischemic tolerance. Rescue effects of pulsed magnetic fields on the recovery of injured neurons in rat hippocampus and substantia nigra were also studied.

Methods. In part 1, we used a superconducting magnet (bore: 100 mm in diameter, 700 mm long, 37 °C), which produced 8 T at its center. Sciatic nerves in Wister rats were transected, and immediately afterwards a silicone tube (1.5 mm in diameter, 15 mm long) filled with type I collagen was used to bridge the space of the nerve defect as an artificial nerve graft. Two types of silicone tubes were prepared: one was filled with randomly oriented collagen fibers as a control, and the other was filled with collagen fibers oriented magnetically by 2 hours of exposure to 8 T fields. 12 weeks afterwards the number of regenerated axons was observed by morphological measurements and the function of the newly generated axons was tested by recording the compound action potentials in vivo.

In part 2, we employed a pulsed magnetic stimulator used in repetitive transcranial magnetic stimulation (rTMS) able to generate pulses of 238 us. The magnetic field peaks were set to 0.75 T (<motor threshold) and 1 T (>motor threshold) at the center of a coil 15 mm in inner diameter and 75 mm in outer diameter, positioned over the rat’s head. Male Wister rats (4 weeks old, 60-80 g) were used. The rats received rTMS in ten 1-s trains of 25 pulses/s with a 1-s interval, 4 times per day for 7 days. 15 h after the final stimulation the rats were anesthetized and the brain removed from the skull. Hippocampal slices were prepared, and field excitatory postsynaptic potentials (fEPSP) were recorded from the dendrites of CA1 pyramidal cells by stimulating Schaffer collaterals with tungsten bipolar electrodes. The long-term potentiation (LTP) was measured to evaluate the effects of rTMS on the hippocampus function.

For the study on the ischemic tolerance, after the hippocampal slices were exposed to ischemic conditions, artificial cerebrospinal fluid (ACSF) was replaced by ischemic ACSF bubbled with 95% N2/2% CO2 for 5, 10, 30, 40 and 50 min), LTPs were induced to compare the rTMS treated group with sham control group.

For the study on the injured neurons, lesions were induced by administering the neurotoxin MTPT (1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine). Male Wister rats received four MTPT (20mg/kg dissolved in saline) or saline injections at 2-h intervals for 1 day to induce neuronal injury in the substantia nigra and other areas including the hippocampus. The rats received rTMS 48 h after MTPT injection, and the number of surviving dopaminergic neurons was evaluated by immunohistochemical determination.
Results. We observed the sciatic nerve regeneration 12 weeks after neurotomy in both control and magnetically treated groups. The morphological examination showed that the numbers and diameters of the regenerated myelinated fibers in the silicone tubes gave a significant difference between control and magnetically treated groups. The number of fibers was 373.4 +27.6 (treated) and 274.0 +11.7 (control). The diameters of the axons were 5.81 +0.087 um (treated) and 5.53 +0.064 um (control).

We measured the compound action potentials to evaluate the functional connection across the silicone tube bridge. The potentials propagated in 2 out of 6 samples in the control group, and in all of the 6 samples of the treated group. Our results suggest that a magnetically aligned collagen structure can guide the growth cone and nerve axon, which results in the acceleration of nerve regeneration.

Long-term potentiations (LTPs) were observed in both the TMS stimulated and sham control groups. The maintenance phases of LTP (from 10 min after tetanus stimulation to 60 min) of the 0.75 T stimulated group (267+-26%) was significantly enhanced compared with the sham control group (212+-10%) whereas there were no significant differences between the maintenance phases of LTP of the 1.00-T stimulated group (223+-13%) and the sham control group (199+-13%). In contrast, when the rat brain was stimulated by 1.25-T, the LTP was suppressed, suggesting that the effect of rTMS on LTP depends on the stimulus intensity.

After hippocampus slices were exposed to ischemic conditions, LTP was induced. The LTP of the stimulated group was enhanced compared with the LTP of the sham control group in each ischemic condition. The rTMS acted as a preconditioning treatment, being effective when delivered before ischemia occurs.

The rats received rTMS 48 h after MTPT injection, and tyrosine hydroxylase (TH) and NeuN expressions were investigated in the substantia nigra to examine the possibility of TH positive mediation. Neuronal survival in the substantia nigra pars compacta (SNpc) was evaluated by double labelled (TH, NeuN) immunofluorescence microscopy. The loss of nigral TH+dopaminergic neurons was significantly prevented in the MPTP-rTMS group (62.9+-3.0) compared with the MPTP-sham group (14.8+-2.0). The number of surviving dopamine neurons in the MPTP-sham rats was significantly smaller than in the SNpc of undamaged rats. In contrast, the number of surviving neurons in the MTPT-rTMS group was significantly larger than in the MTPT-sham group. Our results show proof that the rTMS treatment rescues injured dopaminergic SN neurons from cell death due to MTPT toxicity.

Acknowledgements. This work was supported in part by the Japan Society for Promotion of Science (JSPS) under Grant-in-Aid Scientific Research (S) 17100006. The author wishes to thank his Ph.D. students, Mari Ogiue-Ikeda, Hirofumi Funamizu, and Yawara Eguchi, involved in this work at the University of Tokyo.
Session 13: Dosimetry III

13-1 SAR INDUCED BY MONOPOLE AND PLANAR ANTENNAS TO DETERMINE THRESHOLD POWER LEVELS OF WIRELESS DEVICES

Abu Sayem¹, Gernot Schmid², Benjamin Petric², Mark Douglas³, Mohammad Ali¹
¹University of South Carolina, Columbia, SC, USA ²ARC Seibersdorf research GmbH, Seibersdorf, Austria ³Motorola, Inc., Ft. Lauderdale, FL, USA

Objectives. Earlier we studied the SAR induced by linear dipole antennas in a flat phantom and computed the threshold power level, Pth, below which wireless transmitters are inherently compliant with regulatory standards (Ali et al., IEEE Trans. Electromagnetic Compatibility, in press, and Sayem et al., Bioelectromagnetics Society Meeting, 2006). In this work we study the SAR resulting from linear monopole antennas, planar patch antennas, planar inverted-F antennas (PIFAs), and inverted-F antennas (IFAs). Our goal for this study is to interpret the SAR data as well as its corresponding Pth data in light of our earlier results.

Methods. The first part of the current investigation considers quarter-wave wire (3.6 mm diameter) monopoles placed at the center of the top surface of a metal box (100 mm by 40 mm by 19 mm). The orientation of the box and the antenna with respect to a flat phantom consistent with IEEE Std 1528 is as shown in Fig. 1(a). Two distances, 12 and 20 mm were considered. The distance was measured from the antenna feed-point to the phantom-shell interface. Microstrip patches were studied at 2.45, 3.7 and 6 GHz while PIFAs were studied at 0.9, 1.9, 2.45, and 3.7 GHz respectively followed by IFAs at 2.45 GHz. Exact geometrical configurations and dimensions of each antenna can be found in reports by Ali and Schmid. For planar antennas, distances of 13 mm and 20 mm were considered when the antenna was pointed away from the phantom (called the conventional case). SAR was also computed and measured for distances of 10 mm and 20 mm when the antenna was facing the phantom (called the flipped case). SAR normalized to a 1W of continuous wave power was computed using XFDTD and measured using the DASY3 system.

Results. Computed and measured SAR for quarter-wave monopole antennas for distances of 12 mm and 20 mm are shown in Fig. 1. For instance, for a distance of 12 mm based on the 1g averaged SAR results, a monopole antenna satisfies the 1.6 W/kg SAR limit if the radiated power is 50 mW or less at 1900 MHz. Our earlier results in Ali et al. show that a cylindrical dipole of length λ/16 at a distance of 10 mm from the phantom satisfies the 1.6 W/kg SAR limit if the radiated power is 20 mW or less at 1900 MHz. Clearly the electrically small dipole provides a conservative SAR at that particular frequency and distance. Computed and measured 1-g and 10-g average SAR results for microstrip patches, PIFAs, and IFAs are shown in Fig. 2. It is apparent that the PIFA and IFA SAR data for both the conventional and flipped orientations are in general similar to that for quarter-wave monopoles. Thus the Pth for such antennas will also be similar to that of quarter-wave...
monopole antennas. The SAR data for the patch antennas are markedly different from the PIFAs and IFAs in both the conventional and flipped orientations simply because unlike PIFAs and IFAs, patches are directional antennas. Thus when the antennas are away from the phantom they induce very low SAR while when they face the phantom the induced SAR is much higher. SAR distributions for the conventional case for a patch, PIFA and IFA at 2450 MHz are shown in Fig. 3. Unlike the PIFA and the IFA the SAR distribution for the patch contains two peaks which results in lower mass averaged SAR.

**Acknowledgements.** This work was supported by the Mobile Manufacturers Forum (MMF), Brussels, Belgium and the GSM Association (GSMA), London, UK.
Figure 1: Computed and measured SAR of quarter-wave monopoles.
Figure 2. Computed and measured SAR data of planar antennas.
Figure 3.: Peak 1-g average SAR distribution in the conventional orientation (h = 13 mm, f = 2450 MHz) for the (a) IFA (b) PIFA and (c) Patch.
13-2 FURTHER EXPERIMENTAL DATA VERIFYING THE ACCURACY AND EFFICIENCY OF USING SIMPLE ANALYTICAL FORMULAS FOR COMPLIANCE ZONE ASSESSMENT AROUND BASE STATION ANTENNAS

Frans J. Meyer, Marli L. Strydom, Valpre Kellerman
EMSS Consulting, Stellenbosch, South Africa

Objectives. In previous work [1] we have shown that the analytical formulas first proposed by Nordström in [2] can be used for accurate and efficient Specific Absorption Rate based (SAR-based) compliance zone assessment in all three frequency bands typically used by mobile network operators. In this piece of work we have systematically worked through and investigated the influence of a) human phantom type; b) phantom orientation and c) antenna type, on the 10g local peak SAR as well as the whole-body SAR in front of base station antennas.

Methods. The SAR results were obtained using full wave numerical techniques. Both the Finite Difference Time Domain (FDTD) and a hybrid Finite Element (FE) / Method of Moments (MoM) were used for the simulations. The goal of these full wave SAR simulations was to investigate if the Nordström analytical formulas hold true for the different scenarios encountered at a base station site. If this is the case one would be able to use, with confidence, these analytical formulas for public and occupational compliance zone assessments around base station antennas.

Results. Results were obtained by performing a series of simulations using 6 different human phantoms, 8 different antenna types and various phantom orientations (rotations).

Conclusions. The results obtained show that the Nordström analytical formulas hold true for all the phantom type / orientation scenarios investigated. The results also show that the formulas do not hold true for all antenna types. The applicability of the formulas is restricted to one column arrays with at least four elements.

13-3 NEAR FIELD MODELING WITH OPTIMIZATION ALGORITHMS

Markus Johansson, Andreas Fhager, Mikael Persson
Chalmers University of Technology, Gothenburg, Sweden

Objectives. In dosimetry studies, it is important to be able to model electromagnetic sources, to make it possible to determine whether exposure safety guidelines are complied with, in different situations. Measured fields on a Huygens surface enclosing a source can be numerically propagated to arbitrary locations on the outside of the surface. The Huygens surface can be approximated by a planar surface positioned between the source and the near-field area of interest. If the total field is known on a large enough surface, the field beyond this can be obtained numerically. Generally, however, only the RMS values of the field are measured. The purpose of this study is to develop methods of determining the complete field, including the phase information, when only field amplitudes have been measured on a set of parallel planes close to the source, see figure 1.

Methods. Two different numerical methods were developed, the adjoint field method and the phase angle gradient method. The first method, based on the adjoint fields, involves finding equivalent dielectric properties between the two parallel planes that are closest to the source, such that these properties, together with the measured RMS values of the electric field on the first plane, where the field components are set to be in phase, yield the correct field, amplitude as well as phase information, on the other planes. The numerical scheme FDTD is used for the calculations, and a gradient based optimisation algorithm gives the dielectric properties. The other method makes use of the equivalent magnetic surface current density on the first plane to calculate the total field on the other planes. An optimization algorithm based on the phase angles, is used to search for those angles that give field amplitudes as close to the correct ones as possible.

Results. To test the two methods, field values calculated with an analytical formula for an infinitesimal dipole were used. The adjoint field method was tested for a 1 Ghz 2D case, where field values on a 60 cm long line in front of an infinitesimal dipole were used as the source. Figure 2 shows correct phase angles and the phase angles that the equivalent dielectric properties gave on two 30 cm long lines 17 cm and 23 cm from the source. The phase angle gradient method was tested for a 1 Ghz 3D case with a vertical infinitesimal dipole 75 cm above a horizontal perfectly conducting infinite plane. The correct field for the test case was obtained through mirroring. Figure 3 shows the difference between calculated and correct phase angles on a vertical 50 cm x 50 cm plane, for the vertical field component. The right-angled distance between the centre of the plane and the infinitesimal dipole was 18 cm.

Conclusions. Both methods gave very good results, for the test cases. The differences between calculated and correct phase angles were less than 0.15 rad both for the adjoint field method and for approximately 95% of the area of the plane with the results for the phase angle gradient method. It is reasonable that the errors can be a little larger near the edges of the plane, where the amplitudes are smaller than in the centre of the plane and the larger errors don’t matter so much.
Figure 1. Source in front of planes.

Figure 2. Phase angles.
Figure 3. : Phase difference.
13-4 CHILDREN HEAD RF EXPOSURE ANALYSIS

Joe J. Wiart\textsuperscript{1}, Abdelhamid Hadjem\textsuperscript{1}, Isabelle Bloch\textsuperscript{2}, Man-Fai Wong\textsuperscript{1}
\textsuperscript{1}France Telecom R&D, Issy les Moulineaux, France \textsuperscript{2}ENST PARIS, Paris, France

Objectives. The radio frequency (RF) exposure assessment in children is one of the actual challenges in dosimetry. Many studies have been carried out to analyze the energy absorption induced by handset in the heads of children compared to the absorption in adult. Children heads have been modeled using down sizing of adult one, non uniform down scaling and few models coming from MRI. The results have been compared to different adult head models that have been used. These studies have shown that a child heads is not a small adult head, they demonstrated that the model of head, the position of the handset relative to the head have a large influence on the result of comparison.

Methods. Using MRI data different child heads at different age have (5, 6, 7, 8, 9 12 years old) been built with a millimeter resolution. Using these head models the Specific Absorption Rate (SAR) induced by different handsets operating at different frequency (900, 1800, 2100 MHz) has been estimated using the well known and intensively studied FDTD (Finite Difference in Time Domain) method. The SAR induced by the same handsets has also been estimated in different adult heads (VH, Norman, IOP and FTRD). The influence of the morphology variability within a class of age (12 y.o) has also been investigated using the 12 y.o MRI based model and morphing technique.

Results. For each handsets and frequencies the results in children and adult have been processed to extract the mean value and the standard deviation. The results show that the SAR over 10 gram of tissues in children head is comparable or below the SAR over 10 grams in adult. The maximum SAR over one gram of specific tissue (skin, brain ..) have been compared in adult and children. The result show that brain exposure is weak but the result show also that sub-region of child brain should be higher exposed due to the thinner thickness of pinna, skin and skull.

Conclusions. The representativeness of models used in comparison is a key question since there is a large variability. Because of that the uncertainty estimation represent today the main challenge in numerical dosimetry.
13-5 A MULTI-LEVEL SUBGRID APPROACH FOR HIGH RESOLUTION SAR CALCULATION

Alexander Prokop, Tilmann Wittig
CST, Darmstadt, Germany

Objectives. High resolution human anatomy models in combination with large permittivity values usually require a huge computational effort for electromagnetic field analysis like Specific Absorption Rate (SAR) calculation. In particular this is the case if i.e. real world mobile phone models are to be compliance-checked and additionally raise the required resolution of the simulation grid. Higher frequency ranges further increase the necessary resources.

The standard FDTD method in general has proven capable of handling even those complex simulations, however, the staircase character of the discretization requires a very fine mesh to resolve fine details of e.g. CAD-imported phone models. Small mesh-steps obviously increase the total number of mesh-cells, but additionally – in many cases an even worse effect - they reduce the overall time-step of the simulation. The total simulation times are therefore typically exhaustedly long.

Methods. Advanced meshing techniques such as the PERFECT BOUNDARY APPROXIMATION (PBA) (R) and the Thin Sheet Technique (R) (TST) can be implemented in the related Finite Integration Technique (FIT). They offer very powerful options to keep the mesh relatively coarse even for very detailed structures, improving significantly the simulation efficiency by keeping the same overall result accuracy.

The numerical expense can further be reduced by applying the flexible MULTILEVEL SUBGRIDDING SCHEME (R) (MSS) which automatically increases the grid resolution in and smoothly around complex structures like CAD-imported phone models. Also in critical regions where the field maxima are expected to be positioned a finer mesh can be applied. Uncritical parts of the calculation domain are coarsely discretized, keeping the computational effort reasonable. Vital for the subgridding scheme is an interpolation method
between regions of different grid resolutions as well as an efficient time-step sub-cycling which avoids unphysical behaviour like instabilities of the transient simulation. Additionally, the mentioned subgridding scheme fully supports the PBA and TST techniques on all levels, to make a truly adaptive and numerically stable scheme without sacrificing existing benefits.

A subgrid simulation run results in full 3D information for all field components as well as the power loss density. Well-known algorithms to evaluate the SAR like described in the IEEE C95.3 standard can easily be extended to the described flexible subgridding scheme.

**Results.** The two mostly used examples of compliance assessment for mobile phones demonstrate the abilities of the presented method. First, a detailed 1mm resolution anatomically correct voxel model, containing several different tissues, and second, the "Specific Anthropomorphic Mannequin" (SAM) which is homogeneously filled with a tissue simulating liquid to receive a conservative estimate of the maximum SAR.

For the SAM phantom, the number of mesh-cells even under consideration of PBA is 2.1 mio mesh-cells. If subgridding is applied to the same model, the number drops to only 163,000 cells. Simulation time is 3523 sec versus 466 sec.

The commercial software package CST MICROWAVE STUDIO(R) 2006B was used to perform all simulations.

**Conclusions.** The presented flexible subgridding scheme for a FIT discretization was proven to significantly improve the efficiency of a typical mobile phone SAR simulation including a biological head model. By application of the subgrid, the number of meshcells could be reduced by a factor of 13, the simulation time by a factor of 7.5. The resulting SAR-values agree by both approaches.

![Figure 1. Subgridded Visible Human voxel model with a helical antenna mobile phone.](image)
13-6 A RADIO FREQUENCY RADIATION REVERBERATION CHAMBER EXPOSURE SYSTEM FOR RODENTS

Myles Capstick\textsuperscript{1}, Niels Kuster\textsuperscript{1}, Sven Kühn\textsuperscript{1}, Veronica Berdinas-Torres\textsuperscript{1}, John Ladbury\textsuperscript{2}, Galen Koepke\textsuperscript{2}, David McCormick\textsuperscript{3}, James Gauger\textsuperscript{3}, Ron Melnick\textsuperscript{4}
\textsuperscript{1}IT’IS Foundation, Zurich, Switzerland \textsuperscript{2}NIST, Boulder, CO, USA \textsuperscript{3}IITRI, Chicago, IL, USA \textsuperscript{4}NIEHS, Research Triangle Park, NC, USA

Objectives. This paper presents the design and experimental results for a reverberation chamber based exposure setup for individually housed unconstrained rodents suitable for exposure over extended periods. The idea of using reverberation chambers for animal exposure to electromagnetic fields was first suggested by the National Institute of Standards
and Technology (NIST) in a special session at BEMS 2001. A preliminary study involving an experimental investigation performed by NIST and a preliminary numerical dosimetry study performed by IT’IS, both funded by the National Institute of Environmental Health Sciences (NIEHS) in the USA. The results of this preliminary study were very encouraging and in January 2006 the main study to evaluate the potential toxicity and carcinogenicity of cell phone RF radiation in laboratory animals was issued by NIEHS under the National Toxicology Program. These results constitute the outcome of the chamber prototype development and evaluation phase of the study.

**Methods.** Reverberation chambers are resonant enclosures where the field structure is continuously altered using stirrers such that they provide a statistically homogeneous field distribution within a specific volume in the chamber. In the NTP studies, rats will be chronically exposed at 900MHz and mice at 1.9GHz, different exposure groups will be subjected to either GSM or IS95 signals at one of three SAR levels or sham, over an entire lifespan. The design of the reverberation chamber had to encompass both the electrical design and animal housing issues, this resulted in a fully welded stainless steel design with two mode stirrers. The rodents have to be supplied with drinking water without energy absorption in the water or increased SAR in or RF burns to the animal whilst drinking. The exposure in the chambers is controlled using a closed loop system. This system is based on the measurement of three orthogonal components of both the electric and magnetic field at two locations in each chamber. The required field strength was determined from numerical dosimetry using high resolution animal models based on 4 different size models covering the whole life span. Each model has over one hundred different tissue types differentiated. Using the models the average field strengths required to produce the target SAR in the animals in each exposure group was determined.

**Results.** The important performance metrics for a reverberation chamber used for animal exposure are: the field uniformity, field isotropy, SAR uniformity and efficiency. Using E-Field probes the measured electric-field uniformity (one standard deviation) in the empty chamber measured on a 300mm 3D grid was 0.6dB and the field isotropy 0.85dB and in the fully loaded chamber, over a reduced number of points, 0.74dB and 1.3dB respectively. Figure 1, shows the E-field uniformity results. The SAR uniformity measured in rat and mouse phantoms, using the temperature method, were 0.46dB and 0.40dB respectively. The design achieves an overall efficiency of \(~70\%\) for adult rats and 45% for adult mice. A water system was developed could be installed in the chambers without introducing additional loss. The design for use in a reverberation chamber environment with high RF fields (up to 400 V/m) was developed that avoided or minimized:

1) high local SAR peaks in the animal whilst drinking,
2) variations in whole-body average SAR with respect to the animal not drinking,
3) significant distortions in the fields around the water system.

The design uses flanged quarter wave choke tubes integrated into a stainless steel automatic water system. The numerical analysis was performed with SEMCAD using high resolution anatomical models. Figure 2 shows both the flanged choke arrangement and the anatomical model used for the numerical dosimetry. The experimental verification was done using gel animal phantoms and temperature probes. The designed water system provides a safe
drinking environment without disturbing the field homogeneity and isotropy within the animal enclosures.

**Conclusions.** Overall, the performance across all the criteria of the reverberation chamber for animal exposure is excellent, with all target performance metrics being met or exceeded. The performance of this exposure environment is comparable to the best exposure setups using constrained animals.

**Acknowledgements.** This work was supported by the National Institute of Environmental Health Sciences (N01-ES-55544).

![Figure 1. E-field uniformity at 900MHz](image)

**Figure 1.** E-field uniformity at 900MHz
FIGURE 2. Automatic watering system with anatomical models
Session 14: In Vitro Studies

14-1 IN VITRO EFFECT OF 2.45 GHZ MICROWAVE EXPOSURE ON MUTAGEN-INDUCED DNA DAMAGE.

Anne Perrin1, Maelle Freire1, Alice Collin2, Marylène Cueille2, Christine Bachelet1, Philippe Leveque2
1Health Service Research Center for Defense (CRSSA, Ministry of Defense), LA TRONCHE, France 2XLIM CNRS, LIMOGES, France

Objectives. The aim of the study is to investigate, in vitro, the effect of 2.45 GHz continuous (CW) and pulsed (PW) electromagnetic field exposure combined with a known genotoxic agent. Microwaves energy do not allow DNA strand breaks and there is no clear hypothesis for a possible mechanism supporting such a direct biological action. Nevertheless, an indirect influence of microwaves during an intermediary step of mutagenesis cannot yet be excluded.

The comet assay was used to assess DNA damage with the monocyte human cell line THP1. The cells were treated by the mutagenic agent 4-nitroquinoline-N-oxide (4-NQO) and simultaneously exposed to microwave at several SAR levels. At the higher SAR level, an influence of the electromagnetic field on induced DNA damage was observed. Then, investigations were carried out to determine if the emergence of this combined effect was due to a temperature rise in the sample.

Methods. The carrier frequency was 2.45 GHz CW and PW (radar type, 1 kHz repetition time, 10 % duty cycle) with the same average power density. The experiments were carried out at different SAR values: 4 W/kg, 8 W/kg and 16 W/kg. Specially Plexiglas designed incubators were integrated in three identical anechoic chambers equipped with horn antennas. In each experiment, non-exposed (sham) and exposed (PW and CW) cell culture plates (3 petri dishes by condition, 2 slides per dish) were incubated simultaneously in the presence of 4-NQO, for 2h, at 37°C under gentle shaking. The electromagnetic field was applied alternatively in the three anechoic chambers in order to avoid cage effects. Each experiment was reproducibly repeated 8 times. Care was taken to increase the reproducibility of the experiments and to avoid false positive or misinterpretation of the results. The presence or the absence of the electromagnetic field was the only difference between the sham and exposed assays. The alkaline comet assay was performed according to the method originally described by Singh & al (1988, Exp. Cell Res., 175, 184-91). The images were analyzed with the Komet 3.0 image analysis system. Images of 200 randomly selected cells were analyzed from each sample. Fragmentation was expressed in Tail Extent Moment (TEM) taking into account tail length and the percentage of DNA in the comet tail.

In a second step, the temperature inside the Petri dishes was monitored in the different exposure conditions and further experiments were realized. The DNA damage was quantified for non-exposed cells incubated in the anechoic chamber at different temperature simulating the heating by microwave.
The temperature of the culture medium was measured inside the cell plates with a microprocessor-controlled thermometer using fluoro-optic fiber temperature probes (Luxtron). Numerical dosimetry was calculated using the Finite Difference Time Domain method. A time-scaled form of the heat transfer equation allowed calculating the temperature inside the petri dishes.

**Results.** DNA damage induced by the mutagenic agent remained unchanged when the cells were exposed to 2.45 GHz PW or CW microwave at 4 or 8 W/kg. There was a significant increase (about 40%) in DNA alteration at the power density corresponding to a SAR value16 W/kg (PW and CW) exceeding the occupational exposure limits established in the ICNIRP guidelines. We first stipulate that thermal effect was responsible for this effect at higher SAR level and experiments were carried out to show that. Surprisingly, the results indicate that the temperature rise generated by microwave heating is clearly not sufficient to induce an increased effect of 4-NQO.

**Conclusions.** Our data suggest another mechanism that the simple thermal hypothesis. Further experiments are currently in progress to go into the subject in greater depth. It could provide new insights into the interactions between biological systems and electromagnetic fields at a critical intensity level. This will be discussed at the time of the meeting.

**Acknowledgements.** Research supported by the DGA (Direction Générale de l’Armement)

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**14-2 NO INDUCTION OF TRANSFORMATION IN BALB/3T3 CELLS EXPOSED TO 2-GHZ BAND W-CDMA MODULATED RADIOFREQUENCY FIELDS.**

Masaru Sekijima\(^1\), Hideki Hirose\(^1\), Takeshi Suhara\(^1\), Naoko Kaji\(^1\), Noriko Sakuma\(^1\), Toshio Nojima\(^2\), Junji Miyakoshi\(^3\)

\(^1\)Mitsubishi Chemical Safety Institute Ltd., Kamisu, Japan \(^2\)Hokkaido University, Sapporo, Japan \(^3\)Hirosaki University, Hirosaki, Japan

**Objectives.** Previously, our group reported that DNA strand breaks were not induced in human cells exposed to Wide band Code Division Multiple Access (W-CDMA) radiofrequency (RF) fields up to SAR of 800 mW/kg [1]. The objective was to investigate if carcinogenesis was induced by RF fields. In order to assess carcinogenic potential on the low level RF, which corresponds to the limit of the average whole body SAR for general public exposure defined as a basic restriction in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [2], in vitro BALB/3T3 cell transformation assay was employed using a large-scale in vitro exposure system [3].
**Methods.** We used the in vitro exposure system with a horn antenna and dielectric lens in an anechoic chamber, which allows simultaneous exposure of 49 (7 x 7 array) 35 mm dishes [3]. In this study, we performed the experiments accurately employing two pairs (exposure and sham) of this exposure system [4]. The frequency was 2.1425 GHz, which corresponded to the middle frequency allocated to the downlink band of the IMT-2000 from mobile radio base stations. BALB/3T3 A31-1-1 cells in the log-phase were dissociated enzymatically, and seeded at 5000 cells/35-mm dish in 20 replicates. Non-, 100 ng/ml 3-methylcholanthrene (MCA)-, or 100 ng/ml MCA plus 30 ng/ml 12-O-tetradecanoylphorbol-13-acetate (TPA)-treated cells were exposed to W-CDMA RF field at average SAR of 80 or 800 mW/kg for 6 weeks, to confirm its initiation, promotion, or combination activities. At the end of the incubation period, the transformation dishes were fixed with methanol, stained with 3% aqueous Giemsa, and scored for morphologically transformed foci. The transformed foci were measured by counting type II and type III foci. Type III foci are dense multilayered, basophilic, have a random orientation at the focus edge and invasion into the monolayer of transformed cells. Type II foci contain a more ordered and better defined edge. The RF field exposures dishes were processed in a blind manner. We also studied altered gene expression in BALB/3T3 cells exposed to RF radiation in the promotion phase of transformation assay.

**Results.** Experiments under the same RF exposure and cell culture conditions were repeated three times. No significant difference in transformation frequency was observed between the test groups exposed to W-CDMA RF field at SAR of 80 and 800 mW/kg and the sham-exposed negative controls in the non-treated cells. By contrast, treatment of the cells to 100 ng/ml MCA alone resulted in a significant increase in the transformed foci of each sample, compared to sham and RF field exposed samples. No significant difference in transformation frequency was observed between the test groups exposed to W-CDMA RF field at SAR of 80 mW/kg and the sham-exposed negative controls in the 100 ng/ml MCA- or 100 ng/ml MCA plus 30 ng/ml TPA-treated cells. On the contrary, treatment of the cells to 100 ng/ml MCA plus 30 ng/ml TPA (positive control to 100 ng/ml MCA-treated cells) or 100 ng/ml MCA plus 300 ng/ml TPA (positive control to 100 ng/ml MCA plus 30 ng/ml TPA-treated cells) resulted in a significant increase in the transformed foci of each sample as well, compared to sham and RF field exposed samples. Furthermore, no noticeable differences were observed between any of the RF field exposure groups and the sham exposed controls in the gene expression profile. Our experimental results suggest that long-term exposure to W-CDMA RF field at 2.1425GHz cannot be associated with transformation at the limit of the average whole-body SAR level (80 mW/kg) as defined by the ICNIRP guidelines.

References:  [1] Sakuma et al., 2006. DNA strand breaks are not induced in human cells exposed to 2.1425 GHz band CW and W-CDMA modulated radiofrequency fields allocated to mobile radio base stations. BEMS 27, 51-57.  
Acknowledgements. This work was supported by NTT DoCoMo Inc.

14-3 STUDY ON GENE EXPRESSION OF HSP70 FOR CHO-K1 CELLS DUE TO 2.45GHZ MICROWAVE EXPOSURE UNDER THE TEMPERATURE CONTROLLED ENVIRONMENT

Yukihisa Suzuki\textsuperscript{1}, Saki Hiromoto\textsuperscript{1}, Tomohide Sonoda\textsuperscript{1}, Masao Taki\textsuperscript{1}, Junji Miyakoshi\textsuperscript{2}, Kanako Wake\textsuperscript{3}, Soichi Watanabe\textsuperscript{3}

\textsuperscript{1}Tokyo Metropolitan Univ., Hachioji, Japan \textsuperscript{2}Hirosaki Univ., Hirosaki, Japan \textsuperscript{3}National Institute of Information and Communication Technology, Koganei, Japan

Objectives. Recently, numbers of in-vitro study have been performed to obtain knowledge on biological effects induced by microwave exposure. It is commonly considered that the increase of temperature in biological tissues, caused by the absorption of electromagnetic energy, governs biological effects for microwave exposure. Current guidelines are limited by the specific absorption rate (SAR) based on thermal effect. However, several in-vitro studies suggest the possibility of non-thermal effect. Therefore, it warrants to investigate the possibility of non-thermal effects caused by localized electromagnetic fields (EMFs) with significantly high amplitude under the suppressed condition in temperature rise.

We have been tried to exclude thermal effect due to intense microwave exposure for the in-vitro experiment in the past study. In this study, temperature control system by the use of Peltier element is introduced for the in-vitro exposure apparatus to investigate non-thermal effect. The objective of our study is to suppress temperature rise in the environment surrounding cells in the exposure apparatus up to 200 W/kg, and to investigate the change in gene expression of heat shock proteins (Hsp70) for cultured cells exposed to 2.45GHz microwaves in wide range of SAR values from 5 W/kg to 200 W/kg under the temperature controlled condition at 36-37 °C.

Methods. Temperature around culturing cells should be kept in 36-37 °C, that is normal condition for cell culture, to avoid gene expression caused by thermal effect. In this study, Peltier element is introduced at the bottom end of short-circuiting plate of the cylindrical waveguide-type exposure apparatus. The diameter of Peltier element is 62 mm. Thickness of culture medium is optimized to 6 mm to obtain flat temperature distribution at the bottom of cell culture medium by computer simulation. Temperature at the bottom of cell culture medium is controlled to desirable value by adjusting the temperature at the top of Peltier element. Figure 1 shows temperature transition during continuous microwave exposure period at the bottom of the culture medium with Peltier element measured by the fluoroptic thermometer (Luxtron790). Temperature is well controlled within 36-37 °C for the SAR value from 5 W/kg to 200 W/kg. Here, labels of SAR denote spatially averaged value at the bottom of culture medium (position of cells).

Using the system mentioned above, we examined the effects
of 2.45 GHz continuous microwaves on the expression of Hsp70 in Chinese hamster ovary (CHO)-K1 cells. Cell suspension at a concentration of $1 \times 10^6$ cells/dish were seeded on the culture dish. The cells were exposed to microwaves of 2.45 GHz for 4 hours following incubation for one night. SAR values are 5, 50, 100, and 200 W/kg. The internal electric fields of these SARs are 44.7, 141, 200, and 283 V/m, respectively. Here mass density and conductivity of culture medium is 1000 kg/m$^3$ and 2.5 S/m. Sham-exposure were also performed in this study. Expression of Hsp70 was evaluated by mRNA of Hsp70 extracted from the cells using real-time RT-PCR (Applied biosystems ABI PRISM 7000). Experiments were repeated for 5 culture dishes for each exposure condition.

**Results.** Gene expression ratios of Hsp70 in CHO-K1 cells for each SAR condition are shown in Fig. 2. Each value is normalized by sham exposure gene expression. In this figure error-bars indicate standard deviation, and p values are evaluated by two-sided Student’s $t$-Test. Here, * and ** indicate $p<0.05$ and $p<0.01$, respectively. As shown by this figure, extremely large changes in gene expression of Hsp70 are not found for the SAR condition from 5 to 100 W/kg. Increase of gene expression is observed for the condition of 200 W/kg. However, high temperature gradient of approximately 1.2 °C/mm along the vertical direction is estimated for 200 W/kg condition by computational simulation result. If such a temperature gradient exists, fluoroptic thermometer may not indicate correct value, because that condition is out of its measuring ability. The increase in gene expression of Hsp70 at 200 W/kg should be attributed to thermal effect due to the temperature gradient.

**Conclusions.** We have developed the *in-vitro* exposure apparatus with temperature control at the cell position to investigate non-thermal effect caused by microwave exposure for wide range of SARs. With this apparatus, we performed exposure experiment for the conditions of 5, 50, 100, 200 W/kg to measure gene expression of Hsp70. Evidence of non-thermal effect was not found for the SAR conditions from 5 W/kg to 100 W/kg.

**Acknowledgements.** This work was supported in part by the Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields, Ministry of Internal Affairs and Comminications.

![Figure 1. Temperature transition during exposure.](image-url)
**14-4** IMPROVEMENTS TO A FREE SPACE BROADBAND IN VITRO MICROWAVE EXPOSURE SYSTEM FOR ON-LINE MONITORING OF CATECHOLAMINE RELEASE FROM CHROMAFFIN CELLS

Jihwan Yoon\(^1\), Indira Chatterjee\(^1\), Dana McPherson\(^1\), Gale Craviso\(^2\)

\(^1\)University of Nevada, Reno, Reno, NV, USA \(^2\)University of Nevada, Reno, Reno, NV, USA

**Objectives.** Recently we reported the design and characterization of an in vitro broadband free space exposure system for on-line monitoring of catecholamine release during exposure of chromaffin cells to microwave fields in the frequency range 1–6 GHz (Yoon, et al., 2006). As indicated by Finite-Difference Time-Domain (FDTD) computations, electric (E) field homogeneity on the glass fiber filter (GFF) where the cells are immobilized was significantly decreased at frequencies above 4 GHz partly due to (1) the attenuation caused by the GFF soaked with balanced salt solution (BSS) that is a lossy material, (2) the diameter of the GFF being comparable to the wavelength in the GFF soaked with BSS, and (3) the formation of a standing wave pattern due to reflections from the edges of the GFF. Moreover, thermal modeling (Misra et al., 2007) and actual measurements showed the presence of a temperature gradient from the center to the edge of the GFF, and also between the BSS in the inlet tubing immediately above and in the outlet tubing immediately below the GFF. The goal of this work was both to improve the design of the current exposure system and to work toward a new design for exposing the cells to larger E fields.
Methods. Modifications: For exposure, cells are immobilized on a 24 mm diameter GFF located inside a cell perfusion apparatus (CPA) and superfused with BSS heated to 36 deg.C; the BSS leaving the GFF reaches an electrochemical detector for monitoring of catecholamine release. The CPA is placed in the far-field of a high power broadband horn antenna that generates microwave fields in the 1 to 6 GHz frequency range. As cells are being superfused, a temperature variation exists across the GFF due to (1) heat transferred from the BSS to the CPA via conduction and, (2) the tendency of the BSS to flow faster through the central region of the GFF. To overcome these problems, the CPA has been replaced with a smaller one that incorporates a GFF of diameter 10 mm, a 5 µm nylon mesh of diameter 10 mm with a 5 mm hole in the middle is placed directly on top of the GFF to immobilize the cells within the central part of the GFF and, the CPA is now placed in the near field of the horn antenna. FDTD computations were used both to characterize the E fields and SAR as well as to determine the optimal placement of the CPA in the near field.

New design: Because maximum coupling of the E field into the GFF would occur when the GFF diameter is comparable to the wavelength in the BSS soaked GFF, a new design that also uses a GFF of diameter 10 mm to immobilize cells for cell perfusion now has the GFF embedded in a material with a dielectric constant much larger than air. The design also incorporates a Vivaldi antenna embedded in a planar dielectric substrate material of thickness 2 mm and relative dielectric constant of 20 (Model C-STOCK AK, Cuming Microwave Corp.). The material immediately under the flared end of the Vivaldi antenna is removed to form a holder (1 mm depth and 10 mm diameter) for the GFF. The bottom part of the holder with a silicone rubber gasket screws into a thread block glued under the holder, thereby compressing the GFF against the dielectric substrate and preventing leakage of BSS. FDTD computations were used to characterize the E fields and SAR.

Results. The smaller CPA resulted in a lower measured temperature difference between the center and the edge of the GFF (from 5.8 deg.C to 2.5 deg.C) as well as between the inlet and outlet BSS (from 4 deg.C to 1 deg.C). Also, by using the 5 µm nylon mesh with a central hole, cells were able to be centrally immobilized on the GFF so that the BSS and any injected drug stimulus would pass uniformly through the entire region containing cells, resulting in more consistent responses from the cells. FDTD computations showed that the homogeneity of the E fields was increased since the diameter of the GFF is now smaller than the wavelength in the GFF soaked with BSS over the entire frequency range; however, the E field magnitude was reduced compared to that for the larger GFF. When the smaller CPA was placed in the near-field of the horn antenna, the optimal location being at the mouth of the horn antenna, the E field values increased by a factor of three (at 3.5 GHz) from those obtained for the larger CPA in the far-field.

FDTD computation of the E field distribution in the newly designed exposure system showed that most of the E field is concentrated within the substrate, rather than in the air since the antenna is excited within the substrate. The average E field at 3.5 GHz over the GFF is 8 KV/m which was approximately a10-fold increase over the maximum E field obtainable in the original exposure system. In addition, the reflections from the edges of the GFF were reduced due to the lower relative dielectric constant difference between the GFF soaked with BSS (about 50 at 3.5 GHz) and the substrate. This significantly improved the homogeneity.
of the E field distribution within the GFF (93% of the area is homogeneous to within 30% at 3.5 GHz).

**Conclusions.** Whereas improvements in the design of the original microwave free space exposure system using a horn antenna resulted in overcoming some of the limitations, the new design incorporating a Vivaldi antenna into the system will produce over a 10-fold increase in E fields while at the same time improving the homogeneity of the field over the region containing the cells for the entire frequency range to be studied.

**Acknowledgements.** This work was supported by AFOSR grants F49620-03-1-0262, FA9550-04-1-0194 and FA9550-05-1-0308.

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**14-5 IN-VITRO EXPERIMENTS ON FREE RADICAL PRODUCTION WITHIN HUMAN WHITE BLOOD CELLS DUE TO 900 MHZ MOBILE RADIO WAVES EXPOSURE**

Takashi Hikage, Masataka Endo, Toshio Nojima
Hokkaido University, Sapporo, Japan

**Objectives.** This study is to investigate the effects of microwave exposure on biological free radical production, focusing especially on mobile radio frequencies. The biological free radicals, including some Reactive oxygen species (ROS) are electrophilic and highly reactive. If undesired free radical production occurs in human body, it can trigger a chain reaction resulting in various unwanted effects on important cellular components such as DNA, or the cell membrane at the worst case. In some papers, it has been suggested that DNA-damage due to electromagnetic fields (EMFs) exposure may occur as a non-thermal effect at the frequencies below the high gigahertz spectral regions [1-3]. In this paper, in-vitro experiments estimating hydroxyl free radical production due to non-thermal effects in human white blood cells that has been exposed to 900 MHz RF EMFs are performed.

**Methods.** The procedure treating white blood cells is shown in figures 1. The conditions used for 900 MHz exposure are shown in Table 1. The Ridged-waveguide exposure equipment was employed [4]. Additionally, six different sets of exposure conditions were used: i) continuous wave, ii) pulse modulation, iii) GSM basic signal modulation, iv) PDC signal modulation and v) cdma2000 signal modulation. The exposure level can be changed from cellular level to high SAR level (up to 150 W/kg). In the experiments, the cell’s temperatures were kept below 39°C. A Sham-exposure for the white blood cell experiment was carried out using a thermo control unit without microwave exposure. The inherent influence of microwave exposure on radical production within the cells was assessed by comparison with the sham-exposure. Approximately 500 fractionated white blood cell samples were
used in the experiment. Statistical analysis using independent Student’s t-test was performed to test the differences between exposed and sham-exposed (thermal control) cells. A difference at p<0.05 was considered statistically significant.

**Results.** The influence of cell temperature on radical production within the human cells were confirmed by nonparametric tests using sham-exposed cells’ data. The statistical analysis result of fluorescence intensities after microwave exposure is obtained. This result confirms that there is no statistically significant influence of 900 MHz microwave exposure on human white blood cells.

**Conclusions.** In the experiment using the blood cell, the experimental data showed that there is a correlation between radical production and cell temperature. However, the radical production effect that originated from the microwave exposure was not observed in the non-modulation, intermittent wave or mobile communication modulation. Additionally, when the temperature rise was suppressed, even the high-power exposure did not affect radical production in the cells.

**REFERENCES:**

**Acknowledgements.** This work is supported by Grant-in-Aid from the Ministry of Internal Affairs and Communications (MIC) of Japan.
Objectives. Repetitive pulsed magnetic stimulation (RPMS) is used to make pulsed magnetic fields in order to induce electric fields in human tissues by electromagnetic induction without the need for surgery or external electrodes. Previously, we showed RPMS enhanced effectiveness of the anticancer agent imatinib mesylate (imatinib) on human chronic myelogenous leukemia (CML) cells. However, point mutations in the ATP binding site of BCR/ABL cause the drastic conformational change in ATP binding pocket, resulting in strong imatinib-resistance.

In the present study, the combination effect of RPMS and imatinib was examined using imatinib-resistant human CML cell line TCC-Y/T315I cells.

Methods. The imatinib-resistant human CML cell line TCC-Y/T315I cells were cultured in RPMI 1640 (Nakarai, Japan) with 10% FCS and antibiotics. RPMS were performed with a magnetic stimulator (Nihon Kohden, Japan) which delivered biphasic cosine current pulses
for 238 μsec. The stimulus conditions were used as follows: RPMS: 0.25 T, 25 pulses/s, 6000 pulses/day (40 s = 1000 pulses X 6 times/day). TCC-Y/sr cells were cultured with 30 μM imatinib (Sequoia Research Products, UK) and exposed to RPMS every 24 hrs after drug treatment. Cell growth inhibition was examined by MTT assay at 96 hrs after the drug treatment.

Autophosphorylation level of BCR/ABL (ty-BCR/ABL) was examined by western blot analysis (Anti-4G10, Santa Cruz Biotechnology, USA) to clarify whether RPMS enhances imatinib uptake into cells or modifies its binding ability.

**Results.** The significant combination effect of RPMS and imatinib was observed at 96 hrs after the drug treatment (Table 1). Significant cell growth inhibition was observed in cells with the imatinib and RPMS treatment (62.4% versus control, p>0.05) while only 30 μM imatinib or RPMS treatment had no inhibitory effects on the cell growth (97.6% versus control and 95.2% versus control, respectively).

Next, ty-BCR/ABL level was examined by western blot analysis to clarify whether RPMS enhances imatinib uptake into cells or modifies its binding ability. There was no significant effect of RPMS on the ty-BCR/ABL levels, indicating that RPMS had no effect on imatinib uptake or its binding ability.

**Conclusions.** These results indicate that RPMS treatment is a potential tool to overcome imatinib-resistance in CML cells.
**P-1** EFFECTS ON LOCALIZED SAR OF POWER REDISTRIBUTION BETWEEN THE ANTENNA ELEMENTS FOR LOADED BASE STATION ANTENNAS

Peter Håkansson, Björn Thors, Johan Danestig, Björn Hansson, Christer Törnevik
Ericsson AB, Stockholm, Sweden

**Objectives.** The importance of numerical simulations for base station antenna radio frequency (RF) exposure assessments keeps increasing. When a body is placed in close proximity to the base station antenna the coupling effects of the body on the antenna radiation characteristics can be significant [1]. A change in the excitation coefficients will result in a redistribution of transmitted power between the antenna elements, which for RF exposure assessments will have the largest impact on localized SAR for small separation distances. This effect has been ignored in most of the published exposure assessment studies. The objective with this paper is to investigate for which distances the coupling effects are likely to result in a significant change in localized SAR.

**Methods.** Localized SAR was calculated numerically at 900 MHz for the Kathrein 739 620 base station antenna using the commercial finite-difference time-domain (FDTD) solver SEMCAD for two sets of excitation coefficients corresponding to a free-space and a loaded scenario, respectively. The excitation coefficients were obtained from measurements of the dipole element currents for different loading conditions, using a DASY4 near-field scanner together with a 3-dimensional H-field probe from Schmid & Partner Engineering AG. For the measurements, the body was simulated using two rectangular containers filled with a lossy liquid, while for the numerical simulations a lossy dielectric slab was used. A relative permittivity of 38 and a conductivity of 1.3 S/m were used.

Since the near-field scanner measures the magnitude of the magnetic field no phase information was available for the excitation coefficients. Furthermore, mutual coupling between the antenna elements was in a sense neglected when the measured normalized dipole currents were used to specify the voltage excitation coefficients in the numerical FDTD simulations. Both these approximations were found to be of minor importance after having compared the computed current distribution, where mutual coupling is included, with the measured current distribution.

**Results.** In Figure 1, results are shown from the H-field measurements of the base station antenna radiating in free space. The corresponding results with lossy liquid placed 5 cm in front of the antenna are shown in Figure 2. The results illustrate how the transmitted power is redistributed among the antenna elements, with a reduction in maximum current of approximately 3 dB for the two leftmost elements. In Figure 3, results from the subsequent
FDTD-simulations are given. As expected, close to the antenna the difference between the localized SAR values is significant while for larger separation this effect is reduced.

Conclusions. The obtained results indicate that the effects of power redistribution on localized SAR are limited mainly to the reactive near-field region of the base-station antennas. [1] M. J. van Wyk, M. Bingle, and F. J. C. Meyer, ”Antenna modeling considerations for accurate SAR calculations in human phantoms in close proximity to GSM cellular base station antennas,” Bioelectromagnetics, vol. 26(6), pp. 502-509, 2005.

**Figure 1.** Normalized H-field distribution for the base station antenna radiating in free space.
Figure 2. Normalized H-field distribution for the base station antenna with a lossy phantom placed 5 cm in front of the antenna.

Figure 3. Localized SAR versus distance for two sets of excitation coefficients corresponding to a free-space and a loaded scenario, respectively.
**P-2 COMPARISON OF INDUCED CURRENTS IN REAL AND ROTATIONALLY-SYMMETRICAL HUMAN MODELS BY EXPOSURE TO INTERMEDIATE FREQUENCY MAGNETIC FIELD FROM A HOUSEHOLD INDUCTION HEATER UNIT**

Hiroo Tarao\(^1\), Noriyuki Hayashi\(^2\), Katsuo Isaka\(^3\)
\(^1\)Takamatsu National College of Technology, Takamatsu, Japan  \(^2\)Kyushu University, Kasuga, Japan  \(^3\)The University of Tokushima, Tokushima, Japan

**Objectives.** There has been concerned about possible health effects of human exposure to low- or intermediate-frequency magnetic fields. Induced currents in a human body by magnetic fields of those frequencies are used as the basic restriction in the ICNIRP guideline. Two kinds of human models have been usually used in recent investigations on the numerical evaluation of dosimetry: one is an anatomically-real model and the other is a simple homogenous model such as ellipsoidal bodies. In this paper, numerical results of the current densities induced inside users of a household induction heater (IH) are illustrated, and effects of the human models on the induced current characteristics are discussed.

**Methods.** An anatomically-real Japanese model with high-resolution and whole-body nature, which is developed by NICT, was used as a real human model, while a rotationally-symmetrical model, which is applied in EN50366, was used as a simple human model. The real human model consists of over 50 tissues which had the conductivity ranging from 0.02 to 2 S/m. Meanwhile, the simple human model had the homogeneous conductivity of 0.2 S/m. Both models were constructed with 2mm cubic voxels.

Results of experimental works showed that the frequencies of leakage magnetic fields from the IH were 60 Hz (power frequency), 20 kHz (intermediate frequency), and their harmonics. Only magnetic fields for 20kHz were taken into account in this numerical calculation. Such a magnetic field environment from the IH was simulated by a single dipole moment. The human models erected in front of the IH, and the surface of their abdomen was 24cm apart from the dipole moment.

The scalar potential finite difference (SPFD) method was employed in this calculation.

**Results.** Figure 1 shows the maximum and averaged values of induced current densities (J\(_{\text{max}}\) and J\(_{\text{avg}}\), respectively) on each horizontal plane as a function of the height of the plane, which were calculated in the whole bodies of both models. It is found from Fig.1 that, in both cases of J\(_{\text{avg}}\) and J\(_{\text{max}}\), the qualitative dependencies of the current densities obtained for both models are similar to each other. Figure 1 indicates that, regardless of the models, both J\(_{\text{avg}}\) and J\(_{\text{max}}\) obtained in the torso are much larger than those in the head because the magnetic source is located in front of the abdomen. It is also clear that the difference between J\(_{\text{avg}}\) and J\(_{\text{max}}\) for the real model is larger than that for the simple model.

Table 1 shows the averaged and maximum values of magnetic fields (B\(_{\text{avg}}\) and B\(_{\text{max}}\),
respectively) and the induced current densities ($J_{\text{avg}}$ and $J_{\text{max}}$, respectively) obtained in the heads and torsos of both models. In the head, $J_{\text{max}} (= 3.71\, \text{mA/m}^2)$ obtained from the real model is about four times larger than $0.87\, \text{mA/m}^2$ obtained from the simple model, although the magnetic field environment in the head is similar to each other. Furthermore, in the torso, $J_{\text{max}} (= 29.5\, \text{mA/m}^2)$ obtained from the real model is twice as large as $15.4\, \text{mA/m}^2$ obtained from the simple model as well.

In the case of the real human model, the averaged and maximum values of current densities ($J_{\text{avg}}$ and $J_{\text{max}}$, respectively) obtained in some kinds of tissues and organs including the central nervous system (CNS) tissues are tabulated in Table 2. Table 2 indicates that the $J_{\text{avg}}$ and $J_{\text{max}}$ greatly depend on the tissues and organs concerned. It is obvious from Table 2 that the $J_{\text{max}}$'s for the CNS tissues are much smaller in comparison to the $J_{\text{max}}$ obtained in the torso, head, and whole-body.

**Conclusions.** Numerical results of the current densities induced inside the anatomically-real and simple homogenous models of the IH users are illustrated. It is found that, regardless of the models, both $J_{\text{avg}}$ and $J_{\text{max}}$ obtained in the torso are much larger than those in the head. Furthermore, in the head and torso, $J_{\text{max}}$ obtained from the real model is much larger than $J_{\text{max}}$ obtained from the simple model. It is also concluded that $J_{\text{max}}$ among the current densities in the CNS tissues are much smaller than $J_{\text{max}}$'s among the whole-body current densities.

![Figure 1](image-url)  
**Figure 1.** Layer-averaged and layer-maximum values of current densities on each horizontal plane as a function of model height.
**P-3 SAR CALCULATIONS IN AN ANATOMICALLY REALISTIC WHOLE-BODY MODEL OF PREGNANT WOMEN FOR PLANE WAVE EXPOSURES**

Tomoaki Nagaoka¹, Toshihiro Togashi², Kazuyuki Saito², Masaharu Takahashi², Koichi Ito², Soichi Watanabe¹

¹National Institute of Information and Communications Technology, Koganei, Japan ²Chiba University, Chiba, Japan

**Objectives.** The dosimetry of pregnant women is an important issue in electromagnetic safety, because too few data exist. Therefore, we developed an anatomically realistic whole-body voxel model for pregnant women. The purpose of this study is to predict SAR in the pregnant woman and fetus exposed to plane waves by numerical simulation using the pregnant woman model.

**Methods.** The pregnant woman model was developed by combining the new developed fetus model base on MRI data of the maternal abdomen (28 weeks gestation) and the deformed model based on the non-pregnant adult Japanese female model (Nagaoka et al, Phys. Med. Biol., pp. 1-15, 2004). Figure 1 shows a volume rendered image of the pregnant woman model. This model consists of $2 \times 2 \times 2$ mm³ voxels and is segmented into 56 tissue types. The FDTD method was used to calculate the SAR in the voxel human model isolated in air. Exposure conditions were E- and H-polarized plane wave electromagnetic fields from 10 MHz to 2 GHz. The incident waves were assumed to propagate from anterior to posterior (AP) and from left to right (LR). The incident power density was 1 mW/cm². PML boundary conditions were set at positions of 200 mm (100 cells) outside from the nearest parts of the model. Dielectric properties of the fetus were calculated based on the report by Schepps and Foster (Phys. Med. Biol., pp. 1149-1159, 1980). Electrical constants of other tissues were taken from different study (Gabriel, Brooks Air Force Technical Report, AL/OE-TR-1996-0037, 1996).

**Results.** Figure 2 shows frequency characteristics of whole-body averaged SAR for the pregnant woman model. The maximum SAR value occurs around whole-body resonant frequency for E-polarization (80 MHz). For E-polarization, the SAR is not significant difference between the AP and the LR in frequencies below resonance domain, while the SAR of AP is higher than that of LR at the other frequencies. For H-polarization, the SAR of the AP is markedly higher than that of the LR in frequencies below 300 MHz. The whole-body averaged SARs of the pregnant woman model, which are not presented in this abstract, are also compared with those of the non-pregnant female model. It is shown that the differences in whole-body averaged SARs between the pregnant and female models are at most 1.09 dB. The SAR values of both models agree well with each other under all conditions. These results suggest that pregnancy does not significantly affect the whole-body averaged SAR. The fetus averaged SAR values are shown in figure 3. It is demonstrated that the fetus averaged SAR values are considerably lower than the whole-body averaged SAR values (5-72 %).
**Conclusions.** FDTD calculations of SAR were performed in the pregnant woman model for plane wave exposures. It was confirmed that the pregnancy hardly influenced the whole-body SAR of adult female, and SAR value of the fetus was very low compared with the whole-body SAR value of the pregnant woman.

**Figure 1.** Volume rendered image of pregnant woman model.
Figure 2. Whole-body averaged SARs for pregnant woman model.

Figure 3. Fetus averaged SARs. The SAR values are normalized by the whole-body averaged SAR corresponding to that in figure 2.
**P-4 NUMERICAL INVESTIGATION OF FIELD ELEVATIONS DUE TO MOBILE PHONE USAGE IN TRANSPORTATION MEANS COMPARED TO FREE SPACE CONDITIONS**

Gernot Schmid\(^1\), Stefan Cecil\(^1\), Richard Ueberbacher\(^1\), Reinhard Georg\(^1\)

\(^1\)Austrian Research Centers GmbH-ARC, Seibersdorf, Austria \(^2\)Engineering Office for Telecom Consult, Kronberg/Taunus, Germany

**Objectives.** In recent years questions have been raised whether public exposure limits can be exceeded by simultaneous operation of many mobile phones inside restricted and partially shielded environments as elevator cabins, cars, and other vehicles. Although some basic weaknesses of the original publication triggering this issue (Hondou, 2002) have been pointed out in several more recent papers, still little data is available which allows quantitative estimates of exposure of the passengers, for realistic worst case scenarios.

**Methods.** Numerous exposure scenarios for an elevator cabin, 4 different types (sizes) of cars, a bus and two different trains carriages were modeled and computed using the FDTD-based simulation platform SEMCAD X (SPEAG, Zurich, Switzerland). For each of the vehicles different situations with respect to the number of passengers, number of active mobile phones and used frequencies were considered. Passengers were represented by semi-homogeneous whole body models consisting of a homogeneous body section and a homogeneous SAM-head model (Figure 1). The dielectric properties of the body and the head section were chosen according to Supplement C to FCC OET Bulletin 65. Generic box phones with a \(\lambda/4\) monopole antenna, for frequencies of 900 MHz (250 mW), 1,800 MHz (125 mW) and 2,100 MHz (125 mW) were used as source models. For each scenario up to 10 simultaneously operating sources were considered.

The small sized scenarios (elevator cabin and cars) could be solved within a single FDTD-domain, using a graded mesh with step sizes between 2 mm and 10 mm. In the head region the grid step was kept constant at 2 mm. This resulted, depending on the considered scenario, in approximately 50-200 Million FDTD-cells, which could be handled by a standard 64 Bit machine with 16 GB working memory. Numerical uncertainties of the exposure data in the head region due to cell size dimensions somewhat larger than \(\lambda/10\) in the body region could be shown to be negligible.

The larger scenarios of the bus and the train carriages were investigated for 2 different situations each (“front” and “center”), with truncated computational domains. In the “front” situation high density mobile phone usage in the area close to the front end was considered. Therefore, in this case only the side walls, top, floor and one front wall of the vehicle was modeled. The other (rear) wall was considered to be “far away” and the computation domain was truncated in this direction by absorbing boundary conditions (figure 2). In the “center” situation both rear and front walls were considered to be “far away”. With respect to the exposure in the head region the uncertainty caused by this simplification was obtained to be less than 5%, when persons and sources are more than 1 m away from the boundaries.

**Results.** As expected the results clearly showed highly heterogeneous distributions of field strengths due the partially metallic boundaries (figure 3). However, the maximum local
field strengths at distances > 10 cm from the sources were clearly below the reference levels for public exposure. For a phone user the main source of exposure is its own mobile phone, i.e., the elevation of exposure for a phone user in terms of SAR due to the reflective environment is usually lower than 10-15%. When comparing the extent of exposure of non-users for the situation inside the vehicle and for a (virtual) situation without reflective boundaries, elevations in terms of 10g averaged spatial peak SAR of up to a factor 15 for the small sized scenarios (elevator, cars) and up to a factor 6-8 for the large scale scenarios (bus, train carriages) were found. However, the absolute levels of exposure for non-users are far below the limits of local exposure (usually less than 1% of the limit).

Conclusions. Our results confirmed that simultaneous operation of numerous mobile phones inside metallic vehicles does not lead to over-exposure of passengers, even under worst case conditions (all phones operating at maximum output power). Compared to free space conditions, the relative elevation of exposure due to the metallic vehicle body is usually negligible for the (relatively high exposed) phone users but can be significant for the (low exposed) non-users.

Acknowledgements. This project was supported by the Federal Office for Radiation Protection, Germany.

Figure 1. : Semi-homogeneous body models (left) and, as an example, one of the modelled bus scenarios (right)

Figure 2. : Truncation of computation domains for large scenarios (bus, train carriages)
Objectives. In the last years rising attention has been devoted to possible effects induced by microwave (MW) electromagnetic (EM) fields, as those emitted by mobile phones, on high cognitive functions such as memory and learning. This implied a development of experimental investigations based on electrophysiological recordings in brain slices, which are the most used and best known in vitro system for the study of neuronal connections. In this context, exposure systems based on different EM structures \cite{1}-\cite{4} have been designed and fabricated in order to allow real-time recordings in brain slices under controlled exposure conditions to MW fields. Unfortunately, the experimental evaluation of the SAR inside the slices presents some problems. On the one hand, due to the very small thickness (0.04 cm) of the slice, accurate temperature measurements inside the sample became unfeasible. On the other hand, shape and dimensions of the sample holder (perfusion chamber), needed to maintain the in vivo-like environment of the tissue, may vary from one laboratory to another one. This calls for the repetition of experimental dosimetry with the used vessel. Here, an accurate and efficient methodology is proposed which integrates numerical simulations and experimental measurements in order to evaluate SAR values induced in brain slices by MW exposure.

Methods. SAR evaluation in the biological sample was conducted referring to the exposure system, based on a coplanar waveguide (CPW), specially fabricated for real-time electrophysiological recordings in brain slices \cite{3}, \cite{4}. The system efficiencies for the exposure of the sample at three frequencies representative of the uplink bands of GSM900, GSM1800, and UMTS standards (905, 1750, 1950 MHz) were estimated by means of a
numerical-experimental procedure. Numerical simulations of the system were carried out, by means of Ansoft HFSS commercial code, in the three following operating conditions:

A. two conventional sample holders, mainly circular Petri dishes (3.5 cm of diameter), filled only with 4 ml of RPMI solution, placed in the center of the two exposure zones of the system;
B. a brain slice ($\epsilon=41.5$ and $\sigma=0.86 \text{ S/m}$) of radius 0.4 cm and height 0.04 cm inserted in each of the two Petri dishes mentioned above;
C. a brain slice immersed in RPMI solution inside two circular chambers (3.5 cm of diameter), suitable for an easy positioning and perfusion of the sample, placed in the same positions of the Petri dishes.

In all cases the RPMI medium was modeled with a permittivity value of $\epsilon=77$ for all frequencies and slightly different conductivities: $\sigma=1.9 \text{ S/m}$ at 905 MHz and $\sigma=2.2 \text{ S/m}$ at 1750 and 1950 MHz.

SAR values induced in the slice in the cases B and C were normalized using those obtained in the RPMI solution for the case A, in order to calculate specific scaling factors. This allowed to evaluate in which way the presence of the slice and/or modifications in sample holders affect power absorption.

Experimental results were obtained in the same condition described in A. Temperature measurements were carried out in 12 points equally spaced in the Petri dish, using high impedance Vitek TP100 thermistors. SAR in the RPMI solution was evaluated from measurements in two points where the slice is assumed to be positioned.

The estimation of the efficiency (SAR per unit input power) in brain slice placed within the two different sample holders (Petri dish and perfusion chamber) was achieved by multiplying the efficiency experimentally evaluated by the scaling factors obtained from numerical simulations.

**Results.** Results of simulations showed that SAR values in the slice (A) were smaller than those evaluated in RPMI medium only (B). Such an expected lowering is not due to a change in the field distribution, but to the reduced power absorption in the slice, whose conductivity is almost one half the one of the RPMI solution. Indeed, the scaling factor in SAR values is in fact almost equal to the ratio between the two conductivities, at all frequencies, and specifically of 2.04, 2.48, and 2.05 at 905, 1750 and 1950 MHz, respectively. When the slice was inserted in the perfusion chamber (C), a further decrease of induced SAR was observable. In this case, such a reduction cannot be traced back only to the differences in conductivity but also to a variation of the $-\mathbf{E}-$ field distribution caused by the greater thickness of the chamber sides in comparison to those of the Petri dish. Therefore, the scaling factors between SAR values in the slice and in the RPMI solution are not directly comparable to the conductivity ratio and are equal to 2.46, 3.37, and 2.50 at 905, 1750 and 1950 MHz, respectively.

Results of efficiency experimentally determined and estimated for the slice inserted in the Petri dish and in the perfusion chamber are summarized in Table I.

**Conclusions.** The methodology here proposed represents a powerful tool, since it allows to recalculate the efficiency of an exposure system when the sample holder has changed
without needing a new experimental characterization.

References

Acknowledgements. This work was supported by the European Union, V framework under the RAMP2001 Project.

* P-6 STATISTICAL MULTIPATH EXPOSURE OF A HUMAN IN A REALISTIC ELECTROMAGNETIC ENVIRONMENT

Gunter Vermeeren, Wout Joseph, Christof Olivier, Luc Martens
Ghent University, Ghent, Belgium

Objectives. Several statistical models exist for the description of a realistic electromagnetic environment. If we want to investigate the whole-body exposure of a spheroid human-body model in such an environment, then a huge number of simulations are required with any FDTD- or MoM/FEM tool in order to obtain statistical relevant results. Therefore, a new and fast method is proposed for the assessment of the exposure of a spheroid phantom in a realistic electromagnetic environment.

Methods. In [1] a statistical model of the electromagnetic field in an observation point \( \mathbf{r} \) has been proposed for several realistic environments. This statistical model describes the electromagnetic field distribution as a finite sum of incident plane waves. Using this model, we generate a large number (50000) of complex field distributions.

To investigate the whole-body averaged SAR (\( \text{SAR}_{\text{wb}} \)) in any phantom, it is sufficient to determine the Poynting vector from the electric and the magnetic field distribution on a closed surface around the phantom. Integrating the Poynting vector over the observation surface and taking the real part, gives us the absorbed power inside the observation surface. As only the phantom is inside the observation surface, the absorbed power equals the losses in the spheroid phantom. Taking into account the weight of the spheroid phantom, one finds \( \text{SAR}_{\text{wb}} \).

The linearity of the Maxwell equations allows us to evaluate the fields on the observation surface for each individual incident plane wave and, finally, to make the superposition of the fields on this surface to find the resulting field.
Because a homogeneous spheroid model has rotation symmetry around the major axis and reflection symmetry across the plane defined by the minor axes, the field distribution of any incident plane wave can be determined from the field distributions of the TE (transverse electric) and TM (transverse magnetic) polarized incident plane waves for every elevation angle $\theta$ between 0 and $\pi/2$, and a single azimuth angle $\phi$ (see Fig. 1). The fields of these incident TE and TM polarized plane waves form a complete set of basis field distributions and have to be calculated with a FDTD or MoM/FEM tool.

The amount of elevation angles for which the fields of the TE and TM incident plane waves have to be calculated can be significantly reduced by the use of spline interpolation. With this method we have limited the number of simulations to 18 for the investigation of SAR\(_{wb}\) in a homogeneous spheroid in a realistic electromagnetic environment.

Using this set of 18 simulations of the fields and the interpolation, the absorption can be calculated from every complex field distribution generated with the model of [1].

**Results.** The proposed method was validated with a MoM/FEM tool. All deviations on SAR\(_{wb}\) were all below 1 %. After performing the numerical simulations to determine the set of basis field distributions, calculating the exposure for a single sample only takes 0.5 sec on a PC with a 3.4 GHz processor. Fig. 2 shows the cumulative distribution function of SAR\(_{wb}\) in a homogeneous spheroid (2a=1.75 m, b=0.138 m) with dielectric properties $\varepsilon_r=41.4$ and $\sigma=0.99$ S/m in an urban macrocell environment [1] at a frequency of 950 MHz. The number of samples was 50000. E\(_{rms}\) averaged over free space was set to the ICNIRP reference level at 950 MHz, i.e. 42.38 V/m. For an urban macrocell the median of the SAR\(_{wb}\) is 0.014 W/kg with standard deviation of 0.0025 W/kg. In 99 % of the cases the SAR\(_{wb}\) will be less than 0.02 W/kg. The chance of reaching the ICNIRP limit of 0.08 W/kg is not probable.

**Conclusions.** A new and fast method has been proposed for the investigation of the whole-body exposure of a spheroid model of a human in a realistic environment. The method has been validated with numerical simulations with a MoM/FEM tool and excellent agreement has been observed. The results of SAR\(_{wb}\) for a spheroid in an urban macrocell environment at a frequency of 950 MHz are presented and are compliant with the basic restriction of 0.08 W/kg.

References:
Figure 1. The method for the exposure of a spheroid in a complex electromagnetic environment.
Figure 2: The cumulative distribution function of $SAR_{wb}$ in a spheroid model of a human ($2a=1.75\,\text{m}$, $b=0.138\,\text{m}$) in an urban macrocell environment at 950 MHz when the average of $E_{rms}$ over the entire space equals the ICNIRP reference level.
P-7 LOCAL AND WHOLE BODY EXPOSURE TO RF ELECTROMAGNETIC FIELDS OF PATIENTS UNDERGOING MAGNETIC RESONANCE IMAGING DIAGNOSTICS

Eugenia Cabot\textsuperscript{1}, Andreas Christ\textsuperscript{1}, Michael Oberle\textsuperscript{1}, Niels Kuster\textsuperscript{1,2}
\textsuperscript{1}IT’IS, Zurich, Switzerland \textsuperscript{2}ETH Zurich, Zurich, Switzerland

Objectives. Current designs of Magnetic Resonance (MR) scanners use steadily increasing magnetic field strengths which go along with a rise of the Larmour frequency of the RF fields. Scanners which operate at 1.5T or 3T use frequencies of 64MHz or 128MHz. At these frequencies, the field distribution in the body of the patient is highly inhomogeneous. MR safety standards define limits for the whole body SAR and for the local SAR (hot spots). The reliable assessment of these values, which is a prerequisite for patient safety, becomes a more and more complex task at higher frequencies. The main objective of this study is to numerically characterize the local and the whole body absorption in patients undergoing MR examinations as a function of RF frequency, patient size, weight, tissue distribution and position in the birdcage coil. This includes:
- the assessment of local and whole body SAR in the human body when exposed to the RF-fields of a birdcage coil for different configurations
- the characterization of conditions of tissue distribution and incident field which lead to local hot spots and possible tissue heating
- the identification of the local SAR or the whole body SAR as a limiting factor of the exposure
- estimation of the worst-case local heating

Methods. The SAR distribution in different human body models of adults (53kg – 90kg, 1.60m – 1.80m) and children (17kg – 34kg, 1.07m – 1.48m) is simulated in a generic birdcage coil at frequencies of 64MHz and 128MHz using the FDTD method. The required grid resolution for the anatomical models is assessed using a series of continuously refined simulations, and the numerical model of the birdcage is validated by measurements of the SAR distributions in the ASTM phantom. The thermal simulations had been done with the novel thermal solver that is based on the Pennes model but also features tensorial heat conductivies and connected pseudo-1D discret vessel networks. All computations are carried out using the integrated simulation platform SEMCAD X, and for the validation measurements, the near field scanner DASY5NEO is used.

Results. The peak spatial average and whole body SAR, as well as local hot spots, are evaluated for different positions of the body models inside the birdcage coil. The whole body SAR and the local hot spots are strongly dependent on the positioning of the model in the birdcage coil, with some landmarks presenting more sensitivity than others. While the occurrence and amplitude of several local SAR maxima depend on the position of the body in the coil, many hot spots are independent from the coil configuration and the body
position. This suggests that particular properties of the individual body tissue distribution may lead to localized tissue heating.

**Conclusions.** This study could identify conditions which can lead to a localized SAR increase in patients undergoing MRI examinations. The whole body SAR displayed by the MRI scanner yields no indication of the magnitude or position of the localized SAR in the body. Further studies are required in order to identify the mechanisms and worst-case conditions which lead to the local heating and in order to provide guidelines which can be used for standards for the safe operation of MRI scanners at frequencies where the SAR distribution is highly inhomogeneous.

**Acknowledgements.** This study was greatly supported by the Schmid and Partner Engineering AG, Zurich, Switzerland.

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**P-8 SAR CHARACTERIZATION INSIDE INTRACRANIAL TUMORS FOR CASE-CONTROL EPIDEMIOLOGICAL STUDIES ON CELLULAR PHONES AND RF EXPOSURE**

Nadege Varsier\textsuperscript{1,2}, Kanako Wake\textsuperscript{2}, Masao Taki\textsuperscript{1}, Soichi Watanabe\textsuperscript{2}, Toru Takebayashi\textsuperscript{3}, Naohito Yamaguchi\textsuperscript{4}, Yuriko Kikuchi\textsuperscript{3}

\textsuperscript{1}Tokyo Metropolitan University, Tokyo, Japan \textsuperscript{2}NICT, Koganei, Japan \textsuperscript{3}Keio University, Tokyo, Japan \textsuperscript{4}Tokyo Women’s Medical University, Tokyo, Japan

**Objectives.** The increasing use of mobile phones over the last decade raised a concern about possible health effects of electromagnetic field (EMF) emitted by mobile phones. An epidemiological study is actually in progress in Japan, evaluating the hypothetical relationship between RF exposure and cancer risk [1]. The purpose of our study was to characterize SAR (Specific Absorption Rate, [W/kg]) inside intracranial tumors and provide a new parameter for the exposure index to the Japanese epidemiological study. The goal of our paper is to present the method that was developed to evaluate SAR distribution inside brain tumors and the application of this method to the Japanese case-control epidemiological study concerning gliomas and meningiomas.

**Methods.** SAR data: In order to create typical exposure indexes, we used original data obtained from 76 cellular phones (on the Japanese market in 2001), using Cheek position/antenna extracted conditions. From the measurements, 3D 1 mm SAR distributions in Japanese numerical TARO model’s head were estimated [2]. And phones were finally categorized into 4 clusters (4 groups for right use side and 4 groups for left use side), with a typical 3D SAR distribution for each group [3].

Brain tumor data: Tumor data consist of 275 cases of intracranial tumors. They were localized by medical doctors on a Chart model consisting of 12 axial CT scan cuts acquired every 1cm.
Method of brain tumor localization in TARO model:
In order to estimate average and peak SAR inside brain tumors, it was necessary to localize the tumors in TARO model. The first challenge was to find the 12 cuts of TARO model matching the 12 axial CT scan cuts of Chart model. Then we created a Graphical User Interface, using MATLAB, that allows, by a simple mouse click, to localize tumor tissues inside TARO model matching cuts. After relocalizing tumors in TARO model, we were able to estimate average and peak 1cm-cube SAR values inside tumors for each cluster of phones with different SAR distributions.

Results. SAR inside tumors was characterized for 275 cases of brain tumors including gliomas, meningiomas and acoustic neuromas. Results were highly dependant on clusters. Contralateral tumors, in terms of SAR, were usually categorized as non-exposed tumors (max SAR < 0.001 W/kg) and for 95% of tumors, maximum SAR was less than 20% of maximum SAR in the brain, whatever the cluster. For the purpose of exposure assessment for the Japanese case-control epidemiological study on gliomas and meningiomas, SAR distribution was introduced as a new parameter to evaluate brain tumors exposure level. For each phone user, we combined the cumulative call time information and the average and maximum SAR estimations inside brain tumors.

Conclusions. Two new exposure indexes using SAR distribution inside brain tumors were created, which will be applied to the analysis in the Japanese case-control epidemiological study. By using SAR as exposure metric, these two indexes, compared to conventional indexes using only exposure length, reflect more accurately the intensity of exposure on the specific location of tumors, although, to the uncertainty of the average call duration recall, is added the laterality of use recall bias.

References:
P-9 THE DEPENDENCE OF SAR UPON POSITION OF A MOBILE PHONE USER IN ENCLOSED ENVIRONMENTS

Ally Y. Simba¹, Takashi Hikage², Soichi Watanabe¹, Toshio Nojima²
¹National Institute of Information and Communications Technology, Tokyo, Japan
²Hokkaido University, Sapporo, Japan

Objectives. With the rapid increase in the use of the mobile phones in enclosed environments such as trains and elevators, public concern regarding the possibility of the RF exposure in such areas exceeding the basic restriction of the ICNIRPs guideline has been growing [1]. According to [2], it is very unlikely that the basic limit for the whole body average (WBA) SAR i.e. 0.08 W/kg will exceeded. However, the case of spatial average-SAR is a different thing all together, considering the possibility of the hotspot [1] occurring at the 1 or 10 g mass used for SAR averaging. There has been no detailed information regarding spatial average SAR of the realistic human model in enclosed environments so far, partly because of the large resources required to perform numerical simulations. For example, in [2] a simplified homogeneous human model was used and only WBA-SAR was discussed. Taking this in to consideration, we perform the FDTD calculation of the 10 g average SAR as a function of the human body position inside an elevator at 900, 1500, and 2000 MHz.

Methods. The FDTD model of the elevator is shown in Fig. 1. The dimensions of the elevator were taken from an actual elevator in active service in Japan. The elevator has a maximum capacity of 9 persons, however, in this paper, a simple case of one person using the mobile phone is considered. Half-wavelength dipole antenna placed in the right side of the head of the phantom with the maximum transmitting power of 250 mW is used to represent a mobile phone. The distance between the antenna and the head is chosen to be 16 mm. The non-uniform mesh FDTD technique was used in this investigation [3] to minimize computer resources. Fine size cells of \( \Delta x = \Delta y = \Delta z = 2 \text{ mm} \) are used to model the regions around the human model. The other areas of the problem space are modeled with coarse size cells of 10 mm in all directions. Perfect matched layer (PML) [4] having 8 layers and \( M = 4 \) is placed at all boundaries of the FDTD problem space.

Results. Fig. 2 shows the input characteristics of the antenna as a function of the user position from the wall along the x-direction, with the distance from the wall in the y-direction kept constant and minimum at 184 mm. R and I indicate real and imaginary input impedance, respectively. The input impedance is seen to vary with the user position in a slowly decaying sinusoidal form. Fig. 3 shows the 10 g SAR in the elevator as a function of the position. Our investigation has shown that the peaks of the slowly decaying sinusoidal function of the SAR in Fig 3 occur at odd multiple of \( \lambda/4 \) from the wall along x-axis, i.e. \( d = (2n + 1) \lambda/4 \), where \( n = 0, 1, 2, \ldots \)

Conclusions. Numerical investigations of the spatial average SAR of the mobile phone user in the elevator were carried out to determine whether the exposure in such environment can exceed the basic restriction. The SAR results we have obtained so far are below the ICNIRP exposure guideline.

Reference
Acknowledgements. Calculations in this work were performed using SX-6 series supercomputer provided by the National Institute of Communications and Technology.

Figure 1. : FDTD model for elevator.
Figure 2. Input impedance of the dipole antenna.

Figure 3. SAR averaged over 10 g for the 250mW output power.
**P-10 REDUCTION OF COMPUTATIONAL COSTS IN FDTD SIMULATION WITH A NEW ABC BASED ON PML FOR LARGE SCALE DOSIMETRY**

Kensuke Sasaki, Yukihisa Suzuki, Masao Taki
Tokyo Metropolitan Univ., Tokyo, Japan

**Objectives.** Recently, large scale FDTD[1] simulation is used to high frequency electromagnetic field(EMF) dosimetry. High performance of absorbing boundary condition(ABC) such as Berenger’s PML[1](B-PML) is required to obtain reliable numerical result. The larger calculation region requires the more computational costs. It is desirable to reduce computational costs for ABC because calculation in ABC, such as B-PML, requires a lot of memories and calculation time.

The purpose of this study is to propose a new ABC scheme with similar performance, and with reduced computational costs, to B-PML. For this purpose, we develop a new propagation scheme called uniaxial-pseudo propagation(UPP) scheme. Then the UPP scheme is applied to propagation inside PML region. The proposed ABC is called uniaxial-pseudo propagation PML(UPP-PML). We evaluate performance of FDTD simulation using the new ABC with a simple sphere model.

**Methods.** The concept of UPP scheme is based on directional splitting[2](DS). A Figure shows propagation of $z$ component of electric field $E_z$ between $n$ and $n + 1$. Here, $n$ indicates time step. The conventional propagation is shown by dotted arrow in the figure. Pseudo-time step $n'$ is introduced between $n$ and $n + 1$ in the concept of UPP technique. The direction of wave propagation is split into x and y directions via $n'$ as shown by solid arrows in the figure. Although the propagation process of UPP scheme is different from the conventional process, both schemes are equivalent in wave propagation from $E_z^n <i>$ to $E_z^{n+1} <i>$. We apply the UPP scheme to propagation in PML region.

In this study, we examine preliminary evaluation of UPP-PML with a calculation of scattering by a simple sphere model. Simulation conditions for evaluation are as follows. Calculation region is $140 \times 140 \times 140$ cells, and cell size is 1 mm. The sphere is evaluated by 2 GHz plane waves. The sphere is inserted in the center of calculation region, and radius of sphere is 25 mm. Relative permeability and conductivity of the sphere are 40 and 1 S/m, respectively. The electric constants of sphere are similar to those of biological tissue.

**Results.** Average and maximum of specific absorption rates(SARs) in the sphere obtained by UPP-PML are compared with the results obtained by the conventional B-PML. As a result, there are almost the same. Computational costs are also evaluated. Calculation time with UPP-PML is 10% faster than B-PML simulation with the same calculation condition. Required memory is about a half of the B-PML.

**Conclusions.** In this study, we developed UPP scheme based on DS concept. UPP scheme was applied to propagation inside PML region.
As a preliminary evaluation, we examined scattering problem with a simple sphere model. As the result, average and maximum SARs within the sphere model were almost the same between the results of UPP-PML and B-PML. We also showed that UPP-PML has advantages in computational costs over B-PML.

Figure 1. The propagation concept of UPP scheme

**P-11 SPECIFIC ABSORPTION RATE INDUCED BY A DISH ANTENNA AT 7.75 GHZ**

Man-Fai Wong, Fabrice Lacroux, Joe J. Wiart
France Telecom R&D, Issy Moulineaux, France

**Objectives.** This paper aims at evaluating the SAR (Specific Absorption Rate) in a human body induced by a parabolic antenna at the frequency of 7.75 GHz. The compliance of the exposure to either basic restrictions or reference levels can then be analyzed.

**Methods.** The Finite Difference Time Domain (FDTD) is used to evaluate the wave absorption in a human head. The incident wave is obtained using the decomposition of a given dish antenna into spherical harmonics. The dish antenna is characterized in free space and coupled to the head through a Huygens box in the FDTD.
Results. The SAR and the incident power density are evaluated using the same power, chosen as 26 dBm (typical for this kind of antenna). The antenna is positioned at d=1.2 m and d=1.5m before the head, the incident wave impinging on it from the front or the side. The peak SAR over 10g is obtained for the front position giving 0.0821 W/kg and 0.0966 respectively for the d=1.2m and d=1.5 m. The power density averaged over 20 cm$^2$ is calculated as 1.35 W/m$^2$ and 1.18 W/m$^2$ respectively.

The results show that the exposure is higher at d=1.5m than at d=1.3 m because in the main beam in the near field region the power density varies but is not decreasing as the square of the distance.

Conclusions. In terms of SAR, for the given power, 26 dBm, the peak SAR over 10g is more than 100 times less than the corresponding limit value (10 W/kg). In terms of power density, for the given power, the averaged power over 20 cm$^2$ is 37 times less than the limit of 50 W/m$^2$.

![Figure 1. head exposed from the side: local SAR](image)
Figure 2. head exposed from the front: local SAR

P-12 IMPACT OF THE USED NUMERICAL HUMAN MODELS IN DOSIMETRIC STUDY

Abdelhamid Hadjem, Emmanuelle Conil, Fabrice Lacroux, Man-Fai Wong, Joe J. Wiart
France Telecom R&D, RESA/FACE/IOP, Issy Les Moulineaux, France

Objectives. International organizations such as the International Commission on Non-Ionising Radiation Protection (ICNIRP) and IEEE have set up exposure limits. These limits are defined in terms of basic restrictions and, they allow to protect the public and workers from possible hazards associated to electromagnetic field over-exposure. Thus, the SAR assessment of wireless communications devices is critical for dosimetric analysis, e.g. for compliance problems. It is interesting to analyze the SAR distribution in different body having different age. The question about the variability on the SAR assessment due to the used numerical models is very important. Indeed, the SAR depends of the age, the morphology and the posture. For this purpose, a comparison is performed for the SAR and the power budget induced in adult and child whole bodies.

Methods. Numerous different numerical human models are placed in a Huygens box in order to have a wave plane exposure. Our simulations are based on the Finite difference Time Domain (FDTD) method. Simulations are performed for several frequencies. The child whole body ”CWB” is built using morphing deformation of an adult body. This deformation is realized considering the difference between adults and child (depending on the age): width of the face, height of the upper and lower face, head length, body height, upper and lower segment of body, shoulder diameter and hip diameter. In this study, the
used numerical models are: visible human, Zubal, Norman, Korean model, Japanese male and female models and child versions of these ones. In each case, the body is exposed by a plane wave (both face and side orientations). For each case of exposure, the absorbed power is calculated.

**Results.** Several parameters can significantly affect the variation of the local SAR value, such as the morphology (the body shape), the resolution and segmentation quality. Concerning the values of whole Body SAR, the posture and morphology can also affect it. Both local and whole body SAR values depend on the frequencies.

**Conclusions.** Previous adult and child whole bodies used in this study. the aims is investigate the question about the influence of body morphology with it variability on uncertainly SAR values. It is important to put all these results into their context and note that they are valid only for specific cases: specific human or source models.

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**P-13 DOSIMETRY NEAR A DIRECTIVE ANTENNA : METHOD TO DETERMINE A POSITION MAXIMIZING THE LOCAL SAR**

Fabrice Lacroux, Emmanuelle Conil, Man-Fai Wong, Joe J. Wiart
France Telecom Research and Development, Issy Les Moulineaux, France

**Objectives.** Numerous research groups have used numerical models to predict the human body exposure within the near-field region of an antenna in order to, for instance, ascertain compliance with exposure limits. The specific absorption rate (SAR) depends on the used numerical human body model, the antenna and the relative position between them. Accordingly, a lot of configurations have to be considered. In this context, this paper proposes a method to determine a position maximizing the value of 10g SAR considering one antenna, one body and one distance between them with a limited number of simulations. Moreover, this method allows to predict, for a given configuration, the local SAR values knowing the local incident field levels. It should be noticed that the local SAR depends on the tissue layers and the local body shape which is exposed.

**Methods.** The proposed method is composed of three steps. In the first step, the human model is exposed by a plane wave according to the frequency and the polarisation of the antenna. This simulation allows us to know where, in the body, the local SAR is maximal. Moreover, the 10g SAR values are known for a given density power. In the second step, the antenna is simulated in free space. The distribution and the values of the power density in front of the antenna are assessed. For a given distance this distribution allows to find where the beam is the more focused. In the third step, the antenna and the body are simulated together. They are placed in order to have a superposition between the point where the local SAR is maximal (found in the first step) and the point where the power density is maximal (given by the second step). The configuration will maximize, for a given
distance between the antenna and the body, the local SAR. Moreover, this simulation could be skipped because the first step gives the local SAR values for a given density power and the second step gives the density power for a given antenna input power. Therefore, we would predict the local SAR values for a given antenna input power.

**Results.** As an application, the case of a numerical human body model (visible human) exposed by a typical base station antenna operating at 2140MHz is proposed. The antenna is composed of 4 half wavelength dipoles and reflectors. Simulations have been performed with a simulator based on the finite difference time domain (FDTD) method. The 10g SAR is calculated in a sphere. The plane wave exposure shows that some body parts have a higher 10g SAR value (see figure 1). The higher value for the 10g SAR is in the genitals with 0.0096W/kg for a power density of 1W/m². The antenna is simulated in free space and the maximum of power density averaged on 4cm² (for instance), at 18.6cm in front the antenna, is equal to 8.1W/m² for an antenna input power of 1W. We assume that the 10g SAR is due to an averaged power density on a little surface. Then the main beam of the antenna is placed in front of the genitals. The full simulation is performed and the 10g SAR distribution is presented in the figure 2. In the genitals, the value of the 10g SAR is 0.66W/kg for an antenna input power of 1W. This value might be predicted with the two previous simulations. Indeed, we know that 1W input power gives a power density of 8.1W/m² and a 1W/m² wave plane gives a 10g SAR in the genitals of 0.0096W/kg, so 1W input power would give 0.0096*8.1=0.077W.kg⁻¹ (instead of 0.66W.kg⁻¹). This difference comes from the coupling between the antenna and the body. If the distance between them is higher, the coupling could be neglected.

**Conclusions.** The proposed method allow to find quickly a position maximizing the exposure in terms of local SAR considering an antenna, a human body model and a distance between them. Our method has been applied in the case of a base station antenna exposure. The results show the feasibility of the local SAR prediction for a given configuration.
Figure 1. 10g SAR distribution on visible human exposed by a plane wave
Figure 2. : 10g SAR, visible human exposed by the antenna
*P-14 EVALUATION OF REDUCTION EFFECTIVENESS FOR MF EXPOSURE COMPARES UNDERGROUND TRANSMISSION CABLE WITH OVERHEAD POWER LINE

Hyun-Ju Park¹, Seung-Cheol Hong¹, Yoon-Shin Kim², Sungho Choi²
¹Inje University, Kimae, South Korea ²Hanyang University, Seoul, South Korea

Objectives. When there is a gradual increase in new installation of power transmission & distribution lines and addition of currents loads, which works as the most dominant causes of electromagnetic field emission, an evaluation and an analysis have been performed on how much the underground constructions of power transmission lines, which may be the only technical alternative, affect the reduction of their exposure.

Methods. After choosing a representative region, an assessment and analysis have been conducted between the strength of magnetic field in the existing overhead power transmission lines and that in the underground counterparts for the chosen area. And the assessment and analysis on maximum load capacity were done through simulations with the overhead lines installed at the altitude of 14m and the underground lines buried at the depth of the top surface of the concrete duct bank is assumed to be 1.5m and 3m respectively. And the area where the underground transmission lines are buried was compared and analyzed to the simulated values by real measurements. The strength of magnetic field exposure analysis was done with an emphasis on the virtual receptacle existing within the living space, and from this analysis it is known that the exposure amount of the receptacle may be measured from 10m separation distance from the transmission line, however the actual distances were 17.2m from the ground line and 10.2m from the underground line, showing a difference of the distances by the locations.

Results. The simulation of the overhead transmission lines and the underground transmission lines under maximum load capacity(worst case) through the year has shown as a result that the magnetic field exposed from the underground transmission lines seemed low in both areas, and in ‘Gwangju’ district it was confirmed that although the magnetic field exposure right above the underground transmission lines were densely exposed, those were reduced 19 times as the separation distance gets farther. It was also checked that the magnetic field exposure from 3.0m was 1.5 times higher than that from 1.5m distance, which is characteristic of the underground transmission lines burial. However, the distances beyond 10m did not show any difference in electromagnetic field exposures. It means that right above the buried line, the exposure amount was higher than at the overhead transmission line, but as the separation distance gets farther, the exposure amount remained at the background level. The real-measurement magnetic fields at right above the buried of the underground transmission lines are approximately 83.3 and 870 times less than the ICNIRP and IEEE guidelines, respectively.
Conclusions. Judging from the fact that though in the case of the construction of 154kV lines conversion from overhead transmission lines to underground transmission lines, overhead line construction costs 900 million won/km and underground transmission line costs 6.6 billion won/km, 7 times the cost for overhead construction right now in the Republic of Korea, a conversion construction is deemed useful in the standpoint of exposure reduction.

Acknowledgements. This research work was supported by ECO2 Research Grant No. 2005-09001-0038-0 from the Korea Ministry of Environment (2005~2006).

P-15 COUPLING BETWEEN HANDS FREE WIRE AND THE USER HEAD

Dominique Picard
SUPELEC, Gif sur Yvette, France

Objectives. Since a few years the use of hands free kits (HFK) with mobile phones is increasing. The distance between the phone antenna and the user head is larger with the use of hands free kits (HFK) and one can think that the RF deposited power in the user head is significantly reduced. However the wire of HFK is metallic and the RF currents induced on this wire can be the sources of power deposition in the user head [1]. 124 different HFK has been tested following a first measurement protocol [2]. The obtained SAR values are relatively low but not negligible. Consequently, it is necessary to study the HFK SAR, especially to be able to propose an argued measurement protocol. The problem is separated in three different parts: the coupling between the phone and the HFK wire, the propagation of the current and the radiation on the wire, and the coupling between the end of the wire and the user head. This paper presents the coupling between the wire and the user head.

Methods. This study is devoted to the effect of the different parameters on the induced SAR value in the user head by a HFK wire. We choice a simple model. The user head is a half space with EN50361 standard dielectric constant and conductivity values. The HFK wire has two rectilinear parts: one is parallel to the surface of biological tissue and the second is tilted with an angle alpha. The part of the wire, which is parallel to the surface, is at a distance d from the surface. The different parameters are L1, L2, d, alpha and the frequency.

Figure 1: User head and HFK wire modelling

This configuration is simulated by the mean of IE3D software. A current source is located at the end of the tilted part of the wire. The electric field is evaluated in a 200mm by 200mm part of the biological tissue, centred on the wire. Then the radiated power in this area is calculated and used to normalize the electric field. This field is used to calculate the maximum 10g averaged SAR. This normalization allows the comparison of the different configurations.
**Results.** The value of the length L2 doesn’t modify the effect of the other parameters, and in practice its value results from the total HFK wire length. The distance d between the wire and the user head change hardly the SAR value (figure 2). In practice the wire is in contact with the head and we have to take d=0mm for the measurement protocol. The effect of the length L1 and the angle alpha is low and we choice alpha=45° and L1=20mm for practical reasons.

a) b)

Figure 3: Variations of 10g averaged SAR value due to:

a) length L1 (d=0mm, L2=320mm, alpha=45°),
b) angle alpha (d=0mm, L1=20mm, L2=320mm).

**Conclusions.** This study allows the choice of the different parameters value required for a HFK dosimetric protocol measurement. Only the distance d has an important effect on the SAR value. The other parameters have a poor effect leading to low errors sensitivity. This configuration is actually tested for HFK dosimetry.

**REFERENCES**


**Acknowledgements.** This research was sponsored by the French government within the ADONIS project (RNRT program).
Figure 2.

Figure 3.

P-16 A NEW HIGH PERFORMANCE DOSIMETRIC ASSESSMENT SYSTEM
Dominique Picard\textsuperscript{1}, Nicolas Ribiere-Tharaud\textsuperscript{1}, Abdelhak Ziiyat\textsuperscript{2}
\textsuperscript{1}SUPELEC, Gif sur Yvette, France \textsuperscript{2}UMP University, Oujda, Morocco

Objectives. Standard dosimetric assessment systems use so-called detected probes to measure the local electric field [1]. Such probes detect the RF currents induced by the electric field, to obtain a continuous voltage. The level of this voltage is very low, due to the detector conversion losses. The lines connecting the dipole and the voltmeter are made highly resistive to reduce their parasitic effect. Unfortunately, this results in increasing the noise level. For instance, for the AntennesSA probe using 4.5mm length dipoles, the resistance of the resistive lines is 1.5M\text{Ohm}. As a result, the detected voltage is, typically, 2.5mV for a 10V/m electric field, and 0.025mV for 1V/m. Practically, taking into account parasitic signals stemming from ambient noise, amplifier drift, static electricity, voltage ground, etc. It is recognized that measuring electric field levels lower than a few V/m, that is to say
SAR level lower than a few mW/kg, is difficult. This paper is devoted to a new dosimetric assessment system allowing high sensitivity and very fast measurements.

**Methods.** We have developed a specific electronic interface a few years ago, for a precedent dosimetric assessment system [2] [3]. It consists of 2 main parts: a low noise amplifier (LNA) and a coherent detector. We have modified this electronic interface and improved its performances in term of noise and stability. We use new mechanical displacements allowing high speed and acceleration. The sizes of the explored area are 2.17m by 1.80m in a horizontal plane and 0.60m following the vertical axis. Such sizes allow dosimetric measurements in a whole human body phantom. The SAR data processing software has also been accelerated, leading to an execution duration of about 20ms.

**Results.** The figure 1 shows the comparison between two measurements of the local SAR maps of a GSM phone for two different power levels: 5 and 20. The accurate measured ratio of the emitted power for these two power levels is 27dB, corresponding to the ratio of the maximums of the two SAR maps. The local SAR map for whole body exposed to a base station antenna is presented in figure 2. The antenna emitted power is 0.2W and the distance between the antenna and the phantom is 15cm. For both examples, local SAR level of about 0.1mW/kg are correctly measured. The table 1 contains the comparison between classical and the new Supélec dosimetric assessment system.

a) b)

Figure 1: Comparison of local SAR maps (mW/kg) a) handset power level 5, b) handset power level 20.

a) Local SAR map b) Exposure BTS antenna c) Whole body phantom

Figure 2 : Whole body local SAR (dBW/kg) map for BTS antenna exposure for 0.2W emitted power and a 15cm phantom-antenna separation distance.

**Conclusions.** This new dosimetric assessment system allows rapid and very low SAR measurements. It is about 10 times faster and its sensitivity is about 300 times lower than classical systems. It is well suited for whole body measurements. For the EN50361 standard, entire SAR measurements is performed in less than 25 minutes. The measurement of very low SAR setup as bluetooth earpiece is possible with a good accuracy.

References:

**Acknowledgements.** The authors would like to thank Bouygues Telecom for their financial support.
Objectives. This paper describes the methodology of detailed dosimetry for local *invivo* studies over long periods. We have to complete and to achieve the numerical dosimetry of the loop antenna [1] [2] at GSM (900 MHz and 1800 MHz) and UMTS (1960 MHz) frequencies. This dosimetry is based on electromagnetic simulations to estimate SAR levels in well-controlled numerical rat models.

When the attention of bioelectromagnetics researchers was directed to the safety of the rapid proliferation of the use of personal wireless devices, it became clear that *invivo* biological studies would be necessary to understand better the interactions between electromagnetic waves and biological tissues. *Invivo* exposure systems such as the loop antenna must be well-controlled, to obtain a detailed and accurate dosimetry. The current biological studies intend to be on a large period. We have to consider different numerical rat models, for
whole body analysis but also for local exposure, with different discretisation, size and age in order to take into account the experiment parameters. And we have to average SAR values to take into account the uncertainties in dosimetry with a specific rat model in a specific location. For example, the loop antenna setup has been used to analyse locally the interactions between electromagnetic waves and the brain of the rat.

**Methods.** A three-dimensional numerical model was developed to predict the distribution of electromagnetic fields. The Maxwell equations are solved by the Finite Difference Time Domain method. To have an accurate dosimetry we have to analyse the interactions and the resonances in biological tissues, locally exposed with a loop antenna, as well as possible. We have considered several rat models at different ages (young, middle age, old), and with different size (250g, 500g, 750g).

The rats are exposed on a large frequency band, but the analysis focuses on GSM exposure at 900 MHz and 1800 MHz, and UMTS exposure at 1960 MHz, with dielectric properties ($\epsilon_r$, $\sigma$) in biological tissues linked to the frequency. We compare simulation results with experimental measures in homogeneous animal phantoms for validation.

**Results.** Locally induced fields on rat tissues depend on many parameters: the E-field polarization, the place of the animal in the setup, but also the size and the age of the rat (because of the different brain/whole body ratio), the tissue properties. These parameters are often fixed, SAR values are averaged over all models of animals or all locations of the animal, resulting in significant uncertainties in the dosimetric analysis of *invivo* studies with the loop antenna. Table 1 gives the BASAR in a first numerical head rat model (model 1) for three frequencies (900 MHz, 1800 MHz and 1960 MHz), and Figure 1 represents the SAR distribution of this exposition with the loop antenna at the UMTS frequency (1960 MHz).

A detailed analysis of all these parameters allows accurate dosimetry for local exposure and accurate SAR values for specific organs in the head of the animal, for several frequencies taking into account several head rat models.

**Conclusions.** Detailed and accurate dosimetric information is necessary for adequate interpretations and valuations of *invivo* studies for analysing radiofrequency electromagnetic fields.

**REFERENCES:**
**Figure 1.** SAR in the head of the numerical rat model 1, at 1960 MHz.

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**P-18 A PROPOSAL FOR NEW SET OF REFERENCE FUNCTIONS FOR THE EVALUATION OF THE POST-PROCESSING UNCERTAINTY CONTRIBUTION IN SAR COMPLIANCE TESTS**

Andrea Schiavoni, Mauro Francavilla
Telecom Italia Lab, Torino, Italy

**Objectives.** International Standards define how to compute post-processing uncertainty contribution to SAR compliance uncertainty budget. To do that, three analytical functions are used to represent hypothetical SAR distributions expected for handsets. The goal of the work is the definition of a new set of reference functions based on measured SAR distributions of real handsets rather than based on theoretical or practical considerations.
The aim is to give a better representation of the measurement situations and to stress interpolation and extrapolation methods.

**Methods.** The evaluation of the uncertainty budget in handset SAR compliance tests is described in [1,2]. Within this frame the uncertainty contribution due to the post-processing techniques, used to compute the spatial averaged SAR from a volumetric scan, is determined by using three analytical functions, each one characterized by an a 1.0 and 10.0 g SAR. The process for the quantification of the uncertainty contribution of the post-processing techniques consists of in the determination of the spatial averaged SAR by using a dummy zoom scan distribution whose values are taken from the reference functions. The difference between the analytical and computed averaged SAR is defined as uncertainty of the post-processing method. The reference functions included in standards [1,2] are symmetrical and frequency independent, so are not similar to real SAR distributions generated by handsets. In this way the determination of the uncertainty is affected by a not real representation of the reality given by the reference functions.

The set of functions proposed in the present paper are based on real measured SAR distributions, for the present example at GSM900— even if the basic concepts can be applied to whatever frequency band. A set of real measured SAR distribution is taken into account; for each measured distribution an ”averaged” ellipse has been defined; the ellipse minimizes the distance between 5 arbitrarily points whose SAR value is 50% of the peak SAR (figure 2a). Once the ellipse has been defined (figure 2b), the spatial dispersion of SAR values around peak SAR is evaluated by computing the distances between the point where the peak SAR has been found and the higher and lower distance to the ellipse, in two coordinate directions passing through the peak SAR point.

**Results.** The four distances are defined as dispersion and used to define an analytical ”four Gaussian” SAR function as shown in figure 1, where A and a takes into account for SAR value and field penetration, respectively, and xo - yo are used for peak SAR translation on the plane.

This type of function is non-symmetric, integrable and, by construction, frequency dependent. Figure 3 shows a plot of the ”four Gaussian” function for a set of dispersion parameters based on real measured SAR distributions at GSM900. The same approach can by used at different frequency bands and for different typology of SAR distributions. Furthermore the uncertainty contribution can be evaluated also as a function of the rotation of the distribution, giving a more reliable indication of the behavior of the interpolation and extrapolation methodology.

**Conclusions.** A new reference analytical function for post-processing uncertainty estimation is proposed. Such reference function is based on real measured SAR distributions, providing a more realistic environment where to estimate the uncertainty contribution due to post-processing. The a-symmetric and frequency dependent properties of the function has the advantage to stress interpolation and extrapolation methods that potentially works better for the symmetric functions. Different reference functions able to represent also more complicated SAR distribution, such as 8-shape or multi spots, generated by real devices, can be defined in the same way.

References:
\[ \text{SAR}(x,y) = A \exp\left(-\frac{(x-x_0)^2}{2\sigma_x^2}\right) \exp\left(-\frac{(y-y_0)^2}{2\sigma_y^2}\right) \exp\left(-\frac{z}{d}\right) \]

\[ \sigma_x = \begin{cases} \sigma_{xx} & \rightarrow x \geq 0 \\ \sigma_{xx} & \rightarrow x < 0 \end{cases} \quad \text{and} \quad \sigma_y = \begin{cases} \sigma_{yy} & \rightarrow y \geq 0 \\ \sigma_{yy} & \rightarrow y < 0 \end{cases} \]

**Figure 1.** The proposed "four Gaussian" Reference Function

**Figure 2.** a) Measured SAR distribution at GSM 900; b) "averaged" ellipse passing through 5 points at a defined SAR level.
Objectives. To properly assess skin damage caused by photonic exposure, the mechanisms of photon attenuation and subsequent heat production are investigated. Currently, voids exist in frequency specific electromagnetic properties such as the complex dielectric permittivity and conductivity necessary to define refractive index and attenuation values. We investigate these properties in several tissues such as blood, bone, skin, vitreous humor, cornea, retina and many others. Inside these tissues, exponential decrease in photon energy occurs due to attenuation. Because photon energy absorbed in tissue is expressed as heat in many instances, it follows that the dielectric properties of the material will also change as a function of the heating patterns as well as with frequency or wavelength. Conversely, changes in tissue thermal properties should change photon behavior as dispersion properties change. In our case we are concerned with existing data and theoretically determining dispersion properties over a large range of frequencies or wavelengths.

Methods. While the Debye model describes permittivity data up to the microwave region, at higher frequencies, our ability to predict Debye parameters that correlate with empirical
data decreases. Cole-Cole and Cole-Davidson models improved upon Debye’s original theoretical model by adding terms describing empirically gathered dielectric permittivity data at frequencies from 35GHz to .5THz, notionally.

**Results.** The authors hypothesize that between 35GHz and upwards of 20 THz, all models break down in their explanation of polarized states leading to mechanical or electronic excitation and relaxation. As mechanical excitation decays it gives rise to electronic transitions described classically by Drude-Lorentz theory, and therefore we are operating in a region of mixed modes of excitation without adequate theory to predict material behavior from electromagnetic exposure.

**Conclusions.** The authors see an opportunity to break new scientific ground by theoretically modeling the transition region between Debye mechanical excitation and Drude-Lorentz electronic excitation that notionally occurs in the Terahertz region.

**Acknowledgements.** The author would like to thank Dr. William P. Roach and the Air Force Research Laboratory. The ideas and opinions presented here are those of the authors and not those of the USAir Force or the Department of Defense.

AFRL-HE-BR-PR-2006-008

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**P-20 EFFECTS OF THE ELECTRICAL PROPERTIES OF THE TISSUE-EQUIVALENT LIQUID ON SAR-PROBE CALIBRATION IN 5-GHZ BAND**

Lira Hamada\(^1\), Toshihiro Inoue\(^2,1\), Soichi Watanabe\(^1\), Takashi Iwasaki\(^2\)

\(^1\)NICT, Tokyo, Japan \(^2\)University of Electro-Communications, Tokyo, Japan

**Objectives.** In the calibration of SAR probes, there are many uncertainty factors described in the standards [1] -[3]. In the previous work [4], we have investigated on the influence of the electrical properties of tissue-equivalent liquid to the calibration coefficient of a SAR probe at 900 MHz and 2450 MHz. Considering the recent frequency expansion of the cellular phone and other radio communication devices, further investigation on the calibration uncertainty in higher frequency is necessary. However, in frequency band higher than 3 GHz, it may increase the calibration uncertainty because the size of the probe cannot be neglected. In this study, therefore, the influence of change of the electrical properties of tissue-equivalent liquid, which is one of the typical factors of the uncertainty for the probe calibration using waveguide system [1], is investigated using FDTD numerical simulation in 5-GHz band.
Methods. Conventional SAR probes consist of three orthogonal small dipoles with a diode that outputs DC voltage relating to electric-field (E-field) strength parallel to each dipole. The purpose of calibration of SAR probes is therefore to calibrate the output voltage of each sensor measuring known E-field. Using waveguide is one of the calibration systems which utilize the analytical field or known E-field inside it. A calibration system for a SAR probe consists of an open-ended waveguide and the probe scanner [1]. The waveguide is partitioned with the dielectric slab (matching window), and the upper region above the slabe is filled with the tissue-equivalent liquid. Then the probe is inserted in the center of the waveguide, and measures electric field strength in the waveguide. Calibration coefficient $K_i$ of each sensor ($i=1-3$) is as follows:

$$E^2_i = f(V_i)/K_i$$

where $f(V_i)$: linearised sensor output voltage, and $K_i$: calibration coefficient. Calibration coefficient $K_i$ of the probe is determined by comparing the output voltage with the theoretical values of the electric field strength in the waveguide calculated from the input power. Numerical models of the waveguide and probes whose diameter were 6mm/2.5 mm were used for the numerical investigation with a commercial FDTD simulator (SEMCAD). In this study, squared value of the electric field strength in the center of the sensors in the probe (2.7mm/1mm from tip of the probes for 6mm-/2.5mm-probes, respectively) was considered to be a probe output voltage ($f(V_i)$ in equation (1)). Moreover, the squared value of the standard electric field strength $E^2_i$ is assumed to be a theoretical electric field[1].

Results. The calibration coefficient for the probes at the frequency of 5.2 GHz is obtained by the numerical simulation, along with those at 1950 MHz for a reference.. Target values of the relative permittivity and conductivity of the head tissue-equivalent liquid are 36.0 and 4.65 (S/m) at 5.2GHz, and 40.0 and 1.40 (S/m) at 1950MHz, respectively [1],[2]. Dimension of the waveguides are IEC R22 and IEC R48, respectively. The probes are modeled as hexahedrons whose diameters are 6mm/2.5mm, and the distance of the probe tip and spacer was set at 10mm. Here, the changes in dielectric constants are assumed to be known. Figure 1 shows the difference of the calibration coefficient from those when the electrical properties are set at target values. When the 6mm-diameter probe is calibrated at 5.2GHz, the deviation of the calibration coefficient is larger than in other two cases. On the other hand, the deviation was almost same in the other two examples, and it is because the diameters of the probes were almost same compared to the wavelength (about 1/4 of the wave lengths) in the medium Moreover, the influence of the permittivity on the calibration coefficient is larger than that of the electric conductivity.

Conclusions. As a result of this examination, the uncertainty of calibration coefficients affected greatly by the diameter of the probe, when the electric constants of the liquid. were changed. However, the deviation of the calibration coefficient is small for the thinner probe. Therefore, to reduce the uncertainty of the calibration caused by the change of the electrical
properties of the liquid, particularly in higher frequency band, it will be required to correct the calibration coefficient taking account of the structure of the probe, or to apply other method than conventional method using waveguides.

References
[1] IEC international standard 62209-1: Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures - Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz), Feb. 2004.

Figure 1. Influence of electrical properties of phantom to the calibration coefficient

P-21 SIMPLE EVALUATION METHOD OF NONUNIFORM ELF MAGNETIC FIELD EXPOSURE FOR COMPLIANCE WITH GUIDELINES
Kenichi Yamazaki¹, Tadashi Kawamoto¹, Hideo Fujinami¹, Tsukasa Shigemitsu²
¹Central Research Institute of Electric Power Industry, Yokosuka, Japan ²Central Research Institute of Electric Power Industry, Abiko, Japan

Objectives. To evaluate compliance with existing guidelines on human exposure to ELF (extremely low frequency) magnetic fields, such as ICNIRP’s (International Commission
on Non-Ionizing Radiation Protection) and IEEE’s (Institute of Electrical and Electronics Engineers), the nonuniformity of the fields has been one of the major concerns. This is due to the fact that guideline-level high exposures are generally encountered in the immediate vicinity of magnetic field sources, such as electric power facilities and electric appliances. According to the guidelines, when the maximum magnetic field measured at a space where the subject occupies exceeds the specified field level, induced currents inside human bodies are to be investigated to evaluate their compliance. However, this evaluation requires massive computational resources, which are not readily applicable under practical exposure conditions. The objective of the study is to propose a simple and relevant method of assessing nonuniform magnetic field exposure. There have also been several methods to address the issue.

Methods. In our study, a method of obtaining an equivalent uniform magnetic field using a coefficient (“normalized induction factor Kj”) expressed as eq. (1) is adopted.

\[ K_j = \frac{J_{\text{max-nu}}}{J_{\text{max-u}}} \]  

Where \( J_{\text{max-u}} \) and \( J_{\text{max-nu}} \) are the maximum induced currents for uniform and nonuniform exposures, respectively, when the maximum magnetic fields in the model are assumed to be the same for both exposures. To get the coefficient, induced currents and electric fields inside an anatomically correct human (Japanese Male) model having 2 mm resolution, which are developed by NICT (National Institute of Information and Communication Technology) and universities in Japan, were calculated for uniform and nonuniform magnetic field exposures. The calculation method adopted was the impedance method. For nonuniform exposure, line currents closely placed near the human model were used with variable intervals between the model and the line currents. Then to propose a simple evaluation method, a spherical model was used alternatively to easily obtain (from an analytical formula) the induction factor, and compared with the anatomical model.

Results. The calculated results of normalized induction factors for both the anatomical model and the spherical model (radius of 20 cm) are shown in Figure 1. The normalized induction factors vary with distance from the line sources. They approach unity as distance from the source increases where the field becomes uniform over the volume of the body. The results are also compared with those of a study done by Bracken and Dawson (J. Occup. Environ. Hygiene, 1, pp.629-, 2004) using the US Brooks male model. The results are in good agreements between the anatomically correct human models and the simple spherical model. The results for the spherical model traces the maximum of the induction factors for the anatomically correct human models, that means the simple sphere can be a good index to assess nonuniform exposure.

Conclusions. In this study, a simple and relevant method for assessing nonuniform magnetic field exposure is proposed and verified by numerical calculations for anatomically correct human models. The proposed method is of practical importance for assessing compliance with guidelines in practical exposure conditions.
**Figure 1.** Normalized induction factor $K_j$ for anatomically correct human models (US and Japanese male model). The solid curve shows values estimated using a simple formula for a homogeneous spherical model (radius of 20 cm), which traces the maximum of the induction factors for the anatomically correct human models. Bx: sagittal exposure, By: coronal exposure, Bz: vertical exposure.

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**P-22 CALCULATIONS ON SAR UNDER VARIOUS POSITIONS OF RF COIL DURING MR IMAGING EMPLOYING A NUMERICAL MODEL OF JAPANESE PREGNANT WOMAN**

Satoru Kikuchi$^1$, Kazuyuki Saito$^2$, Masaharu Takahashi$^2$, Koichi Ito$^3$, Hiroo Ikehira$^4$

$^1$Chiba University, Chiba, Japan $^2$Chiba University, Chiba, Japan $^3$Chiba University, Chiba, Japan $^4$National Institute of Radiological Sciences, Chiba, Japan

**Objectives.** MRI (Magnetic Resonance Imaging) is one of the modalities for diagnosis. The MRI system is composed of several units including RF (Radio Frequency) technologies, and RF coil is one of the important units for imaging. The RF coil operates as an antenna, which "radiates an EM (ElectroMagnetic) pulses to the body" and "receives the NMR
(Nuclear Magnetic Resonance) signals emitted from the body”. Recently, it is necessary to estimate SAR (specific absorption rate) in the human body due to the radiated EM pulses from the RF coils. Until now, the SAR evaluations in the human head have been investigated during MR (Magnetic Resonance) imaging. However, MR imaging is used not only for the head but also for other portions of the body. Especially, in this study, the SAR distributions in the abdomen of a pregnant woman are investigated (J. W. Hand, et al., Magn. Reson. Med., vol. 55, pp. 883-893, 2006.). Concretely, the SAR distributions inside the abdomen of pregnant woman and her fetus are calculated using a high resolution numerical model of pregnant woman placed into a bird cage coil for MRI system. In addition, we calculate the SAR inside the fetus by varying the position of the coil.

**Methods.** We calculated the SAR distributions using high resolution pregnant woman model placed into a bird cage coil. In the numerical calculations, we employed the FDTD (Finite Difference Time Domain) method. Figure 1 shows the calculation model that consist of the pregnant woman model and the bird cage coil, which is one of the most fundamental RF coils. The operating frequency of the coil around 64 MHz, which is used for the 1.5 T MRI system. Here, the pregnant woman (28th gestational week woman) model, which is developed by the National Institute of Information and Communications Technology and Chiba University, is applied as the last stage of pregnancy period. In this study, it is considered that worst-case condition of the SAR inside the fetus by the position of the RF coil during MR imaging. In order to do so, the coil position will be shifted \( \pm 15 \) cm every 5 cm in z direction.

**Results.** Figure 2 shows the calculated SAR distribution. The observation line is placed in a coronal plane almost center of the body and includes the fetal head. Here, the SAR values are normalized by 1.0 W radiation power from the coil. From figure 2, relatively high SAR values are observed around the skin, muscle, amniotic fluid etc, which have a high electrical conductivity. Moreover, SAR at the fetus is low compared with other tissues around the fetus. Figure 3 shows fetus average SAR and whole body average SAR under various positions of the coil. From figure 3, whole body average SAR is confirmed that it is almost no variation. Meanwhile, the fetus average SAR, fetal eye average SAR and fetal brain average SAR show maximum value at \( z = 10 \) cm (the position that shifted the coordinate origin to +10 cm in z direction).

**Conclusions.** In this study, the SAR distribution of pregnant woman model was calculated under various positions of the coil. As a result of calculations, low SAR value was observed at the fetus. In addition, we confirmed the fetus average SAR was changed by position of the RF coil. As a further study, it is necessary to calculate the temperature rise inside the fetus due to the EM pulse radiation based on these results.

**Acknowledgements.** The authors would like to thank Dr. Tomoaki Nagaoka and Dr. Soichi Watanabe, National Institute of Information and Communications Technology, Tokyo Japan for their valuable comments in terms of using the realistic high-resolution whole-body voxel models.
**Figure 1.** Numerical calculation model.

**Figure 2.** SAR distribution on the observation line including fetal head.
Figure 3. Whole body average SAR and fetus average SAR by position of RF coil.
("z=0" means that origin of coordinate system and the center of the coil are the same position.)
P-23 RESEARCH PROGRAMME AND KNOWLEDGE PLATFORM ON ELECTROMAGNETIC FIELDS AND HEALTH IN THE NETHERLANDS

John Bolte, Mathieu Pruppers
National Institute for Public Health and the Environment (RIVM) of the Netherlands, Bilthoven, Netherlands

Objectives. In the Netherlands, at the end of 2006 the Research Programme on Electromagnetic Fields and Health (EMF&H) was started, followed by a Knowledge Platform EMF&H in the beginning of 2007. Both are funded by the Dutch government. The National Institute for Public Health and the Environment (RIVM) is one of the partners in the Knowledge Platform and also hosts the secretarial office. In the Research Programme RIVM has submitted a proposal for Exposure Characterisation using personal exposimeters.

The purpose of the Research Programme is to substantially enhance the Dutch knowledge infrastructure in the field of electromagnetic fields (0-300 GHz) and health, giving the Netherlands its 'own' scientific authority. The infrastructure will be set up in such a way that it makes a substantial contribution to the international research effort in this area (www.zonmw.nl/en/programmes/electromagnetic-fields-and-health-research.html).

The programme has earmarked 16 million Euros to study three research areas over the next 8 years. The areas of research supported are:

1) Sociological and epidemiological research: a chair (group), determinants of risk perception, the societal impact of precautionary policies and a prospective, epidemiological cohort study on mobile telephony.

2) Biological research: a chair, human experiments, animal experiments and in vitro studies in all relevant frequencies between 0 Hz and 300 GHz.

3) Technological research: a chair, studies aimed at improving measuring methods and EMF modelling, and the development of instruments for these applications.

The Dutch government has commissioned the Netherlands Organisation for Health Research and Development (ZonMw) as an independent intermediary to coordinate the programme and award the grants. The first grants will be awarded in the first half of 2007.

The Knowledge Platform is an independent platform which will be responsible for communication with the general public, the private sector and the public sector. It is a collaboration between national expertise centres on EMF&H: RIVM, ZonMw, TNO, Radio Communications Agency and the Municipal Health Services (GGD). Also the Health Council of the Netherlands will be involved. The Research Programme and the Knowledge Platform will collaborate on several levels, coordinating their activities in order to achieve the common goals.

RIVM’s ambition is to be the Dutch expertise institute on sources and levels of EMF exposure. Therefore, RIVM is permanently filling a literature database and also has developed a
GIS database containing dwellings and locations and characteristics of power lines and RF-transmitters in the Netherlands a.o. the base stations for mobile telecommunications, radio and TV. The next step is to measure exposure to EMF by means of personal exposimeters for ELF and RF.

**Methods.** RIVM is planning to build an Activity Exposure Matrix (AEM), containing per activity the estimate of the exposure level in measurable frequency bands. The measure characterising the exposure level for each activity is based on personal exposimeter measurements during the activity. In this way epidemiological studies can select high and low exposed groups based on a questionnaire on the activities / activity patterns of the participants. An activity will be characterised by the actual activity (f.i. travelling) combined with a location (f.i. trainstation).

The proposed project is divided into four stages: the preparation stage; the pioneer study; the field test; and, finally, the publication stage. The research plan closes with a description of an extra stage: the follow up stage. The preparation stage is planned in the first calendar year, in the second year the pioneer study and the field test will be performed, and the publication stage will be covered in the third year. The entire project will be performed in 24 months (excl. the follow up stage). In the pioneer study temporary workers will be commissioned to perform the preliminary identified list of activities included in the AEM while carrying exposimeters, preferably both an RF-exposimeter and an ELF-exposimeter. Based on these measurements an exposure classification scale will be constructed from a characterisation of the exposure during the activities. In the AEM per frequency band every activity will be classified. In the field test the exposure will be estimated based on a combination of this AEM and a questionnaire. This exposure estimate will be compared with the exposimeter data in combination with a diary. In this field test a number (N=100) participants, preferably from real cohort studies, with an everyday activity pattern will be selected. This will not be a representative sample for the general population, but will be a test population for the AEM and the questionnaire.

During the research we will collaborate with other groups performing personal exposimeter measurements for instance in Austria, France and Germany.

**Results.** On the poster the first activities of the platform will be discussed. Also preliminary results of the exposure characterisation will be presented.
* P-24 STATISTICAL MODEL OF THE ELECTROMAGNETIC FIELDS IN A REALISTIC ENVIRONMENT

Gunter Vermeeren¹, Christof Olivier², Wout Joseph¹, Luc Martens¹
¹Ghent University/IBBT, Ghent, Belgium ²Excentis, Ghent, Belgium

Objectives. A general statistical model for the electric and magnetic field distribution in an observation point \( \mathbf{r} \) in a realistic electromagnetic environment is proposed. The statistical model has been derived from spatial channel models proposed for outdoor and indoor environments [1]. The statistical model can be used to evaluate the averaging schemes for the electric and magnetic field measured in a realistic environment.

Methods. Any electromagnetic field \( \mathbf{X}(\mathbf{r}) \) (\( \mathbf{X}=\mathbf{E} \) for electric fields, \( \mathbf{X}=\mathbf{H} \) for magnetic field) in an observation point \( \mathbf{r} \) can be decomposed in its angular spectrum of incident plane waves. In other words, any electromagnetic field can be written as a vector sum of incident plane waves, i.e.: 

\[
\mathbf{X}(\mathbf{r}) = \sum_{i=1}^{N} X_i \exp(i\alpha) \exp(-i\mathbf{k} \cdot \mathbf{r}) \mathbf{u}_{X,i}.
\]

The angles of incidence and polarization are defined in Fig. 1. In an arbitrary environment the number of incident waves \( N \), the amplitude of the electromagnetic field \( X_i \), the phase of the electromagnetic field \( \alpha \), the azimuth angle \( \phi \) of the incident wave, the elevation angle of the incident wave \( \theta \) and the polarization angle \( \psi \) behave as statistical variables with a certain probability distribution. The probability distribution of each statistical variable depends on the type of electromagnetic environment. In the literature, several papers describe the probability distribution of one or more of these parameters based on measurement campaigns in realistic environments. The models for four typical environments are listed in Table 1. We have associated a Gao distribution for the number of paths \( N \), a log-normal distribution for the amplitude \( X_i \), a uniform distribution for the phase \( \alpha \) and azimuth angle \( \phi \), a double-exponential distribution for the elevation angle \( \theta \) [2] and a normal distribution for the polarization angle \( \psi \) around the mean of the polarization angle, \( \psi_T \), at the transmitting antenna. The variance of the distribution for the polarization is related with the cross polarization XPR as 

\[
\text{XPR} = \coth(\sigma_{\psi}^2).
\]

Results. Fig. 2 shows the cumulative distribution function of the rms electric field in a point \( \mathbf{r} \) at 950 MHz for the four types of environments of Table 1. For each type of environment, 10000 constellations of incident plane waves are generated. For each constellation, the root sum squared average of the rms electric field taken over the entire space is set to the reference level for general-public exposure at 950 MHz in the ICNIRP guidelines, i.e. 42.38 V/m. The mean of the rms electric field in a single observation point equals approximately the reference level of 42.38 V/m with standard deviations from 8.7 to 10.8 V/m for the different environments.

Conclusions. We have modeled a complex electromagnetic environment in an observation point \( \mathbf{r} \) as a vector sum of plane waves. The parameters of four typical environments are determined. The distribution of the rms electric field in a single observation point has been investigated and the according standard deviations on this rms field have been derived. Hence, when the exposure is assessed in one type of environment, the required number of measurement samples to be taken to achieve a certain accuracy will depend on the type of environment.
REFERENCES:

![Diagram of angles of incidence and polarization]
Figure 2. The cumulative density function of the rms electric field in a point for four realistic electromagnetic environments.

P-25 SIMULATION OF SAR NEAR LONG PASSIVE RE-RADIATORS AT VHF FREQUENCIES RELEVANT TO ON TOWER OCCUPATIONAL EXPOSURES

Edwin D. Mantiply, Saurbh Chhabra, Robert F. Cleveland
Federal Communications Commission, Washington, DC, USA

Objectives. It is standard practice to measure fields not closer than 20 cm from passive re-radiators such as the supporting tower structure of broadcast antennas, see IEEE Standard C95.3 - 2002. The question arises whether fields that exceed MPE limits at less than 20 cm need to be considered for the tower climber situation. To help answer this question, this study calculates SAR with a simple phantom and calculates fields without the phantom present near passive re-radiators exposed to plane waves. The fields calculated at 20 cm due to the re-radiator without the phantom present are compared to the plane wave field alone. Also, the SAR in the phantom due to the re-radiator is compared to the SAR due to the plane wave alone.

Methods. Preliminary models using linear conductors and a cuboidal phantom were set up in the WIPL-D Pro software package - a method of moments/surface equivalence code. Good agreement was found with SEMCAD X light, a finite difference time domain code,
when grids and plates of adequate spatial resolution are used. The box phantom is modeled after Schallner et al with a height of 170 cm, width of 35 cm, depth of 15 cm, relative dielectric constant of 50 and conductivity of 1 S/m. A 1 cm radius conductive rod was placed in front of the phantom with the rod axis aligned with the phantom with 1 cm from the surface of the rod to the phantom surface. A linearly polarized plane wave was propagated into the front rod side of the phantom with the electric field aligned with the phantom’s long axis and rod, see figure 1. Models were run for two different rod lengths and two different frequencies.

**Results.** Maximum current is induced by the plane wave on a 1.7 meter rod without the phantom at about 80 MHz. 300 MHz is the upper end of the VHF band and is used as the second test frequency. Models were run at 80 and 300 MHz for the 1.7 meter rod and for an electrically long 41.25 meter rod. The long rod is 11 wavelengths long at 80 MHz. Table 1 gives the ratios in dB, with and without the rod present of the maximum SAR found 5 mm into the phantom along a line parallel to and behind the rod. This table also gives the ratios in dB of the maximum electric (E) and magnetic (H) field found 20 cm in front of (+20 cm) and behind (-20 cm) the rod along a line 170 cm long without the phantom present relative to the plane wave field.

**Conclusions.** These early results show that local SAR is modified by passive re-radiators. The largest enhancement of local SAR appears to occur for long re-radiators at frequencies near body resonance where the electric and magnetic fields at 20 cm are relatively weakly perturbed. Because of the simple model and the fact that only spatial peak SAR and fields are considered along specific lines it is difficult to make general conclusions. However, the maximum local SAR calculated along the line 5 mm into the phantom behind the long rod with the 8 dB enhancement at 80 MHz is still 9 dB below the local SAR limit of 8 W/kg (occupational/uncontrolled exposure) when the SAR is scaled for the plane wave set to the MPE limit of 10 W/m².

Reference:
Schallner M, Waldmann J, Hübner S, Landstorfer F, Keller H, Bitzer R.

**Acknowledgements.** The views expressed are those of the authors and do not necessarily reflect the views of the U. S. Federal Communications Commission (FCC). Mention of trade names does not constitute endorsement by the FCC.
Objectives. In cases of far-field exposures in VHF band, it is reported that the whole-body resonance could occur. At the whole-body resonance, the whole-body SAR could be maximum value. The RF safety guidelines therefore recommend the most strict exposure limits in VHF band. When a human body stands on the ground plane, local SAR becomes very high at ankles and sometimes exceeds the guideline limits in terms of the local SAR for extremities. Because local SAR at ankles can be estimated from induced ankle current, the guidelines set additional limits in terms of the induced ankle current. However, measurement methods of induced ankle current have not been established nor standardized yet. Because of ethical issues, furthermore, it is necessary to use a surrogate of a human body in measuring the induced ankle current for very high-strength exposure conditions. In this presentation, therefore, we propose a human-body equivalent antenna with tissue-equivalent liquid for measurement of the induced ankle current.
**Methods.** Figure 1 shows the human-body equivalent antenna. This antenna consists of acrylic boards on a metal board. Tissue-equivalent liquid is filled in the antenna. First, we calculated the induced current of the human equivalent antenna and compared with measured one in order to verify the validity of the numerical analysis. Secondarily, we determined the optimized electrical properties of the tissue-equivalent liquid for estimation of the induced ankle current.

In these simulations, the antenna and a realistic-shape homogenous human model are exposed to the near-field of a monopole antenna. Frequency is set around the whole-body resonant frequency (45 MHz). Electric conductivity of the tissue-equivalent liquid is 0.48 S/m and relative permittivity is 52. in Fig. 2. Electric conductivity of the tissue-equivalent liquid is 0.44 S/m and relative permittivity is 55. in Fig. 3. Antenna input power is 25 W. Perfect matched layer (PML) conditions are employed as absorbing boundary conditions. The height of both tissue-equivalent liquid in the antenna and the human model is 170 cm. For measurement of the induced current, the developed human-equivalent antenna and the monopole antenna were set in the anechoic chamber with the ground plane. The induced current was measured by a clamp-type induced current meter (HI-3702).

**Results.** In Fig. 2, it is shown that the calculated induced current agrees well with measured one, which suggests that the validity of the calculation method is verified. In Fig. 3, it is shown that the induced current of the human-equivalent antenna with the same electrical properties of 2/3-muscle is significantly smaller than that of the human model while the induced current of the human-equivalent antenna with the electrical properties as high as 8.0 times of those of the human model nearly equals to that of the human model. Results shown in Figure 2 and 3 are normalized to 1 W.

**Conclusions.** We have investigated the human-body equivalent antenna for estimation of the induced ankle current. First, we verified that numerical analysis is valid for designing the specification of the antenna, i.e., the electrical properties of the tissue-equivalent liquid. Next, we determined the optimized electrical properties of the tissue-equivalent liquid for simulating the actual induced ankle current.
Figure 1. A design method of human-body equivalent antenna.

Figure 2. Comparison of calculated value of induced current distribution with measured one.
Figure 3. Induced current distribution by using numerical analysis.
A CONSIDERATION OF THE UNCERTAINTY OF CALIBRATING ANTENNA GAIN IN THE LIQUID FOR THE SAR PROBE MEASUREMENT

Nozomu Ishii\textsuperscript{1,2}, Hiroki Shiga\textsuperscript{3}, Kenichi Sato\textsuperscript{4}, Lira Hamada\textsuperscript{2}, Soichi Watanabe\textsuperscript{2}
\textsuperscript{1}Niigata University, Niigata, Japan \textsuperscript{2}NICT, Tokyo, Japan \textsuperscript{3}Niigata University, Niigata, Japan \textsuperscript{4}NTT Advanced Technology, Tokyo, Japan

**Objectives.** It is required to develop some calibration techniques for the SAR probe above 3GHz. One solution is to use the conventional technique with the waveguide and matched spacer, which is mostly used in the frequency range of 300MHz - 3GHz. However, it has a drawback that its accuracy can be deteriorated as the frequency is higher, because the probe diameter is comparable with the cross-section of the waveguide. Another solution is to use a gain-calibrated reference antenna in the tissue equivalent liquid. With no use of the waveguide, the calibration system breaks loose from the restrictions of the above problem. In the latter solution, first the gain of the antenna is calibrated on the basis of the Friis transmission formula, and then the expression for the electric field intensity radiated by the antenna in the liquid is related to the output voltage of the SAR probe. In this paper, we present the uncertainty of the gain calibration. Because the principle of the calibration is based on the Friis transmission formula, the data should be measured in the far-field region of the antennas. However, because of the large attenuation of the liquid, the measurement in the far-field region is impossible. Rigorously, we must take into account of this condition. In this paper, however, we ignore this effect to obtain approximate value of the uncertainty.

**Methods.** As shown in the figure, two identical antennas are inserted and faced in the liquid with perfectly matched polarization. Then, two ports of the antennas are connected to the vector network analyzer and \( S_{21} \) can be measured as a function of the distance between the antennas, \( r \). According to the procedure of two-antenna method, the far-field gain of the antenna, \( G \), can be expressed as a function of \(-S_{21}\) as well as the attenuation and phase constants, \( \alpha \), \( \beta \), in the liquid. In our proposed calibration, \( G \), \( \alpha \) and \( \beta \) can be determined by fitting the magnitude and phase of measured \( S_{21} \) to the corresponding equations derived from the Friis transmission formula. Also we can find that the expression also includes \(-S_{11}\) and \(-S_{22}\). Therefore, the uncertainty of the gain would consist of the uncertainty of \( \Lambda \), \( \alpha \), \( \beta \), \(-S_{11}\) and \(-S_{22}\) throughout the relative standard uncertainty of the \( G \). The constant, \( \Lambda \), includes the information of the gain determined by the magnitude curve fitting of \( S_{21} \). Of course, the sensitivity constants of the uncertainty sources are dependent upon the expression of the gain. For simplicity, we assume that \(-S_{11}=-S_{22}=-\Gamma\). Moreover, the uncertainty caused by the curve fitting for the magnitude and phase of \( S_{21} \) depends upon the system uncertainty, especially of the vector network analyzer. Strictly speaking, the system uncertainty also depends upon the measured level of \(-S_{21}\). However, to obtain the approximate value of the uncertainty, the system uncertainty is assumed to be constant and represent the given values at the center of the fitting range.
**Results.** The operating frequency is 2.45GHz. Offset antennas are used. The range of the curve fitting is from 30mm to 80mm. Estimated attenuation and phase constants are 460dB/m and 325.5rad/m and A is -63.2dB. The magnitude of the reflection coefficient of the antenna —Γ— is equal to 0.455. The system standard derivation of the magnitude and phase of S21 are assumed to be 0.5dB and 3 degrees. After some mathematical manipulations, the uncertainty of A, β and —Γ— can be estimated as shown in the table. The latter uncertainty can be read from the spreadsheet provided by the manufacturer of the network analyzer. At this point, we discuss the type B evaluation of the uncertainty of the gain measurement. However, there are some human errors in the measurement, for example, the derivation of the antenna alignment. Therefore, we examine the type A evaluation of the uncertainty. The same procedures are repeated 10 times by three persons. The result is also listed in the uncertainty budget. As a result, the expanded total uncertainty of the gain measurement is equal to 6.11% (k=2).

**Conclusions.** In this paper, outline of a simple uncertainty analysis of the gain measurement in the liquid is presented. To obtain the uncertainty of the SAR probe calibration, we will try to evaluate the uncertainty of the second procedure after calibrating the gain of the reference antenna.

![Figure 1](image-url)
**P-28 NUMERICAL SAR ANALYSIS AND MEASUREMENT OF A SMALL INDOOR BASE-STATION ANTENNA**

Sami Ilvonen¹, Tommi Toivonen², Tim Toivo², Ilkka Laakso¹, Tero M. Uusitupa¹, Kimmo Kärkkäinen³
¹Helsinki University of Technology, Espoo, Finland ²STUK - Finnish Radiation and Nuclear Safety Authority, Helsinki, Finland ³Nokia Corporation, Espoo, Finland

**Objectives.** The specific absorption rates (SAR) in a close proximity of a small indoor base station antenna of type Kathrein 80010248 was studied. The objective of this study was to test the accuracy of a numerical model in order to calculate SAR values using anatomical phantoms that are placed very close to a base station antenna. One reason for choosing this particular antenna was easy access to the internal parts, so that we were able to generate a more detailed model of the antenna.

**Methods.** For evaluation of the performance of the antenna, SAR measurements were made at the frequency of 1800 MHz using a standard flat phantom (CENELEC EN 50383) and automatic SAR scanning system (DASY4, SPEAG). The phantom was filled with tissue-equivalent liquid (IEC 62209) with relative permittivity of 37.55 and conductivity of 1.39 S/m. The thickness of the liquid layer was 76 mm. The RF power fed to the antenna was generated using a signal generator and amplified with a RF power amplifier. The input and reflected powers were measured with two RF power meters connected to a bi-directional coupler. Different distances between the antenna and the phantom were studied, starting from a direct contact of plastic parts.

Simulation results were obtained by performing Finite-Difference Time-Domain (FDTD) modeling of the antenna and the phantom using 2 mm resolution. The illustration of the antenna is shown in Figure 1. Two antenna elements are both modeled, while only the smaller is active at 1800 GHz. Since the exact operation of the feed network is not known, it was not taken into account in the modeling.

**Results.** The comparison between computed and measured data shows that when small distances are considered, the positions and even shapes of the elements have to be known in order to achieve good accuracy. In Figure 2, an example of normalized SAR distribution is shown in case when the antenna is positioned 9 cm from the liquid. The difference between results is small even at -25 dB level, where the effect of the reflection from the liquid surface is visible. However, the absolute radiated power is difficult to determine directly from the simulations due to the unknown losses of the antenna feed and elements and the unknown operation of feed network.

**Conclusions.** A study of a small base-station antenna is presented. The normalized SAR profiles can be modeled accurately even at small distances from the antenna, if the internal structure of the antenna is known. The exact power levels are, however, more difficult to determine due to unknown antenna losses.

**Acknowledgements.** This study was supported by Tekes, Nokia Corporation and GETA.
Figure 1. FDTD model of the antenna.

Comparison of simulation and measurements

Figure 2. Comparison between the simulated and measured SAR values.
P-29 DIELECTRIC PROPERTIES OF FRESHLY EXCISED HUMAN PINEAL GLAND TISSUE AND RF POWER ABSORPTION IN THE FREQUENCY RANGE 400 MHZ – 1,850 MHZ

Gernot Schmid¹, Richard Ueberbacher¹, Peter R. Mazal², Manfred Tschabitscher³
¹Austrian Research Centers GmbH-ARC, Seibersdorf, Austria ²Medical University Vienna, Vienna, Austria ³Medical University Vienna, Vienna, Austria

Objectives. In the context of several studies concerning mobile phone use and cancer possible effects of radio frequency (RF) exposure on the melatonin synthesis have been discussed. Despite the fact that RF-studies so far did not show any indications for an impact of RF exposure on the melatonin synthesis, it is interesting to note that no RF dosimetric data for the pineal gland is not available so far. The reason is that most of the current head models used in RF dosimetry do not consider the pineal gland due to limited resolution and that no dielectric data for the pineal gland in the RF range have been published yet.

Methods. In order to enable detailed RF dosimetry in the pineal gland a high resolution numerical model of this organ was developed and the dielectric properties of human pineal gland tissue were measured on a sample of 20 freshly excised glands, less than 20 hours post mortem, in the frequency range 400 MHz – 20 GHz. For developing the numerical model of the pineal gland, vertical slices (separation 0.1 mm) of a corresponding male human tissue sample were obtained by frozen section technique. Each slice was scanned at a resolution of 1200 dpi using a commercially available document scanner. Based on these digital images the segmentation (0.1 mm x 0.1 mm) of the pineal gland was carried out by IT’IS Foundation, Zurich, Switzerland. Using the FDTD-based simulation platform SEMCAD X the developed pineal gland model was then ”inserted” into a commercially available male head model (figure 1). For measuring the dielectric properties a probe made of a commercially available 50 Ohm semi rigid coaxial cable with an outer diameter of 1.3 mm was used in combination with a computer controlled vector network analyzer. An air/short/water calibration procedure was performed prior to each measurement and the calibration was validated by measurements of reference liquids (methanol and 0.9% NaCl solution). All procedures related to excision and handling of human tissue were approved by the Ethics Committee of the Medical University of Vienna.

Using the developed anatomical model and the obtained dielectric properties for pineal gland tissue (all other tissue parameters were chosen according to Gabriel et al. 1996), first numerical FDTD-computations at 400 MHz, 900 MHz and 1,850 MHz were carried out and RF exposure in the pineal gland was analyzed. As radiation sources generic models of handsets (in ”tilt” orientation) with quarter wave monopole antennas (for 900 MHz and 1,850 MHz) and a helical antenna (for 400 MHz) on top were used, respectively (figure 1).
**Results.** Figure 2 shows the mean and standard deviation of the measured dielectric properties of 20 freshly excised samples. The rather high standard deviation over the total tissue sample is mainly caused by brain sand (acervulus cerebri), which was detectable in approximately 50% of the investigated glands. Figure 3 depicts the SAR distributions (normalized to 1W radiated power, not averaged) in a cross section through the pineal gland for the 400 MHz, 900 MHz, 1,850 MHz irradiation. Due to their similar dielectric properties, there is only little contrast in SAR between the pineal gland and the surrounding brain tissue. The power absorption in the pineal gland was highest at 400 MHz and lowest at 1,850 MHz due to the higher penetration depth of lower frequencies. In terms of SAR (normalized to 1 W radiated power) averaged over the entire mass of the pineal gland (96 mg), values of 0.21 mW/g, 0.13 mW/g and 0.12 mW/g were obtained for 400 MHz, 900 MHz and 1,850 MHz, respectively.

**Conclusions.** During usage of modern mobile phones emitting maximum RF power levels in the range of 0.125 W - 0.25 W the amount of RF power absorbed by the pineal gland is rather low and similar to that of the surrounding brain tissue. Handsets operating at frequencies around 400 MHz, usually available for RF power levels of up to several watts, may lead to considerably higher RF power absorption in the pineal gland.

**Acknowledgements.** This project was supported by the Federal Office for Radiation Protection, Germany.

![Anatomical head model with pineal gland (red) and considered sources for 400 MHz (left), 900 MHz (center) and 1,850 MHz (right) exposure](image)
**P-30 MODELING OF SAR IN THE USER FOR BODY-WORN WIRELESS DEVICES**

Mark Douglas, Giorgi Bit-Babik, Jag Nadakuduti, Antonio Faraone, Chung-Kwang Chou
Motorola Labs, Ft. Lauderdale, FL, USA

**Objectives.** This study analyzes the SAR due to body-worn wireless devices and compares the results for a homogeneous phantom with a simplified anatomical model. In some cases, local SAR enhancements are found in the skin layer, suggesting the use of scaling factors to compensate.
**Methods.** Numerical simulations were performed on both homogeneous and planar multi-layered (skin, fat and muscle) phantoms and the peak 1-gram and 10-gram averaged SAR values were computed. The ratio of the SAR values for the multi-layered phantom over the homogeneous phantom indicates the underestimation or overestimation of SAR using the homogeneous phantom. The parameters of the homogeneous phantom are in accordance with IEEE 1528 and IEC 62209 standards. The dielectric parameters of skin, fat and muscle are from Gabriel et al. (e.g., Physics in Medicine and Biology, Vol. 41, No. 11, pp. 2251–2269, 1996). Dipole antennas with lengths ranging from $\lambda/20$ to $\lambda/2$ and distances to the phantom of $5 - 200$ mm were used at frequencies in the range $150 - 6000$ MHz. For the multi-layered model, tissue thicknesses were selected based on statistical distributions at different locations on the body (David and Fretz, unpublished, 2006). The body locations were selected from published literature on likely locations for body-worn devices (e.g., waist, wrists and triceps). SAR values were weighted according to the tissue thickness probabilities. At each frequency and distance, the statistical distribution of the SAR ratio was analyzed, and the 90th percentile case was found. Thermal simulations were also conducted so as to understand how the change in SAR translates into a change in temperature rise in the body. The FEKO (R) and FDTDLab codes were employed for the electromagnetic and thermal computations.

**Results.** A contour plot of the 90th percentile SAR ratio for a typical case is shown in Fig. 1, plotted as a function of frequency and distance of the antenna to the phantom. This case represents a mean skin thickness of 1 mm and a fat thickness ranging from 3.8 – 7.2 mm. Ratios greater than one indicate that the SAR is higher in the multi-layered phantom than in the homogeneous phantom (i.e., the homogeneous phantom underestimates SAR compared to a simplified anatomical model). It is observed that the ratios are less than one at lower frequencies and closer distances to the body. At greater distances and at frequencies from 900 – 5000 MHz, ratios greater than one are possible. Scaling factors have been proposed in the IEC 62209-2 standard to account for this. A total of 104 different tissue distributions were studied from the David and Fretz paper, and it was found that the SAR ratios are not strongly dependent on the statistical distributions of the tissue thicknesses. The reason for the higher SAR ratios is illustrated in Fig. 2. For certain skin and fat thicknesses, reflections at the boundaries between different layers result in a higher SAR confined to the skin layer. The SAR in the fat layer is much lower due to its relatively low electrical conductivity, and the SAR in the muscle layer is low due to its location beneath the skin and fat layers. However, the temperature rise is more spread out (see Fig. 2), due to the similar thermal conductivities of the three tissue types. Questions have been raised about the physiological relevance of the higher SAR in the skin layer, considering that skin temperature varies with a wide range of environmental temperatures and is usually lower than the core temperature.

**Conclusions.** Measured SAR in a homogeneous phantom due to body-worn transmitters may be lower than the SAR in an anatomical model in some cases. Factors may be used to account for the underestimation. However, the fact that the higher SAR in the layered model is confined to the skin and that the temperature rise does not have the same behavior raises questions about the physiological relevance of the higher SAR at the body surface.
**Figure 1.** Contour plot of the ratio in 10-gram averaged SAR values for the multi-layered phantom over the homogeneous phantom.

**Figure 2.** Distributions of SAR (top) and temperature increase (bottom) in a cross section of skin, fat and muscle.
**P-31 30 MHZ MEASUREMENT USING THE AGILENT 85070C DIELECTRIC PROBE KIT**

Maurice Ballen, Mark Douglas, Chung-Kwang Chou  
Motorola Labs, Ft. Lauderdale, FL, USA

**Objectives.** Dielectric measurements using an open ended coaxial line at frequencies as low as 30 MHz are difficult to perform and time consuming due to the inherent polarization error of the probe and undesired background noise of the instrument. This study shows that dielectric measurements of a liquid at 150 and 300 MHz can be used to predict dielectric parameters of that liquid down to 30 MHz.

**Methods.** A common method to measure the dielectric parameters of tissue-equivalent liquids is to use the open ended coaxial probe. The widely available Agilent 85070C dielectric probe kit has a stated operating frequency of 200 MHz to 20 GHz. In a previous presentation (Ballen et al., Bioelectromagnetics Society Meeting, 2004), we were able to show that by applying a conversion factor we can extend the probe measurement capability of tissue-equivalent liquids down to 75 MHz. However, measurements below 75 MHz experience large fluctuations due to instrument background noise. The method is first to characterize a liquid at 150 MHz and 300 MHz, then to use these data to predict liquid recipes at 30 MHz.

**Results.** Two recipes were used, one containing Diacetin (R), water and salt, and the other containing water, sugar, salt and hydroxyethyl cellulose. Measured permittivity and conductivity for the Diacetin-based recipe are shown in Fig. 1. Data show that obtaining good permittivity measurement repeatability at 150 and 300 MHz is easily achievable when using the dielectric probe kit. However, permittivity measurements below 75 MHz reveal an increasing deviation in the data spread, leading to ±10% deviation at 30 MHz (see Fig. 1). The conductivity does not suffer from this problem. In order to produce measured results which carry a high level of confidence we thoroughly characterized the liquid by performing several repeatability studies and analyzing the effects of standard calibration, liquid homogeneity, and recipe consistency. Understanding liquid dielectric parameter trends with frequency and their impact is also required. This study consists of a parametric analysis to understand the impact that an existing solution at higher frequencies, 150 and 300 MHz, will have at the lower frequency of 30 MHz with regards to drift in the dielectric parameters with time (e.g., due to water evaporation). For example, experiments are needed in order to know if a solution which could experience a permittivity drift of -5% from the target at the higher frequencies translates to a similar shift in permittivity at 30 MHz.

**Conclusions.** After developing a 30 MHz recipe which meets target values with expanded uncertainty at 30 MHz, conducting dielectric measurements only at 150 and 300 MHz, understanding solution trends, and knowing the corresponding target values for both permittivity and conductivity of the recipe at 150 and 300 MHz, we can conclude that the dielectric properties of the liquid will be within the specifications at 30 MHz.
P-32 EVALUATION OF BOUNDARY EFFECT IN THE PHANTOM LIQUID
Lira Hamada\textsuperscript{2}, Yukihiro Miyota\textsuperscript{1}, Kenichi Sato\textsuperscript{1}, Toshihiro Inoue\textsuperscript{3}, Soichi Watanabe\textsuperscript{2}, Takashi Iwasaki\textsuperscript{3}
\textsuperscript{1}NTT Advanced Technology Corporation, Musashino-shi, Tokyo, Japan  \textsuperscript{2}National Institute of Communication Technology, Koganei-shi, Tokyo, Japan \textsuperscript{3}University of Electro-Communications, Chofu-shi, Tokyo, Japan

Objectives. There are some international/domestic standards which apply to electromagnetic field (EMF) transmitting device intended to be used with the radiating part of the device in close proximity to the human head, including mobile phones, cordless phones, etc. These standards specify the measurement method for specific absorption rate (SAR) of such devices. In the measurement of the SAR, a very thin SAR probe is inserted into the phantom. Though the probe tip diameter is very thin, it affects to the E-field distribution to some extent. Particularly, the effect is sometimes not negligible on the measured data near the phantom shell. The term ”boundary effect” represents a change in the sensitivity of the SAR probe when the probe is located close to media boundaries. Few discussions have been made about the detail of this effect so far although it significantly affects to measured peak SAR which usually appear around the internal boundary between the shell and the liquid.
Therefore we investigate the effect of the tip diameter size of the SAR probe on the boundary effect in the experiment and numerical simulation. In this paper, we investigate the

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Measured permittivity and conductivity of a Diacetin-based recipe. The solid line represents the mean of repeated measurements, and the error bars represent the standard deviation.}
\end{figure}
Effect of the tip diameter size of the SAR probe on the boundary effect in numerical simulation because it is easy to change the size of SAR probe model. Then we use the FDTD calculation in numerical simulation.

Methods. FDTD calculation setup is shown in Fig.1(i). The flat phantom was filled with the head-equivalent liquid and was irradiated by the dipole antenna. The dimensions of the flat phantom and the dipole antenna are listed in Table1. The distance between the dipole antenna and the flat phantom was 10 mm at 900 MHz, 15 mm at 1950 and 2450 MHz. SAR probe models are shown in Fig.1(ii). The tip diameter of Probe(A) was 6.8 mm and the tip diameter of Probe(B) was 2.6 mm. These SAR probes were modeled as an air tube. These probes were scanned along the z-axis and we changed the distance between the tip of SAR probe and the surface of flat phantom. Then we defined the point which was 2.7 mm upper from the tip of Probe(A) and the point which was 1 mm upper from the tip of Probe(B) as the measurement point in Probe(A) and (B) each other according to the actual mechanics of SAR probes. When the probe was scanned, we recorded E-field strength at the measurement point in each probe. The examined frequencies were 900, 1950 and 2450 MHz.

Results. Figure 2 shows the deviation of the calculated E-field strength at the measurement point in each probe with/without probe existence at 900 MHz. From the result, the deviation increases suddenly only near the surface of phantom. When the distance between the measurement point and the phantom bottom is larger than 8 mm in probe(A), the deviation becomes stable. When the distance between the measurement point and the phantom bottom is larger than 3 mm in probe(B), the deviation becomes stable. IEEE-Std 1528-2003 describes that the boundary effect is negligible for most designs in the SAR probe calibration if the closest distance between the probe tip and the phantom bottom is always larger than half of the probe-tip diameter. In this paper, when the distance between the probe tip and the phantom bottom is same as the half of the probe-tip diameter, the deviations are within about 0.2 dB in probe(A) and about 0.5 dB in probe(B). And when the distance between the probe tip and the phantom bottom is same as the probe-tip diameter, the deviations are within about 0.1 dB in probe(A) and probe(B). Therefore the boundary effect can be almost negligible if the distance between the probe tip and the phantom bottom is larger than the probe-tip diameter in the SAR measurement. Almost same tendencies were found in other frequencies.

Conclusions. In this paper, we investigated the effect of the diameter size of the tip of SAR probe on the boundary effect. We have confirm that the region of the boundary effect depends on the size of probe-tip and the boundary effect is almost negligible if the distance between the probe tip and the phantom bottom is larger than the probe-tip diameter in the SAR measurement. In further study, we will compare between calculated result and measured result, and we will investigate the boundary effect in the waveguide because the SAR probe calibration is usually performed inside it.
Figure 1. FDTD Calculation models

Figure 2. Deviation between the calculated E-fields with/without probe
DEVELOPMENT OF THE SAR-PROBE CALIBRATION SYSTEM USING THE REFERENCE DIPOLE ANTENNA IN HEAD-SIMULATING LIQUID

Lira Hamada\textsuperscript{2}, Kenichi Sato\textsuperscript{1}, Nozomu Ishii\textsuperscript{1,3}, Soichi Watanabe\textsuperscript{1}
\textsuperscript{1}NICT, Tokyo, Japan \textsuperscript{2}NTT Advanced Technology Corporation, Tokyo, Japan \textsuperscript{3}Niigata University, Niigata, Japan

Objectives. The SAR-probe can be usually calibrated using a rectangular waveguide with a matching dielectric spacer below 3 GHz. However, the probe diameter is comparable with the cross-section area of the waveguide above 3 GHz and it can deteriorate the accuracy of the calibration. Therefore, we have proposed an alternative technique for calibrating the SAR-probe, that is, relating the output voltage of the probe to the field intensity produced by a reference antenna in the tissue equivalent liquid. In this paper, we present some calibration results of absolute gain of the reference antenna and SAR-probe sensitivity using our proposed technique in the head-simulating liquid at 2.45 GHz.

Methods. Calibration for reference antenna gain: Two polarization-matched reference antennas are aligned for maximum directional radiation in the liquid, as shown in Fig. 1. If two antennas are assumed to be identical, their gains are also equal. And then a vector network analyzer can measure $S$ parameters which give the information to determine the gain. The Fresnel region gain $G_F(r)$ at the distance $r$ from the center of the antenna can be given by the equation (1). The equation (2) is a dB form of the equation (1). When the effect of the Fresnel approximation, which dominates in the Fresnel-field region, is taken into consideration, the Fresnel gain $G_{F, dB}(r)$ can be replaced as the equation (3), which consists of the far-field gain $G_{dB}$ and the constants, $C$ & $D$, related to the Fresnel field. Two unknown constants, $C$ & $D$, which are included in the $G_{F, dB}(r)$ can be obtained by fitting measured data obtained by the equation (1) to the equation (3).

Calibration for SAR-probe factor: The reference antenna and the SAR-probe are aligned for maximum directional radiation in the liquid, as one antenna is replaced by a SAR-probe in the configuration of Fig. 1. The electric field $E(r)$ at the distance $r$ between the reference antenna and the SAR-probe can be given by the equation (4) where $P_{in}$ is the net input power at the reference antenna port. Most SAR-probes consists of three small dipole sensors with orthogonal directivity patterns. For such probes, the total field can be evaluated by the equation (5) where $V_i$, are the output voltages, $K_i$ are the absolute sensitivities of the dipole sensors. Therefore, the sensor’s sensitivity factor $K_i$ can be obtained by using the equations (4) and (5) with the sensor’s output voltage, $V_i(r)$, at the distance $r$ from the center of the reference antenna. If the sensitivity factor in air, $N_{Fi}$, were given by another method, the sensitivity factor in the liquid can be replaced as the equation (6) where the Factor is the ratio of the sensitivity in the liquid.

Results. Table 1 shows parameters of the SAR-probe that was calibrated by waveguide technique. We changed the distance, $r$, in increment of 0.5 mm from 6 mm to 56 mm and checked a change of the Factor. The input power, $P_{in}$, of the reference antenna is 22 dBm. As showed in Fig. 2, the Factor is almost constant and its value can be read as 6.94 between 10 mm and 30 mm. However, over 30 mm, the Factor is not constant because
the sensitivity of SAR-probe is not enough for rapidly attenuated E-field in this region. The value of the Factor obtained by use of the waveguide system is 6.51. Therefore, the deviation of our proposed technique from the waveguide technique is 6.5 % [0.28 dB]. The calibration uncertainty of the waveguide technique at 2.45 GHz is 11.8%. As discussed, our proposed technique can be used for calibrating the gain of the reference antenna and the sensitivity of the probe as well as the waveguide technique.

**Conclusions.** We discuss the SAR-probe calibration technique above 3 GHz with the reference antenna. In this paper, we propose new gain calibration technique of the antenna in the liquid by including the effect of the Fresnel approximation. And the comparison with the waveguide techniques at 2.45 GHz suggests that our proposed technique is reliable for the SAR-probe calibration at higher frequencies. We can calibrate the reference antenna gain and SAR-probe sensitivity factor in the liquid. And we inspect the validity of our proposed technique.

In future, we will deal with the validity of our proposed calibration technique in above 3 GHz as well as its uncertainty analysis.

| \( G_j(r) = \frac{|S_{ij}(r)| \exp(i\varphi)}{\sqrt{|r - S_{ij}|^2}} \) | \( E(r) = \frac{P \cdot G(r) \exp(-2\varphi)}{4\pi^2 \text{Re}[\varepsilon]_r} \) | V/m |
|---|---|---|
| \( G_{p,\omega}(r) = 10 \log_{10} G_j(r) \) | [dBd] |
| \( |\varphi| = \sum_{m} |\varphi_m| = \sum_{m} \frac{K_m}{\text{Re}[\varepsilon]} \) | [V/m] |
| \( G_{r,\omega}(r) = G_{d} + (Gr)^+ + (Dr)^+ \) | [dBd] |
| \( K_r = NF \times \text{Factor} \) | [\mu V/(V/m)] |

**Figure 1.**

**Figure 2.**
**P-34 COMPUTATIONAL SAR DOSIMETRY INSIDE THE JAPANESE WOMAN MODEL IN THE EARLY PERIOD OF PREGNANCY EXPOSED TO THE PLANE WAVE**

Hiroki Kawai¹, Tomoaki Nagaoka¹, Soichi Watanabe¹, Kazuyuki Saito², Masaharu Takahashi², Koichi Ito³
¹National Institute of Information and Communications Technology, Koganei, Japan ²Chiba University, Chiba, Japan ³Chiba University, Chiba, Japan

**Objectives.** Today many devices emitting EMFs (electromagnetic fields) are widely used in the close vicinity of the human body. Consequently, the evaluation of the SAR (specific absorption rate) in various models, such as adults, children, and pregnant women and their fetuses is necessary. Especially the priority on EMF dosimetry in embryos and fetuses is growing (WHO, The International EMF Project, June 2004). In the early term of pregnancy, it could be possible that the embryos are high exposed to EMFs when mothers do not know their pregnancy yet. Until now, the limit of EMF exposure inside the embryo is undefined. Therefore, the EMF dosimetry in the embryos is important. This paper presents the computational EMF dosimetry inside the whole-body woman model in the first, second, and third gestational month, when the model is exposed to the E-polarized plane wave. Here, the EMF is calculated using the FDTD (finite-difference time-domain) method over the frequency range from 10 MHz to 2 GHz.

**Methods.** Figure 1 shows a numerical model. The distance between the each boundary and the model was 200 mm. The pregnant woman model was composed of a whole-body voxel model of Japanese female (Nagaoka et al, Phys. Med. Biol., vol. 49, pp. 1-15, Jan. 2004.) and the cubic (one month) or spheroidal (two and three month) embryo. The embryos were placed on the center of uterus in the female model. Here, in the early terms of pregnancy, the amniotic fluid and placenta have hardly generated yet. Hence, we did not build the two into the uterus. Table 1 describes size and weight of embryos (Murooka et al, ed., The lifelong obstetrics and gynecology science (in Japanese), vol. 2, Kanehara, Tokyo, 1984.). The FDTD method was used for the EMF calculating. The parameters of calculation employed in this paper were as follows. The cell size was 2 mm. The absorbing boundary condition was the perfectly matched layer (eight layers). The computational domain was 906 X 670 X 2004 mm³. The incident wave was E-polarized ($E_z$ applied) plane wave propagating from the front (+$y$) to the back (-$y$) of the model. The incident power density was 1 mW/cm². The dielectric properties of biological tissues and those of embryo were referred from literature (Gabriel, Brooks Air Force Technical Report, AL/OE-TR-1996-0037, 1996.) and (Kawai et al, IEICE Trans. Commun., vol. E89-B, no. 12, pp. 3401-3410, Dec. 2006.) in each frequency.

**Results.** Figure 2 shows calculated result of whole-body average SAR in the mother and three types of embryos by the E-polarized wave's exposure over the frequency range from 10 MHz to 2 GHz. From Fig. 2, the SAR in the embryos is less than that in the mother over the evaluated frequency range. In addition, the value in the one-month embryo is about the same that in the two-month embryo, because the size of the two is very small as expressed in Table 1. Moreover, the SAR in the three-month embryo is higher than that in the other
month embryos over the most frequency range, because the distance between the surface of the mother’s body and this embryo is shorter than the others. The results suggest the SAR in the embryo is mainly dependent on the distance from the surface of the mother’s body and the resonant length of themselves.

**Conclusions.** This paper presented the computational SAR dosimetry inside the whole-body woman model in the first, second, and third gestational month using the FDTD method, when the model was exposed to the E-polarized plane wave over the frequency range from 10 MHz to 2 GHz. As a result, the whole-body average SAR in the embryo was less than that in the mother over the evaluated frequency range.

*Figure 1. Numerical model.*
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Figure 2. Whole-body average SAR in the mother and embryos by the E-polarized plane wave’s exposure.

P-35 DEVELOPMENT OF A SAR PROBE CALIBRATION SYSTEM IN VHF BAND BASED ON TEMPERATURE MEASUREMENT (2)

Hiroyuki Asou\(^2\), Lira Hamada\(^1\), Kenichi Sato\(^2\), Soichi Watanabe\(^1\), Takashi Iwasaki\(^3\)

\(^1\)National Institute of Information and Communications Technology, Koganei-shi, Japan
\(^2\)NTT Advanced Technology Corporation, Musashino-shi, Japan
\(^3\)University of Electro-Communications, Chofu-shi, Japan

**Objectives.** SAR probe is usually calibrated by use of a rectangular waveguide filled with the tissue-equivalent phantom liquid. However, this calibration method is difficult to apply at lower frequencies due to the size of the waveguide. Therefore, we have proposed an alternative method by a temperature probe for the calibration method of SAR probe on VHF-band. In this paper, we have presented some calibration results by a temperature probe at 900,1950MHz and compared calibration results with a waveguide method. And we have discussed about validity of this calibration method.

**Methods.** SAR can be calculated both from the magnitude of the electric field and from measured temperature rise (Equation1). The Figure 1 shows calibration setup. At first, the tissue-equivalent phantom liquid filled in the flat phantom is irradiated by a resonant dipole antenna for each frequency. Then the temperature rise at the observation point in the phantom liquid is measured with the temperature probe, and SAR value, SAR\(_T\), can be calculated from the specific heat and the measured temperature rise. Next, the SAR
value, $\text{SAR}_S$, in the same measurement setup and instruments is measured with the SAR probe under calibration. Finally the calibration factor can be evaluated by comparing the reference SAR values evaluated by the temperature measurement with that obtained with the SAR probe.

**Results.** The Figure 2 shows distance properties of $\text{SAR}_T$ and $\text{SAR}_S$. The left figure shows properties in $\gamma = 1$. We can obtain optimized calibration factor $\gamma$ by fitting $\text{SAR}_S$ to $\text{SAR}_T$. The right figure shows properties after calibration. In this case, the region of fitting is from the point above 20mm to 40mm from the surface. Table 1 shows calibration results by temperature method and waveguide method and a comparison of calibration factors between temperature method and waveguide method. The deviation of calibration factor between both methods is less than 2%. We can find that both methods have a good agreement.

**Conclusions.** We have proposed the calibration method of SAR probe by using a temperature probe.

We have performed SAR probe calibration by that method and the deviation of calibration factor from the waveguide methods is less than 2%. Therefore we have confirmed the validity of this calibration method. In further study, we will evaluate the uncertainty of this calibration system.

[References]
[1] IEC international standard 62209-1: Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures - Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz), Feb. 2005.
\[ \text{SAR} = \sigma \frac{E^2}{\rho} = c \frac{\Delta T}{\Delta t} \quad [\text{Equation 1}] \quad \frac{E^2}{\gamma} \quad [\text{Equation 2}] \]

| \( \sigma \) | Conductivity [S/m] | \( \rho \) | Density of living body [kg/m³] |
| \( c \) | Specific heat of tissue-equivalent liquid [J/(kg · K)] | \( E \) | Electric field strength [V/m] |
| \( T \) | Temperature [K] | \( \tau \) | Irradiation time [sec] |
| \( V \) | Voltage [mV] | \( \gamma \) | Calibration factor [mV/(V/m²)] |

**Figure 1.** Calibration setup

Before fitting

After fitting

**Figure 2.** Distance properties of \( \text{SAR}_T \) and \( \text{SAR}_S \)
P-36 SAR MEASUREMENT METHOD BASED ON THE THEORETICAL ESTIMATION FOR FAST SAR ASSESSMENT

Katsuki Kiminami, Takahiro Iyama, Teruo Onishi
NTT DoCoMo Inc., Yokosuka, Japan

Objectives. The SAR measurement methods with respect to wireless mobile terminals for the compliance test were standardized by the IEC [1] and other standardization bodies. These standards provide a rigorous common SAR measurement procedure. However, it is desirable to shorten the SAR measurement time and a few studies were conducted on SAR estimation methods to achieve this goal [2][3]. In order to shorten the SAR measurement time, we proposed a new SAR estimation method and an arrangement of a number of the electric field probes in a two-dimensional (2D) array. This paper presents the verification results of the proposed SAR estimation method and an overview of our SAR measurement system that employs the 2D arrayed probes.

Methods. The proposed SAR estimation method employs the equivalence theorem and Maxwell’s equations [4]. By applying a few assumptions, the SAR distributions in a phantom depth can be calculated by measuring only the electric field on a 2D plane (observation plane). Numerical and experimental verifications were performed. A flat phantom was used in this study. A cubic acrylic container (200 mm × 200 mm × 200 mm) that was filled with the tissue-equivalent liquid was employed. We used three kinds of radiating sources, a dipole antenna, monopole antenna, and PIFA that were located at the bottom surface of the liquid. The tested frequencies were 900 MHz, 1950 MHz and 2450 MHz. In order to measure simultaneously the amplitude and phase of the electric field, an electro-optic (EO) probe was employed in the experiments [5].

Results. The 3D SAR distribution was estimated based on the calculated or measured electric field on the observation plane (x-y plane) at 5.0 mm deep from the phantom surface. The estimated SAR distributions in the phantom depth (z-axis) when the dipole antenna was employed are plotted in Fig. 1. All SAR values are normalized to the maximum SAR value at the phantom surface. Figure 1 shows that the estimated SAR distribution agrees very well with the calculated results. Moreover, the spatial averaged SAR over a 10g mass was calculated from the estimated 3D SAR distribution and an approximate difference of less than 1.0% was observed compared to the original SAR value. The estimated results from calculated data for the monopole antenna and PIFA cases were shown in Fig. 2. Again, the estimated results are in good agreement with the original SAR distributions. In order to shorten the measurement time of the 2D electric field, we employed the 2D arrayed probes. The EO probe has no metal around the tip of the probe and employing the 2D arrayed probes is reasonable compared to a 3D probe alignment. By combining the SAR estimation method and 2D arrayed probes, the 3D SAR distribution and mass averaged SAR value can be obtained in several tens of seconds or a few minutes.

Conclusions. This paper presented numerical and experimental verification results of the proposed SAR estimation method for shortening the SAR measurement time. As a result, we confirmed that the proposed method can determinate the 3D SAR distribution and spatial averaged SAR values at a high accuracy level regardless of the frequency bands and
radiating sources in a very short amount of time.

References:
[1] IEC 62209-1, “Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz),” Feb. 2005.

Figure 1. Estimated SAR distributions along z-axis compared to the calculated SAR distributions using FDTD at 900 MHz, 1950 MHz, and 2450 MHz.
Figure 2. Estimated SAR distributions along z-axis when monopole antenna and PIFA are employed.

P-37 EVALUATION OF MEASUREMENT TECHNIQUES TO SHOW COMPLIANCE WITH RF SAFETY LIMITS IN HETEROGENEOUS FIELD DISTRIBUTIONS

Sven Kühn¹, Axel Kramer¹, Peter Sepan², Niels Kuster¹
¹ETH Zurich, Zurich, Switzerland ²SPEAG, Zurich, Switzerland

Objectives. Testing of compliance of base station transmitters when put into service with RF exposure safety limits should always include an experimental verification if the limits are met at the maximum RF output power of the transmitter. Such compliance tests involve in-situ free-space measurements at locations where the general public as well as the occupational personal have access. In particular, we focussed on testing compliance with respect to exposure of the general public, i.e., in mostly indoor environments. Here, it is in particular difficult to test compliance since typical field distributions at the sites of interest are strongly in-homogeneous.
The objective of this study was to evaluate and develop measurement methods and procedures that are practical and provide high repeatability with minimal uncertainty for in-situ testing of compliance of base station transmitters with RF safety limits.

**Methods.** In the study, the suitability of various measurement methods in a known indoor field distribution at 930 and 2140MHz was evaluated. We reviewed typical indoor field distributions in the vicinity of fixed base station transmitters and set up an indoor propagation test room according to these typical parameters.

We developed a semi-automated field scanner (Figure 1) equipped with miniature isotropic field probes to map the field distribution (E- and H-fields) with a resolution of 10 cm. In the test room, the fields were mapped with low uncertainty (±1 dB total uncertainty of the measured field) in a volume of 3×3×2m$^3$ using the field scanner developed in the context of this study (Figure 2).

The mapped field distribution was then assessed using the methods described in prEN 50492 [1], ECC/REC/(02)04 [2] and Swiss Ordinance for Non-Ionizing Radiation (sweeping method) [3] with measurement antennas calibrated under plane-wave conditions. Additionally, a maximum search was performed by sweeping the room with a miniature isotropic E-field probe.

The values thus determined were then compared to the target values of the mapped field distribution in the test room.

**Results.** It was found that the reproducibility of the sweeping method was < ±2 dB (maximum search according to [3]). The reproducibility of the averaged values by application of the averaging methods was found to be within the same range for six point averaging according to prEN 50492 [1] and considerably higher than for ECC/REC/(02)04 [2]. In all cases the maximum determined using directive antennas as well as the isotropically determined values with the ADD3d method were >6dB lower than the maximum determined during the field mapping and >4dB lower than the maximum determined by sweeping the test room with miniature field probes.

**Conclusions.** It can be concluded that averaging does not yield any advantage regarding the reproducibility of the results. These methods suffer from underestimation when using typical measurement antennas, e.g., conical dipoles or logarithmic periodic antennas.

In summary, the peak search method was found to be superior with respect to demonstrating compliance in strongly scattered field environments. It is fast and simple to apply and provides high reproducibility for a same antenna or probe. The uncertainty of this method and the repeatability between different instruments can be significantly improved using isotropic time-domain field probes instead of standard antennas.

**Acknowledgements.** We would like to acknowledge the financial support of the CTI, Switzerland and the Research Foundation on Mobile Communication, Switzerland [1] CENELEC, ”Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations (DRAFT)”, aug 2006.


Figure 1. Schematic of the developed semi-automated field scanner equipped with E- and H-field probes.

Figure 2. Slice view of the E-field distribution in the test room at 2140 MHz.
**P-38 DOSIMETRY FOR LOCAL BRAIN EXPOSURE OF RODENTS AT 2 GHZ**

Volkert Hansen¹, Andreas Bitz¹, Joachim Streckert¹, Kerstin Ladage², Dorothee Krause-Finkeldey², Abdessamad El Ouardi¹, Tina Reinhardt¹  
¹University of Wuppertal, Wuppertal, Germany ²Ruhr-University Bochum, Bochum, Germany

**Objectives.** In order to study effects of rf exposure on the blood-brain barrier of rats a new brain-only exposure set-up was used and presented formerly [1]. Here, an analysis is given by the numerical calculation of the electromagnetic field (and thereby the SAR) and of the temperature distribution inside a highly resolved rat model and by temperature measurements inside the brain of rat cadavers and of narcotized rats. The aim of this investigation was to determine the maximum permissible SAR in order to find the suitable dose for the final experiments and to ensure that possible effects are non-thermal.

**Methods.** The exposure in vivo was applied via a double-cone TEM waveguide with a coaxial feed at the tip and the exposure field leaking from the rim to the head of 6 restrained rats (fig. 1). Based on a computer model for a rat a numerical thermometry in combination with a numerical dosimetry was carried out by means of FDTD computations using an advanced parallelized in-house code with an implemented heat-transfer solver based on the bio-heat equation. Moreover, thermal responses from animals were measured. To do so, the sensitive zone of a fibre optic temperature probe was brought into the brain of cadavers and narcotized subjects through a 2 mm bore drilled in the cranial bone (fig. 2) and temperature changes were recorded during application of the rf field. From the slope of the temperature curves also the SAR was derived in order to get an additional experimental estimate for the exposure.


**Results.** Table I shows one set of data for the results of SAR and temperature measurements and computations. For the chosen input power each of the six rats dissipates c. 0.19 W of rf power - most of it within the 2.3 g-brain. The brain-averaged SAR calculated from the electrical field distribution fits well with the SAR value extracted from the temperature measurements at rat cadavers. The total temperature rise in dead animals after an exposure time of 20 and 100 minutes was 1 °C and 2.2 °C, respectively. In order to adjust the adequate SAR for the final experiments in such a way that no thermal effect occurs (e.g. \(dT < 0.1^\circ\text{C}\)) one has to consider that - in contrast to the temperature development in cadavers - the temperature change in living animals is much smaller due to the blood flow and due to the thermal regulatory system. Therefore, measurements of the temperature rise in living narcotized rats were performed in addition. Compared to non-narcotized rats, narcotized
rats have reduced thermoregulatory capabilities. It turned out, that the temperature response depends mainly on the state of the narcosis as well as on the individual animal. Nevertheless, it is found, that narcotized rats significantly reduce the temperature increase during a 20 min. exposure interval to about 0.2-0.4 °C compared to the temperature rise in the cadavers at the same power level. The computational analysis of the temperature rise by means of solving the bio heat equation, taking into account the blood flow but not the thermoregulatory system, yields a temperature rise of about 0.3°C, what is in good agreement with the measured results for narcotized rats.

Conclusions. Temperature measurements in rf exposed narcotized rats showed elevations between 0.2 and 0.4 °C. The temperature rise in non-narcotized rats is expected to be even smaller due to the active thermal regulation. Thus, the calculations from the thermal rat model and the measurements with narcotized animals, respectively, are judged to give worst case results for the temperature increase enabling an rf power adjustment with a sufficient safety distance from the thermal limit for an experiment with healthy living rats.

Acknowledgements. The authors greatly acknowledge the scientific support of this project by Drs. G. Friedrich and F. Gollnick from Forschungsgemeinschaft Funk, Germany.
P-39 EFFECTS OF LONG-DURATION MILLIMETER WAVE EXPOSURE OF RAT SKIN: NUMERICAL AND EXPERIMENTAL RESULTS

David A. Nelson1,2, Robert V. Blystone2, Mohini A. Shah3, Juliana L. Robles2
1University of South Alabama, Mobile, AL, USA 2Trinity University, San Antonio, TX, USA 3Michigan Technological University, Houghton, MI, USA

Objectives. The millimeter wave (MMW) portion of the radio frequency (RF) band comprises frequencies of 30 GHz - 300 GHz. An increasing number of technologies utilize MMW frequencies for communications, imaging and detection, and weaponry. A growing number of medical and therapeutic devices also operate at one or more MMW frequencies. Exposure of humans and animals to RF energy at MMW frequencies is characterized by shallow ( < 1 mm) energy penetration and superficial heating. Under some circumstances, MMW exposure can result in highly localized energy absorption and skin tissue temperature elevations in a region of considerable heterogeneity and histologic diversity. Establishing safe exposure guidelines, therefore, can be exceedingly difficult.

There is a need for validated, high-resolution, heterogenous models to predict tissue damage or other end-effects from MMW exposure. This is particularly problematic for long-duration, low-power exposures, in which temperature increases may be affected by blood flow, metabolism, and thermal diffusion.
Methods. All animal experiments were conducted under protocols approved by the Brooks City-Base (TX) Institutional Animal Care and Use Committee (IACUC). Isoflurane anesthetized, adult male Sprague-Dawley rats were exposed on the left lateral abdominal flank to 94 GHz (CW) RF radiation at a power density of 75 mW/cm$^2$ for a duration of 1 hour at 23 °C ambient. Skin surface temperatures were measured by infrared thermometry. Experimental results were compared with simulations from a heterogeneous, high-resolution (2 x $10^{-2}$ mm) numerical model of energy deposition and tissue heating in a planar geometry. The model consists of epidermis, dermis, fat and muscle tissues. Tissue layer thicknesses, thermal properties, blood flow and metabolism rates were determined from the literature. The numerical model employed a finite difference - time domain (FDTD) algorithm to predict localized energy deposition rates (or SAR). The local SAR values provided an input to the finite-difference thermal model, which also incorporated blood flow (via a Pennes-type model), tissue metabolism, conduction and surface cooling (convection, thermal radiation). Temperature histories were applied to a damage-integral model to predict threshold exposure levels and durations for tissue injury. The damage integral is based on an Arrhenius-type model of tissue injury.

Results. Surface temperature histories, as measured and as predicted by the model, are shown as Figure 1. Note both the experiments and the model incorporate an initial three-minute latent period during which no MMW energy was applied. The model predicts a surface temperature increase of approximately 9 °C over the course of a 60-minute exposure, in agreement with the measured temperature increase. The temperature increase occurs in two distinct phases. There is a rapid, initial increase of approximately 6 - 8 °C, followed by a sustained increase at the rate of roughly 8 x $10^{-2}$ °C/min. The latter phase (gradual increase) is associated with a comparable rise in the animal’s core temperature over the course of the exposure.

Calculated values of the damage integral, based on predicted tissue temperatures at depth (0 - 4 mm) are shown as Figure 2. Note the maximal damage integral values occur sub-surface, but at very shallow depth (1 mm nominal). All values obtained under these exposure conditions, however, are well below levels which might indicate tissue injury. (A damage integral value of 1.0 nominally is associated with second degree burns in skin.)

Histological examination of tissue samples obtained from the exposed regions indicated an increased diameter of collagen bundles following exposures of 45 min. and 60 min. duration. There also was evidence of vasodilation at the dermal muscle junction, and the panniculus muscle fibers were condensed.

Conclusions. While the observed histological changes may not be considered injurious per se, they may suggest locations of potential tissue damage. Current studies are devoted to evaluating exposures at higher power densities (e.g., 150 mW/cm$^2$) and at other MMW frequencies (35 GHz) to correlate histological and numerical indicators of tissue damage. Parametric studies will address the impact of MMW frequency, surface heat transfer, blood flow, and other model parameters on tissue heating and the potential for thermal injury.
**Figure 1.** Surface temperatures of rat skin as measured by infrared thermometry and as predicted by the model, during exposure to 94 GHz (CW) at 75 mW/cm².
**Figure 2.** The value of the damage integral is shown as a function of exposure time at five spatial locations.
* P-40 COMPLETE DOSIMETRY OF TEM CELL FOR MICROSCOPE FOR A FREQUENCY BAND FROM 500 MHZ TO 2.5 GHZ

Marylène Cueille¹, Alice Collin¹, Rod O’connor², Philippe Leveque¹
¹XLIM-UMR CNRS n°6172, Limoges, France ²Babraham institute, Babraham, United Kingdom

Objectives. In recent publications, biologists conclude that low intensity microwave exposure could induce a thermal response in proteins of worms exposed in a TEM cell [1]. Thus, a complete dosimetry proves to be necessary. This paper describes the results of an accurate dosimetry of an in vitro microwave exposure system : the TEM cell for microscope. This dosimetry is based on electromagnetism and thermal conduction (due to temperature variations induced by SAR and metallic conductors) and allows to predict SAR and temperature distribution for a frequency band from 500 MHz to 2.5 GHz.

Methods. A transverse electromagnetic cell (TEM cell) was design for biological experiments with open sides to permit the precise control of temperature and gas exchange (Fig 1). The distance from the septum to ground plate was minimized to accommodate the dimensions of a imaging chamber and maximize the electric field, which is located near the septum. The TEM cell was fitted with SMA connectors and designed to present a 50 ohms impedance at frequencies from DC to 2 GHz.

A 20 mm aperture was machined in the bottom ground plate to permit the imaging of biological samples during exposure in the TEM cell. A pair of the open TEM cells were fixed on an aluminum base and mounted on the motorized stages separated by a distance of 80 mm. The isolation between the two TEM cells was greater than 30dB.

A numerical model was developed to predict the distribution of electromagnetic fields, power distribution, SAR and temperature within different containers like Petri dishes. The specific absorption rate distribution was calculated by the finite difference time domain method applied to the Maxwell’s equations, and a time-scaled form of the heat equation allowed to calculate the temperature distribution in the heated media. A lot of particular points were considered as interfaces, boundary conditions…

Results. The analysis is carried out on a frequency band ranging between 500 MHz and 2.5 GHz. SAR distribution is studied (Fig 2), in particular the SAR dependence of frequency, sample size and diameter of the aperture using for microscope. Results showed the importance of these parameters, indeed, spatial SAR distribution vary according to these parameters. For example, in some specific cases, SAR obtained is higher than 2 W/kg/Winc. Moreover, a thermal analysis was performed considering elements which could generate heating : SAR but also metallic losses induced by metallic part.
Conclusions. A complete dosimetry of the TEM cell for microscope was carried out for a frequency band from 500 MHz to 2.5 GHz. SAR and temperature were determined according to different parameters like frequency...


Figure 1. : TEM cell exposure set up
P-41 FINITE DIFFERENCE TIME DOMAIN (FDTD) SIMULATIONS OF A HIGH RESOLUTION EYE MODEL

Jason Payne¹, John M. Ziriax², Robert Garay³, Steve Chalfin⁴

¹Air Force Research Laboratory, Directed Energy Bioeffects Division, Brooks City-Base, TX, USA
²NHRC-DET DEBL, Brooks City-Base, TX, USA
³Naval Health Research Center Detachment, Directed Energy Bioeffects Laboratory, Brooks City-Base, TX, USA
⁴University of Texas Health Science Center, San Antonio, TX, USA

Objectives. Radiofrequency (RF) safety standards are based on the amount of energy absorbed within the whole body and within localized averaging volumes. However, RF dosimetry is complicated and depends on a number of parameters such as the size and orientation of the biological object, its material properties, and the frequency of the RF field. Furthermore, it is not practical to measure these fields inside a living body. Computational modeling techniques, such as the Finite Difference Time Domain (FDTD) combined with realistic anatomical models, have become valuable tools because they can predict the rates of RF energy absorption throughout a body. Thermal modeling software, such as Thermoreg (Thermoanalytics Inc., Calumet, MI), takes as input SARs from FDTD to predict thermal changes based on a given exposure duration and power density.
**Methods.** An ongoing collaborative effort at Brooks City-Base has created a number of anatomically accurate animal and human body models. Among these models is a 1-mm resolution human-body model, dubbed the ”Brooks Man”. The Brooks Man and other similar anatomical models have been made freely available to the research community and as a result have become widely used by RF researchers.

**Results.** This research has shown that RF fields can be absorbed non-uniformly within the body, resulting in localized SAR hotspots. These hotspots may be of concern for thermally sensitive tissues.

**Conclusions.** One organ of particular interest is the eye. Research has shown that the eye may experience higher SARs or resonances at 1-2 GHz. In addition, the human eye has significantly less blood flow than other tissue, and therefore is more reliant on conduction for thermoregulation. In order to further study RF absorption and thermoregulation in the eye, a higher resolution anatomical model of the eye was used to simulate exposures at a number of frequencies.

![Figure 1](image)

**Figure 1.** Left panel is a visualization of horizontal slice of 1-mm human head 1GHz SAR results showing higher energy absorption rates through the eye (green and blue)s The right panel shows a cut out rendering of the 0.1mm eye model.
P-42 THE BROOKS FINITE DIFFERENCE TIME DOMAIN (FDTD) CODE

John M. Ziriax\textsuperscript{1}, Jason Payne\textsuperscript{2}, Samuel Adams\textsuperscript{3}, Aldon Lyssy\textsuperscript{3}, William Hurt\textsuperscript{2}
\textsuperscript{1}NHRC-DET DEBL, Brooks City-Base, TX, USA \textsuperscript{2}Air Force Research Laboratory, Brooks City-Base, TX, USA \textsuperscript{3}Air Force Research Laboratory, Brooks City-Base, TX, USA

Objectives. The Brooks Dosimetry Project is a joint effort between Naval Health Research Center Detachment and Air Force Research Laboratory researchers located at Brooks City-Base, Texas. As government-funded research efforts, the products of this research have been released to the public as technical reports, a variety of anatomical models, and several versions of the Brooks FDTD code. These products are being used by laboratories all over the world, providing the first tools allowing for independent inter-laboratory comparison of modeling results. They are also being incorporated into The International Electromagnetic Field (EMF) Dosimetry Project (http://www.emfdosimetry.org).

Methods. Fortunately, this effort has been able to continue and this paper reports on the latest improvements to the parallelized FDTD code. The original code was based on sample code published by Kunz and Leubbers (1993) and written to run on single processor computers. However, the need to use larger anatomical models necessitated the move to a parallelized version and a Linux-based Beowulf computer system.

The current version of the code is written in FORTRAN 95 and parallelized using LAM/MPI (http://www.lam-mpi.org). Recently, the code has been enhanced to meet needs of ongoing projects. These changes include replacing the original outer boundary condition with a perfect matching layer (PML). This enhancement allows modeled objects to be placed closer to the outer boundary of the modeled volume reducing memory requirements.

Results. In the previous version, the RF source options were limited to a far field source, or a standard gain horn. The new version adds a point source, which is capable of accepting pulses in the form of a sinusoidal wave, a Gaussian pulse, or an arbitrary wave form injected into a single voxel. The pulse will then propagate from the point of injection into the air or down adjacent material which could form an antenna. The ability to inject an arbitrarily shaped pulse distinguishes this source from both the far field and standard gain horn options which were limited to a continuous sine wave as output.

Conclusions. Previously, the Brooks anatomical models and the FDTD code were available on the Brooks anonymous FTP site. Unfortunately, this site has been closed and the files will eventually be incorporated into a new web site. Until that time requests for the models and software may be made by email to: jason.payne@brooks.af.mil or john.ziriax@brooks.af.mil.
MODELING HUMAN ELECTROMUSCULAR INCAPACITATION WITH
FINITE DIFFERENCE TIME DOMAIN

John M. Ziriax\textsuperscript{1}, Jason Payne\textsuperscript{2}, James Comeaux\textsuperscript{3}, Samuel Adams\textsuperscript{3}, Aldon Lyssy\textsuperscript{3}, John D’Andrea\textsuperscript{1}

\textsuperscript{1}NHRC-DET DEBL, Brooks City-Base, TX, USA \textsuperscript{2}Air Force Research Laboratory, Brooks City-Base, TX, USA \textsuperscript{3}Air Force Research Laboratory, Brooks City-Base, TX, USA

Objectives. Devices which deliver pulses of electricity into the body sufficiently powerful to cause incapacitation are being widely deployed by law enforcement agencies and even by private individuals. Being stimulated by one of these devices will be one of the most powerful deliberate exposures to electromagnetic energy that a person will ever experience. The widespread and growing use of these non-lethal weapons makes the study of their bioeffects of increasing importance. A typical exposure starts when either wired darts or electrical contacts make electrical contact with the skin and a series of pulses is delivered. The stimulation prevents effective voluntary control of skeletal muscles. The objectives of this work were to: (1) modify our existing finite difference time domain (FDTD) code to support the injection of electrical pulses into realistic anatomical models via two wires connected to the body at various locations; and (2) begin development of a metric of dose which could be used to scale exposure to biological effect.

Methods. Simulations were performed using a 5-mm voxel model of the thorax of an adult male, the ”Brooks Man”, which was modified to incorporate two wires connecting source voxel to two locations on the body of the model. The electrical pulse was injected into the volume at the ”source voxel” and allowed to propagate down the wires and into the thorax at the points of contact. Wave forms were recorded at selected voxels using the XFDTD code (Remcom, State College, PA). In addition, peak E-fields were collected for all voxels using the Brooks FDTD code.

Results. Pulse duration was a critical parameter both in determining the propagation of the pulse through the body and the length of time required to perform the simulation. Distribution of peak E-field was not uniform.

Conclusions. Simulations of the longer pulse durations required much more computer time than simulations of RF exposures on similar anatomical models. We are currently looking into alternative modeling algorithms to simulate exposures at higher resolutions and longer pulse durations.
**P-44 AVERAGING METHODS FOR RELIABLE MEASUREMENTS**

Georg Neubauer\(^1\), Patrick Preiner\(^1\), Stefan Cecil\(^1\), Gunter Vermeeren\(^2\), Wout Joseph\(^2\), Luc Martens\(^2\), Sven Kühn\(^3\), Niels Kuster\(^3\)

\(^1\)ARC GmbH, Seibersdorf, Austria  \(^2\)Ghent University, Gehnt, Belgium  \(^3\)ITIS, Switzerland

**Objectives.** Assessment and evaluation of exposure in radio frequency (RF) fields requires averaging procedures of electric field strengths, e.g. the ICNIRP guidelines of 1998 include the requirement that the electric field strengths have to be averaged over a volume corresponding to the body of a human being. It is stated in such documents that the measured electric field strengths have to be averaged over a volume corresponding to the human body. Some of these documents give rather general recommendations, others define very precise an averaging procedure. Anyway, there is almost no scientific rationale available to justify specific averaging procedures. Therefore there is high need to earn knowledge on specific field distributions in the environment of fixed installed RF transmitters, e.g. base stations and to identify reliable averaging procedures for limited numbers of assessed field levels. Based on the field distributions assessed in [1], the reliability of different averaging procedures was examined. In the frame of the EUREKA project BASEXPO specific averaging procedures were developed for mobile communication frequency bands. First results of this work are presented within this abstract.

**Methods.** Based on the results and evaluated data presented in [1] different averaging schemes were applied to volumes corresponding to the dimensions of the human body exposed to RF fields. A large amount of simulations performed in this project with a simulation tool solving the Maxwell’s equations delivered a considerable data base taking into account multipaths propagation. To make the data comparable with data obtained in the frame of measurement campaigns [2], the chosen templates were built by averaging the 3mm voxels over the volume of a measurement antenna (i.e. a biconical antenna [3] with an integrating volume of a sphere with approximately 13.6cm diameter). To simplify evaluations the sphere was replaced by a cube with the same volume (edge length of 11cm). Deviations of -0.22 to 0.42dB were found by comparing the mean value of the field strength averaged over a sphere with the volume averaged over a cube. Averaging over such a cube delivered the mean field level for a single position of a template. In order to get different templates a certain amount of such positions (3 and 4) were extracted and arranged consecutive to each other with a distance of 15cm or 30cm as well as four positions arranged in a square with a distance of 15cm to each other from center to center (see Figure 1). These templates were than moved through the whole examined volume and the mean value of the 3 or 4 positions was calculated to obtain averaged field values. The grid step for moving the built templates through a volume was for all cases 15cm in each orthogonal direction. Analyses of the evaluated data will be performed to find suitable averaging schemes for assessing the mean field strength value averaged over the whole body.

**Results.** Preliminary results are available for 946 MHz. For the Line 3 Template the mean values of the electromagnetic field strength are shown in Table 1. The variation of the mean value of the 4 templates moved through each volume gives preliminary results of the
variability of the local averaged field levels compared to the global electromagnetic field strength.

**Conclusions.** Only very limited and preliminary conclusions can be drawn at the present state of the evaluated data due to the lack of results. It can be said that the simpler shape of a cube instead of a sphere can be applied with only sparse uncertainties. At the moment it looks as if the derived mean values delivered by the templates are showing no big difference between the four tested templates, so more positions building a template or a more complex configuration (square instead of a line) might not lead to more precise results.

**Figure 1.** Averaged Voxels over a cube building the position of a template. Cube with an edge length of 11cm. Four different templates are shown consisting of a different number of positions (3, 4) and with a different distance of each consecutive position (15cm, 30cm). The right graphic should display a template consisting of 3 positions moved through the investigated volume. On each location the mean value of the e.g. 3 positions was build.

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**P-45 AN ON SITE SAR EVALUATION USING PLANE WAVE SPECTRUM REDUCTION**

Fadila Saidi¹, Man-Fai Wong¹, David Lautru², Azeddine Gati¹, Emmanuel Nicolas³, François Jacquin³, Joe J. Wiart¹, Victor Fouad Hanna²

¹France Telecom R&D, issy les Moulineaux, France ²Université Pierre et Marie Curie, Paris, France ³Télédiffusion de France, Paris, France

**Objectives.** In this paper we present a study which aims at developing an evaluation method of the human exposure to electromagnetic fields in terms of specific absorption rate (SAR) in order to compare to the ICNIRP or IEEE limits. The objective of this study is the direct evaluation of the SAR through on site measurements of electric field.
site SAR evaluation is very difficult, thus a hybrid technique such as [1] combining in-situ measured incident fields amplitude, and FDTD [2] calculation of the SAR is more suitable.

**Methods.** After reviewing some constraints, we adopt the plane wave spectrum as an efficient mean to couple the measurement to the FDTD calculations via the Huygens box. A planar scanning is more practical especially on site. The plane wave representation allows evaluating the electric and magnetic fields at any distance (in the near or far field zone) and especially on the Huygens box that contain the phantom inside which the SAR would be estimated.

This approach has the advantage of being more realistic as the source and the environment are characterized by means of measurements. Furthermore, FDTD solutions for the normalized incident plane waves can be pre-calculated. As the plane wave spectrum is determined by measurements, no more FDTD simulations would be necessary to evaluate the SAR. We further study the influence of the spectrum reduction by truncation and regrouping components around canonic directions. Thus we construct an equivalent model built from predefined components.

**Results.** To illustrate this approach we have chosen to test it on an example where a defined domain which contains a dielectric material representing the human tissue is enlightened by an electromagnetic field which has the same structure as a base station antenna. The plane wave spectrum is calculated by the Fourier transform technique applied on planar electric field measurements. (F=1GHz).

We have compared the total electromagnetic field induced in the considered domain obtained first by the direct FDTD calculation using the entire spectrum and then by combining the pre-calculated responses of spectrum components which have a magnitude at least 10% of the maximum magnitude (21 spatial components only). Fig1 shows the error induced in the second case.

As it shown in Fig1, we observe that more than 84% points in the tissue have an error less than 1dB for the magnetic field, and more than 96% points at least for the electric field.

A second test was studied where we reduce the spectrum until one component (the fundamental one) for a fast evaluating of the whole SAR (using only one FDTD simulation). For this purpose, we calculate the entire spectrum power and we allocate it to the chosen component. Tab1 illustrates the results obtained with this technique.

We can already note that for this first example, we have obtained a similar result.

**Conclusions.** We describe in this study a technique which allows evaluating optimally the induced electromagnetic field and the SAR in a human tissue using pre-calculated results of canonic cases. We test also spectrum reduction in order to make this method easier and faster and we note that it is possible if the established modification on the spectrum is realistic and respects the energy conservation. The challenge now is to generalize this technique for other cases and frequencies where the spectrum would be more complicated to analyze and to apply this method on.


**Figure 1.**

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**P-46 VARIABILITY IN REACTIONS TO WEAK ULF VMF IN RATS**

Natalia A. Temuryants, Vasilyi Martynyuk, Elena I. Nagaeva, Elena Y. Grabovskaya, Victoria I. Minko
Tavrida National University, Simferopol, Ukraine

**Objectives.** At the present time, the phenomenon of hypersensitivity to variable magnetic field (VMF) has been noted and population research has been conducted in which the distribution of this phenomenon has been established and physiological status peculiarities of those sensitive to VMF have been documented. In addition, a ”physiological portrait” - a group of symptoms - of the sensitive individuals has been drawn. However, in hypersensitivity to VMF, especially to ultra low frequency VMF (ULF VMF), in experimental animals remains insufficiently studied. To extend our knowledge in this area, we have studied inter-individual differences in reaction to ULF VMF in rats.

**Methods.** Reactions of laboratory rats with different mobile activity to VMF were studied in laboratory rats with different mobile activity in the ”open field” setup. Such scenario has gained wide use whenever one attempts to study typological characteristics of animals, as well as to prognosticate their reactions to various stimuli. Three groups of animals were put together: the ones with low mobile activity (LMA), medium mobile activity (MMA) and high mobile activity (HMA). All animals exhibited low emotionality. Reaction of animals to 8Hz, 5µTl VMF was studied based upon changes in the functional and infradian activities of neutrophiles, catecholamine excretion with urine, as well as upon changes in the content of lipid hydroxidation and oxidative enzymes in both hypothalamus and both brain hemispheres.
**Results.** The majority of rats in general population can be placed in the MMA category, thus one can consider a typical reaction to the exposure to VMF. Following a 3-hour exposure, the following changes were identified: decrease in the activity of hydrolytic, bacteriolytic and energy-producing systems in neutrophiles and an elevation in adrenalin and noradrenalin excretion with urine. Following 3-5 sets of 3-hour exposure to VMF, these changes increased and peaked after the 9th 3-hour exposure. Following the 3rd 3-hour exposure to VMF, the following changes were identified: changes in hemispheric metabolic activity, predominantly in the right hemisphere, where no changes in hypothalamic metabolic processes were noted. Rats with HMA exhibited similar directions and extent of changes, albeit with a 3-5 day delay in onset. Rats with LMA exhibited a significant decrease in the hydrolytic and energy-producing systems, while bactericidal activity sharply increased, sympathoadrenal system sharply activated and metabolic changes in the brain were more pronounced in the hypothalamus, rather than in the hemispheres. Animals in this group demonstrated significant disturbance of rhythm processes, as demonstrated through the development of desynchronosis.

**Conclusions.** Therefore, rats of different individual characteristic react differently to weak 8 Hz ULF VMF. The most drastic changes were noted in animals with low mobile activity and, thus, these animals should be regarded as hypersensitive.

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**P-47**  A PRELIMINARY STUDY ON PERSONAL EXPOSURE CHARACTERIZATION OF MOBILE PHONE BASE STATIONS IN KOREA

Mina Ha\(^1\), Hyoungjune Im\(^2\), Hojang Kwon\(^1\), Nam Kim\(^3\), Ae-Kyoung Lee\(^4\), Hyung-Do Choi\(^4\)

\(^1\)Dankook University College of Medicine, Cheonan, South Korea \(^2\)Hallym University, Sacred Heart Hospital, Anyang, South Korea \(^3\)Chungbuk National University, School of Electrical and Computer Engineering, Chungju, South Korea \(^4\)Radio Technology Research Group, Radio & Broadcasting Research Division, ETRI, Daejun, South Korea

**Objectives.** A widespread public concern has been raised about the possible hazardous health effect for the exposure of radiofrequency radiation (RFR) from the mobile phone base stations, which has been constructed widely in recent years. We tried to examine the RFR exposure level and variability from base stations of mobile phone among people as a feasibility study for epidemiologic investigation on the related health effects.

**Methods.** Using the personal exposure monitoring device (EME Spy100 (R), Antennesa), newly developed for this study, we measured 10 windows of radiofrequency range which were widely used in Korea, e.g., FM (88.1-107.9 MHz), TV7 (177-213 MHz), TETRA
(350-400 MHz), TV47 (473-749 MHz), CDMAtx (824.025-848.85 MHz), CDMArx (869.025-893.35 MHz), PCStx (1750-1780 MHz), PCSrx (1840-1870 MHz), IMT-2000tx (1920-1980 MHz), IMT-2000rx (2110-2170 MHz), for 24 hours with a 255 seconds recording interval. A total of 30 persons was measured RFR exposure and administered a brief questionnaire for demographic information and activity log per hour. The mean, minimum and maximum of the average exposure for 24 hours of each window of the radiofrequency were calculated by the groups with categories of age, gender, occupation, place and activity.

Results. Among 30 persons, 19 (63.3%) were women, 5 (16.7%) were less than age 18, and 3 were workers who maintain and repair the mobile phone base stations. The means of exposure of each window were around 0.05 V/m (range, 0.05, 0.11) and almost the same between groups, except for CDMArx (mean, 0.07; range, 0.05, 0.44), PCSrx (mean, 0.06; range, 0.05, 0.47), and IMT-2000rx (mean, 0.05; range, 0.05, 0.22). In the later three frequency windows, the base station workers showed the highest exposure; the means were 0.10 (range, 0.05, 0.97), 0.10 (range, 0.05, 1.74), and 0.07 (range, 0.05, 0.57) V/m, respectively. The younger group aged 20 to 29 showed slightly higher exposure than the others in the frequency windows of CDMArx (mean, 0.07) and PCSrx (mean, 0.06). By the place excluding the workplace of base stations, the exposure in outside buildings was slightly higher than in inside buildings in the frequency windows of CDMArx (mean, 0.07), PCSrx (mean, 0.08), and IMT-2000rx (mean, 0.06). Similarly, the exposure during the outside activities (ex, walking in parks or transporting) excluding the working activity in base stations, was slightly higher than during the inside activities (ex, activities at home or school) in the three frequency windows.

Conclusions. Although the radiofrequency exposure level from the mobile phone base stations was very low on average, the results suggested a possible variability of exposure by the occupation, age, place and activity. In a future extended study, we planed to measure the exposure in groups including more categories of occupation, area and place, to assess the feasibility of a large scaled epidemiologic study and pilot the job-exposure, or place/activity-exposure matrix of the mobile phone base stations.
P-48 META-ANALYSIS OF CHILDHOOD BRAIN TUMORS AND MAGNETIC FIELDS

Gabor Mezei\textsuperscript{1}, May Gadallah\textsuperscript{2}, Leeka Kheifets\textsuperscript{2}
\textsuperscript{1}Electric Power Research Institute, Palo Alto, CA, USA \textsuperscript{2}University of California, Los Angeles, Los Angeles, CA, USA

Objectives. Magnetic field—childhood brain cancer epidemiologic studies have shown inconsistent results. To provide a comprehensive assessment of the epidemiologic data, we conducted a meta-analysis of studies examining a potential association between magnetic field exposure and childhood brain cancer. A comparison with the childhood leukemia literature may also enable us to evaluate the potential for selection bias in childhood leukemia epidemiologic studies.

Methods. While a pooled analysis is a preferable method when all the data is available, meta-analysis of the published studies provides complementary information due to its ability to include all published literature. In this meta-analysis we identified all epidemiologic studies on magnetic fields and childhood brain tumors and evaluated different exposure metrics. Additionally, we will investigate a potential for publication bias, as well as influence of individual studies on the overall result.

Results. Malignant tumors of the brain and other parts of the nervous system are the second most common form of cancer in children aged 0-19 years, representing more than one-fifth of all childhood malignancies. We have identified 13 studies for the potential inclusion in the meta-analysis. Results for several exposure metrics will be presented, including distance, wire codes, spot measurements, long-term measurements, and calculated fields.
Conclusions. Recent focus of research into power frequency magnetic fields has been on childhood leukemia and included several pooled and meta-analyses. This meta-analysis will present new results by its focus on childhood brain tumors. A comparison of pooled and meta-analyses is informative in evaluating the effect of the choice of exposure cutoff points on the results. It is also useful to evaluate the effect of combining different studies with different inclusion and exclusion criteria. A comparison of the meta-analyses of childhood leukemia and childhood brain cancer may also foster a better understanding regarding the potential role of control selection bias in childhood leukemia studies.

P-49 STUDY ON EEG, ECG, CONGNITIVE POWER AND LEARNING ABILITY OF SCHOOLCHILDREN NEAR BY AND AWAY FROM POWER LINE

Yoon-Shin Kim¹, Sungho Choi¹, Ju-Hyun Song¹, Chul min Lee¹, Young man Roh¹, Seung-Cheol Hong²
¹Hanyang University, Seoul, South Korea ²Inje University, Kimhae, South Korea

Objectives. The goal of this study is the comparison of EEG, ECG, cognitive power and learning ability between schoolchildren near by power line and away from power line.

Methods. This study carried out personal measurement and assessment of 60 Hz magnetic field, EEG, ECG, cognitive power and learning ability, and questionnaire for schoolchildren near by power line and away from power line. Personal measurement and assessment of 60 Hz magnetic field was researched as collecting the bag including EMDEX -lite (Enertech) with which volunteers carry for 24hr. EEG, ECG, cognitive power and learning ability was measured by using QEEG-8, QEEG-3 (LAXTHA.ltd).

Results. Table 1 is the result of comparison on EEG section’s power between G elementary school students (away from power line) and B elementary school students (near by power line).

In case of elementary school students near by power line, value of absolute alpha wave are 47.51 uV(channel 1) and 51.52uV(channel 2), and which are higher than 31.14uV(channel 1), 32.85uV(channel2), value of elementary school students away from power line. The difference of absolute alpha wave between schoolchildren of G and B elementary school is statistically significant (p-value : 0.0186, 0.0147).

Absolute beta wave of elementary school students near by power line is the average 19.57uV value. As this result, we know that of elementary school students near by power line is higher than 14.75uV value of elementary school students away from power line (p-value : 0.0097).

Table 2 is the result of comparison on Mean-RR interval between G school and B school.
Value of G elementary school is higher than that of B elementary school. And the difference between G and B elementary school is statistically significant (p-value : 0.0462).

**Conclusions.** Although both two groups indicate the ordinary power of absolute theta wave, relatively average absolute theta wave’s power of elementary school students near by power line tend to higher than that of elementary school students away from power line. So further study about these result will need to advance and analyze and solve complex related matter.

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* P-50 THE NATIONAL REGISTER OF RF WORKERS: A LONG-TERM FOLLOW-UP STUDY (UK)

Ian Litchfield, Tom Sorahan
University of Birmingham, Birmingham, United Kingdom

**Objectives.** AIMS AND OBJECTIVES: In 1999, the Minister of Public Health asked the National Radiological Protection Board (NRPB) to set up an independent expert group to examine the possible effects on health from the use of mobile phone telecommunication technologies. The group, under the chairmanship of Sir William Stewart, published its report in May 2000 [1]. A key recommendation was that a register of occupationally exposed workers be established to facilitate studies into cancer incidence, mortality or other potentially harmful effects.

A Working Group, consisting of representatives from broadcast companies, mobile phone operators (MOA), contractors, the Ministry of Defence, National Grid, Trade Unions, and Health & Safety Executive, was established. To ensure involvement across the whole industrial sector, the Working Group agreed to set up a register of exposed workers with a potential for exposure to radio-frequency radiation, and that the register would be confined to people whose work brings them in close proximity to transmitting antennas on telecommunication, broadcasting masts or other similar structures. Information about the workers would be retained and maintained in a centralised database or register. The Institute of Occupational and Environmental Medicine (IOEM) was contracted to administer the database. The study described in this protocol seeks to obtain important new information on the topic of long-term health effects of occupational RF exposure by examining data from the on-going National Register of RF workers.

**Methods.** MATERIALS AND METHODS: STUDY POPULATION. The cohort available for analysis will comprise of a minimum of 2,500 male employees. All employees have some period of employment working in close proximity to transmitting antennas on telecommunication, broadcasting masts or other similar structures in the period 1961 onwards. In order to account for variation in exposure between different occupationally exposed jobs, participants are asked to supply their job title. This is then placed in one of
seven job categories. The level of exposure typically experienced by each job category is informed by a five-year study undertaken by the IOEM in conjunction with the Radiation Protection Division of the Health Protection Agency (formerly the NRPB). This work, titled 'A Feasibility Study for an Epidemiological Investigation into the Health Effects of Radiofrequency Fields and Radiation' [2] produced a job exposure matrix for job titles relevant to the Register. The Register follow-up study will receive follow-up particulars (copies of death certificates and cancer registration (incidence) details from the National Health Service Central Register (NHSCR) of the Office of National Statistics (ONS). Underlying cause and multiple-cause coding will be supplied by the ONS for all deaths according to the tenth revision of the International Classification of Diseases (ICD-10).

STANDARDISED MORTALITY RATIOS AND STANDARDISED REGISTRATION RATIOS
The mortality experience of the cohort will be compared with that which might have been expected to occur if rates of mortality for the general population of England and Wales had been operating on the study cohort, having due regard to the composition of the study cohort by sex, age (five-year age groups), and calendar year (five-year calendar periods). Expectations based on person-years-at-risk (pyr) will be calculated using the PersonYears computer program. [3] Individuals enter the pyr on the date of consenting to join the Register. Individuals leave the pyr on the date of death, date of emigration, date last known alive or the closing date of the study, whichever is the earlier. Individuals make no further contributions to expected or observed numbers past the age of 85. Standardised mortality ratios (SMRs) will be calculated as the ratio of observed to expected numbers of deaths expressed as a percentage. In calculating P-values and confidence intervals, it will be assumed that deaths occur as a Poisson process [4]. Any significance tests will be two-tailed. Similar analyses will be performed on the cancer registration data to calculate standardized registration ratios (SRRs). Overall SMRs and SRRs will be calculated for individual sites of cancer (3-digit IICD codes) as well as SMRs for broader non-cancer causes (ICD chapters). Causes of special interest will be selected on the basis of significantly elevated SMRs or SRRs obtained either from this study or from similar studies of RF workers in other parts of the world. For causes of special interest, SMRs and SRRs will also be calculated by industry sector (telecommunications or broadcast), job type (1-7 names) and period from first RF work (ten-year intervals). In addition SMRs and SRRs for causes of special interest will also be calculated separately for workers reporting any high exposure incidents.

Results. FUTURE COLLABORATION: A central tenet of the National Register of RF Workers is that it will actively seek to collaborate with those undertaking similar research across Europe and the rest of the world to the mutual benefit of those working with RF radiation

Conclusions. REFERENCES
1. Independent Expert Group on Mobile Phones; Mobile Phones and Health, 2000 (IEGMP pub)
2. A Feasibility Study for an Epidemiological Investigation into the Health Effects of Radiofrequency Fields and Radiation (University of Birmingham, unpublished)

P-51 CASE CONTROL STUDY OF CANCER INCIDENCE IN EARLY CHILDHOOD AND PROXIMITY TO MOBILE PHONE BASE STATIONS: EXPOSURE MODELLING

Mireille B. Toledano, Paul Elliott, Linda Beale, Nicky Best, James Bennett, Catherine Keshishian, Cees de Hoogh, David Briggs
Imperial College London, London, United Kingdom

Objectives. This matched case-control study investigates the risk of leukaemia/non-Hodgkin’s lymphoma (NHL) and all incident cancers in children aged 0-4 years diagnosed during the period 1999-2001 in England, Wales and Scotland, in relation to the proximity of their home to mobile phone base stations.

Methods. Cases were identified from the national cancer registry and controls selected from the national births registers. Residential addresses for cases and controls were obtained and geo-referenced within a geographical information system (GIS). The locations and characteristics (including power output, transmitter orientation and height) of base stations were obtained from the mobile phone operators.

Results. 1,918 cases of childhood cancer were registered in 1999-2001, including ~750 cases of leukaemia / NHL. Disease risk was estimated in relation to three exposure measures computed and applied using GIS techniques: 1) linear distance from the place of residence to the nearest base station; 2) the sum of power outputs from all base stations within a 500m radius of the residence; 3) modelled power density at the place of residence. Power density was estimated using a new, three-dimensional Gaussian model, developed and validated by comparing predictions with measurements taken during a purposely designed field survey at over 600 measurement locations in over 120 sites across England. Data from the field survey are also used to explore sources of variation in power density at different spatial scales.

Conclusions. A valid model for estimating radiofrequency power density has been developed, providing a useful tool for evaluating exposure to mobile phone base stations in a national case control study of childhood cancers.
P-52 ADULT CANCERS NEAR OVERHEAD POWER LINES

Mireille B. Toledano¹, David Briggs¹, John Swanson³, Gavin Shaddick², Catherine Keshishian¹, Cees de Hoogh¹, Paul Elliott¹
¹Imperial College London, London, United Kingdom ²University of Bath, Bath, United Kingdom ³National Grid Transco, Leatherhead, United Kingdom

Objective. This case-control study investigates the risk of incident cancers in adults aged 15-74 years, diagnosed in the period 1974-2003 in England and Wales, in relation to proximity of their home to overhead power lines. The number of adults in England and Wales with residential exposure to significant electromagnetic fields from power lines will also be estimated.

Method. Three hypotheses are being investigated. The first concerns the possible association between magnetic fields and risk of leukaemias, central nervous system cancers, malignant melanomas and breast cancers. Exposure to the power line at residence is represented in four ways: modelled magnetic field strength, continuous linear distance, exposed (<100m) versus unexposed (100-1000m), and distance from power line stratified into bands. The second hypothesis involves the possible association between the inhalation of charged particles downwind of power lines and excess risk of cancers of the respiratory system and mouth. Exposure to charged particles is assessed using a simple downwind/upwind measure, as well as a model that takes into account distance, wind patterns and the power line’s propensity to produce corona ions, proportional to the electric field strength. The last hypothesis concerns the possible association between increased deposition of charged aerosols on skin in the vicinity of a power line and excess risk of non-melanoma skin cancer. Exposed versus unexposed cases and controls are compared.

Control groups comprise people diagnosed with other non-exposure related cancers, within the same time period. Cases and controls were identified from the national cancer registry held at the UK Small Area Health Statistics Unit and residential addresses were geo-referenced within a Geographical Information System. Data on power lines (mainly 400 and 275 kV) were obtained from the UK Energy Networks Association. Magnetic field strength and wind-based exposure measures were modelled by National Grid Transco. Data on potential confounders include the Carstairs index for socio-economic status and estimates of urban-rural status. Migration statistics for the population living within 1000m of a power line will be obtained from the ONS Longitudinal Study (LS). This includes data for 30,000 LS participants living within 1000m of a powerline across England with follow-up since 1971.

Result. Nearly 93,000 cases and 140,000 controls living within 1000m of a power line have been identified from the national pool of cancers. Initial findings from the study relating to the first hypothesis, including modelled magnetic field density, will be presented.
Conclusions. The design of the epidemiological study, the modelling of the distance based and non-distance based (magnetic field strengths) exposure metrics, and the initial epidemiological results for the possible association between magnetic fields and cancer will be discussed.

* P-53 CYTOGENETIC ANALYSIS OF HUMAN LYMPHOCYTES AFTER ACUTE IN VIVO EXPOSURE TO EXTREMELY LOW FREQUENCY MAGNETIC FIELDS

Genevieve C. Albert¹, James P. McNamee², Pascale V. Bellier², Frank S. Prato¹, .. Vijayalaxmi³, Alex W. Thomas¹
¹Lawson Health Research Institute, St. Joseph’s Health Care, London, ON, Canada ²Health Canada, Ottawa, ON, Canada ³University of Texas Health Science Centre, San Antonio, TX, USA

Objectives. The general public has been deriving the benefits from the use of electricity for nearly a century. The consequences of electricity production, transmission through power-lines, and commercial and residential use are chronic exposures to weak, extremely low frequency electric and magnetic fields (ELF-EMF). Based on results from human epidemiological and independent scientific committee reports on the chronic exposure to ELF-EMF, the adverse health effects of ELF-EMF remain controversial (Vijayalaxmi and Obe 2005). Hence, there is an urgent need for a reproducible laboratory assay on prolonged exposure to ELF-EMF on humans.

The objective of this research is to assess for DNA damage and micronucleus induction in peripheral blood lymphocytes collected from healthy adult volunteers before and after acute exposure to 200 µT, 60 Hz EMF.

Methods. Fifteen healthy, non-smoking human males between the ages of 20 and 45 years will participate in this project. Participants will be exposed for 4 hours to either 60 Hz EMF at 200 microTesla (n=10) or to a sham exposure (n=5). Statistical analysis for justifying sample size was performed using a paired t-test calculated by Sample Power (R) (Borenstein, 2000). Peripheral blood samples will be collected prior to and following the 4 hour exposure period, with small aliquots collected before ELF-EMF exposure to be used as positive controls (γ-irradiation). Micronuclei Assay: The human blood samples will be stimulated with phytohemagglutinin, then cultured for 44 hours. A cytokinesis blocker (cytochalasin-B) is then added and the lymphocytes are cultured an additional 28 hours prior to fixing and slide preparation. Slides will be stained with Acridine Orange, followed by manual analysis of blinded samples. Micronuclei (MN) will be observed and analyzed in binucleate (BN) lymphocytes. From each culture, a total of 2000 consecutive cells will be examined to determine the frequency of BN cells, and a total of 2000 BN cells will be analyzed to record the incidence of cells with one MN (BN1MN), two MN (BN2MN) or 3
and more MN (BN≥3MN). The number of BN cells containing MN will be assessed from (BN1MN) + (BN2MN) + (BN≥3MN). The total numbers of MN will be derived from (1x BN1MN) + (2x BN2MN) + (3x BN≥3MN) (Vijayalaxmi et al., 2001). Alkaline Comet Assay: The comet assay will be conducted according to a modified method of Singh et al. (1994) on Trevigen Cometslides (R), then stained with SYBR Gold prior to analysis. From each culture, a total of 50 cells will be analyzed to determine the extent of DNA damage. The comet images will be analyzed on an Olympus BX-60 fluorescence microscope using ‘NB’ filter cube, a programmable Hitachi KP-D581 digital camera and the Alkomet v3.1 image analysis system (McNamee et al., 2000). Statistical Analyses: For each volunteer, data obtained before and after 60 Hz ELF-EMF exposure will be compared. In addition, the data will be pooled from all volunteers and the appropriate statistical analyses performed.

Results. The whole body exposure facility used to expose the volunteers to 60 Hz ELF-EMF at 200 microTesla was developed and has been in use at the Lawson Health Research Institute since 2001. Ethics approval has been granted by the Health Sciences Research Ethics Board (HSREB) at the University of Western Ontario. Experiments are currently underway and data is currently being collected. The results will be presented at the conference.

Conclusions. This is currently a work in progress.

References

Acknowledgements. I would like to acknowledge the Canadian Institute of Health Research for funding this research initiative. I would like to thank Dr. Scott Karnas for his support with the Cobalt-60 irradiation system and his advice, Don Kulh for collecting volunteer samples, and Lynn Keenliside and John Robertson for the technical support.
**P-54** EFFECTS OF EMF EXPOSURE FROM MOBILE PHONE BASE STATIONS: DIFFERENCES IN REACTION TIMES BETWEEN SUBJECTS WITH MOBILE PHONE RELATED SYMPTOMS AND WITHOUT THEM

Toshiaki Furubayashi¹, Yasuo Terao¹, Yoko Mizuno¹, Kei Shirasawa¹, Akira Kageyama¹, Tomoko Okano¹, Masami Nishikawa², Kaori Miyawaki¹, Asako Yasuda¹, Mitsunori Uchiyama¹, Hitomi Kobayashi-Yamashita¹, Akira Ushiyama³, Hiroshi Masuda³, Shogo Hirota³, Miyuki Takahashi³, Shigeru Sokejima⁴, Eiji Maruyama⁵, Pornanong Pongpaibool⁶, Kanako Wake⁶, Soichi Watanabe⁶, Masao Taki⁷, Chiyoji Ohkubo⁸, Yoshikazu Ugawa¹

¹The University of Tokyo, Tokyo, Japan ²Kawamura Gakuen Woman’s University, Chiba, Japan ³National Institute of Public Health, Saitama, Japan ⁴National Institute of Public Health, Saitama, Japan ⁵Kobe University, Kobe, Japan ⁶National Institute of Information and Communications Technology, Tokyo, Japan ⁷Tokyo Metropolitan University, Tokyo, Japan ⁸World Health Organization, Geneva, Switzerland

**Objectives.** Worldwide use of mobile phones has raised several concerns about its health effect, above all, the effect of electromagnetic fields (EMFs) emitted from the base stations. However, there has been a controversy as to whether the persons who report subjective symptoms actually have more symptoms when exposed to EMF emitted by mobile phone terminals or that emitted from mobile phone base stations. The first population-based questionnaire survey was conducted in Japan as to the prevalence of individuals with mobile phone related symptoms (MPRS). In randomly sampled subjects responding to a questionnaire, we also investigated whether subjects with MPRS are more susceptible to the EMF than controls. In this communication, we will show the discomfort levels during 30 minutes exposures and the choice reaction time (RT) tasks before and after the exposure.

**Methods.** The subjects were 54 Japanese female volunteers aged from 20 to 60 years old. They were randomly selected from those responding to our questionnaire and accepted to participate in our experiments. They were sorted into 2 groups based on the answers to the questionnaire; 11 MPRS group and 43 control group. All of them had given their written informed consent to participate in our experiment prior to the experiment. The procedures described here were approved by the Ethics Committee of the National Institute of Public Health.

The precued choice RT task (Terao et al., 2006) was performed before and after any exposures for 30 minutes. There were four exposure conditions: continuous EMF exposure, intermittent exposure in which EMF was turned on and off randomly every five minutes, sham exposure without EMF, and exposure to pink noise (65dB(A)) without EMF. The subjects were exposed to a 2 GHz W-CDMA EMF at an intensity of 10 V/m from a horn antenna simulating the base stations. Preliminary numerical simulation with a realistic human model exposed to plane wave revealed that the whole-body averaged SAR of the subject is 1.4 mW/kg. During the exposures, subjects were asked about the subjective discomfort level every 5 min.

In the RT task, subjects comfortably seated on a chair and were instructed to keep pressing the home keys of the response pad with both hands until the go-signal was presented. On
its presentation, the subjects quickly released the home key with the indicated hand (left or right) and pressed the left or right target button with the same hand. A precue preceding the go-signal by a random interval between 2 and 3 seconds conveyed full, partial or no information about the movement parameters (i.e., the hand to be used [right or left] and the button to be pressed [right or left]). The RT from the presentation of the go-signal to releasing the home key was measured. A double blind, cross-over design randomized within participants was used. Two factors ANOVA (exposure conditions and subject groups) was performed for the discomfort, and three factors ANOVA (the exposure conditions, subject groups and timing of the experiment) was performed for each precue information in the RT task.

Results. For the level of discomfort during exposures, two factors ANOVA revealed that both the groups and exposure conditions had a significant effect on the discomfort. However, there were no significant interactions between them. The levels were significantly higher in MPRS than control. The noise exposure had a significant effect. Three factors ANOVA revealed that both the groups and the timing had a significant effect on the RTs. However, the exposure conditions had no effects on the RTs. There were no significant interactions among them. The RTs were significantly longer in MPRS as compared with those of the control. The RTs were longer after exposure as compared with before it. However, these results were not modulated by the exposure conditions.

Conclusions. We used the precued choice RT task in order to examine the health effect by EMF exposure from mobile phone base stations. The RTs were prolonged after the exposures of any kinds even with or without EMF exposures in either subjects with or without MPRS. These suggest that the EMF exposure does not affect RTs. In addition, subjective levels of discomfort increased after noise exposure in both groups. This indicates that the noise caused a similar stress to both groups. No discomfort increase in the other exposure conditions suggests that EMF from the base station dose not induce the discomfort. We conclude that the EMF from base stations had no significant effects on the neuronal circuits involved in our precued choice RT task and dose not induce the discomfort felt by the subjects.


Acknowledgements. This study was financially supported by The Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields, the Ministry of Internal Affairs and Communications, Japan.
THE EFFECT OF ACUTE EXPOSURE TO A 60 Hz, 1800 µT MAGNETIC FIELD ON HUMAN MICROCIRCULATION

David A. McNamee, Alexandre G. Legros, Alex W. Thomas, Frank S. Prato
Lawson Health Research Institute, London, ON, Canada

Objectives. The effects of magnetic field (MF) exposure on the peripheral circulatory system have been questioned and debated in the literature for many years now. Several studies that have investigated the effects of pulsed and static MFs on both human and animal models have yielded inconsistent results. This is likely due to the heterogeneous field characteristics employed in these experiments. Presently, the effect of power line frequency MF exposure on human peripheral microcirculation remains undefined. Previous unpublished work conducted in our laboratory on rats has suggested a decrease in microcirculation as a result of exposure to power line frequency MFs. This information would be of value in determining risk assessment models for populations subject to this type of exposure and as a possible therapeutic approach to microcirculatory pathologies.

Our objective thus, is to determine if changes in peripheral microcirculation and other cardiovascular parameters occur during and/or after an acute, 60 Hz MF exposure session at 1800 µT.

It is hypothesized that MF exposure will decrease peripheral microcirculation and heart rate variability (HRV) and have no effect on heart rate frequency (HR) or systolic blood pressure (SBP).

Methods. This project is part of a current study protocol (University of Western Ontario Health Sciences Research Ethics Board # 11956E) investigating various physiological responses to power line frequency MF exposure. Ethics has been obtained to recruit 70 healthy adult volunteers between the ages of 18 and 55 years of age. The experiment uses a double blinded computer program (National Instrument Inc., USA) to assign subjects to 2 counterbalanced exposure sessions administered on 2 separate days. The exposure sessions are either real (active) or control (sham). Each session is composed of 4 blocks of testing inter spaced with 15 minutes of rest. Testing occurs 15 minutes before the beginning of exposure, after 15 and 45 minutes of exposure and 15 minutes following exposure.

During each block of testing, the subject’s peripheral microcirculation is measured with a laser Doppler flowmetry probe (PF 5010 Laser Doppler Perfusion Unit, Perimed, Sweden) attached to the ventral tip of the middle finger of the non dominant hand. After each perfusion recording has been taken in each block of testing, a systolic blood pressure measurement is taken with a digitally controlled pressure cuff (PF 5050 Pressure Unit, Perimed, Sweden). Additionally heart rate and skin temperature are continuously recorded throughout the testing block with an ambulatory electrocardiogram (Siesta, Compumedics Inc., USA) and skin surface thermistor (Series 400, Yellowstone Scientific Instruments, USA) respectively.

The exposure chamber consists of two Helmholtz like orthogonal coils, 1.6 m wide (80 turns of AWG10 wire) spaced with 1.2 m apart. The subject is seated in the middle of the coils for whole body exposure.
Results. Data is presently being collected and analyzed (SPSS 15.0, SPSS Inc., Chicago, USA). Results will be presented at the BEMS conference in June as only preliminary data is available at this time.

Conclusions. This is a work in progress.

Acknowledgements. Research funded by Hydro-Québec, EDF-RTE (France), ORDCF (Ontario), CIHR (Canada) and LHRI.

Figure 1. Skin blood perfusion data of one subject to demonstrate how findings will be presented.

P-56 EFFECTS OF ELECTROMAGNETIC FIELD EXPOSURE FROM MOBILE PHONE BASE STATIONS
-SUBJECTIVE PERCEPTION OF THE FIELDS AND PHYSIOLOGICAL RESPONSES DURING EXPOSURE AMONG THE PEOPLE WITH/WITHOUT MOBILE PHONE RELATED SYMPTOMS -

Akira Ushiyama¹, Hiroshi Masuda¹, Shogo Hirota¹, Miyuki Takahashi¹, Shigeru Sokejima², Eiji Maruyama³, Yoshikazu Ugawa⁴, Yasuo Terao⁴, Toshiaki Furubayashi⁴, Yoko Mizuno⁴, Kei Shirasawa⁴, Akira Kageyama⁴, Tomoko Okano⁴, Masami Nishikawa⁵, Kaori Miyawaki⁴, Asako Yasuda⁴, Mitsunori Uchiyama⁴, Hitomi Kobayashi-Yamashita⁴, Pornnanong Pongpaibool⁶, Kanako Wake⁶, Soichi Watanabe⁶, Masao Taki⁷, Chiyoji Ohkubo⁸

¹National Institute of Public Health, Saitama, Japan ²National Institute of Public Health, Saitama, Japan ³Kobe University, Kobe, Japan ⁴University of Tokyo, Tokyo, Japan
**Objectives.** The recent spread of mobile phone has been accompanied by some concerns about possible health risks. It is still a controversial issue whether symptoms of electromagnetic hypersensitive people are attributed to the electromagnetic fields (EMFs) from mobile phone terminals or their base stations, although recent several reports concluded there were no relationship between the symptoms and fields. Therefore, we tested whether the physiological parameters would be affected by EMFs emitted by mobile phone base station in the subjects with self reported mobile phone related symptom (MPRS). Furthermore, we tested whether MPRS people could perceive the EMFs and feel any discomfort during EMF exposure.

**Methods.** We randomly sampled 11 subjects with MPRS and 43 control subjects without MPRS from population based questionnaire survey of 5,000 women in Kanto area in Japan. A double blind, cross-over design randomized within participants was used. There were four exposure conditions all lasting 30 minutes: continuous EMF exposure, intermittent exposure in which EMFs were turned on or off randomly every five minutes, sham exposure without EMFs, and exposure to pink noise (65dB(A)) without EMF. The subjects were exposed to a 2 GHz W-CDMA EMFs at an intensity of 10 V/m from a horn antenna simulating a base station. Preliminary numerical simulation with a realistic human model exposed to plane wave revealed that the whole-body averaged SAR of the subject is 1.4 mW/kg. (Detailed investigation considering the reflection from the walls of the room and so on are now undertaken.) Throughout the each experimental condition including 30 minutes EMF exposure, subjects were asked to feel relaxed on a plastic chair. We monitored their physiological measures of autonomic function, including skin temperature, arterial oxygen saturation, heart rate, and local blood flow of the finger tip, continuously. In addition, to test whether the subjects were able to perceive the EMFs, we asked them if they perceived EMFs or felt any discomfort every 5 minutes during the experiment. An overall difference among the four exposure conditions was determined by one-way ANOVA or two-sided Student’s t test. These research protocols were approved by the local research ethics committee in National Institute of Public Health.

**Results.** We tested 11 female subjects with an average age of 37.3 years (SD 9.7 and range 26-57 years) for the MPRS group and 43 female subjects with an average age of 38.0 years (SD 8.2 and range 21-53 years) for the control group. Physiological data were continuously recorded for 33 minutes in total, including 3 minutes’ pre-exposure period and the recorded values were averaged for every 1 minute. No statistically significant changes were observed in the skin temperature, arterial oxygen saturation, heart rate responses, or local blood flow in either the MPRS group or the control group with one exception. In the sound noise exposure, transient local blood flow decrease was evoked due to autonomic reaction only in the control group. There were no statistical differences among the four exposure conditions in any physiological parameters. Result of perception of EMFs also showed no differences in the rates of accurate answers between MPRS and control subjects, and those rates were not greater than that expected.
by chance. Regarding subjective level of discomfort, the MPRS group complained more discomfort than the control group, however the level of discomfort is independent of the presence of EMFs.

**Conclusions.** The findings of this randomized, double blind, crossover study in MPRS and control subjects show that 30 min exposure to 2GHz W-CDMA signals at an intensity of 10 V/m, which is simulated exposure from the mobile phone base station antenna, does not change the skin temperature, arterial oxygen saturation, heart rate, or local blood flow under our experimental condition. Regarding the perception of the EMF, neither the MPRS nor control subjects were able to perceive the field more often than expected by chance. In conclusion, we found no causal relationship between W-CDMA base station-like EMFs and MPRS under given exposure conditions.

**Acknowledgements.** This study was financially supported by The Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields, the Ministry of Internal Affairs and Communications, Japan.

**P-57 EFFECTS OF ELECTROMAGNETIC FIELD EXPOSURE FROM MOBILE PHONE BASE STATIONS -MENTAL AND PSYCHOLOGICAL RESPONSES DURING EXPOSURE IN THE SUBJECTS WITH/WITHOUT MOBILE PHONE RELATED SYMPTOMS -**

Masami Nishikawa¹, Kaori Miyawaki², Asako Yasuda², Mitsunori Uchiyama², Hitomi Kobayashi-Yamashita², Yasuo Terao², Toshiaki Furubayashi², Yoko Mizuno², Kei Shirasawa², Akira Kageyama², Tomoko Okano², Akira Ushiyama³, Hiroshi Masuda³, Shogo Hirota³, Miyuki Takahashi³, Shigeru Sokejima⁴, Eiji Maruyama⁵, Pornanong Pongpaibool⁶, Kanako Wako⁶, Soichi Watanabe⁶, Masao Taki⁷, Chiyoji Ohkubo⁸, Yoshikazu Ugawa²

¹Kawamura Gakuen Woman’s University, Abiko, Japan ²University of Tokyo, Tokyo, Japan ³National Institute of Public Health, Wako, Japan ⁴National Institute of Public Health, Wako, Japan ⁵Kobe University, Kobe, Japan ⁶National Institute of Information and Communications Technology, Tokyo, Japan ⁷Tokyo Metropolitan University, Tokyo, Japan ⁸World Health Organization, Geneva, Switzerland

**Objectives.** We have pursued our study of mobile phone related symptoms (MPRSs) elicited by the electromagnetic fields (EMFs) from mobile phone base stations as the first massive project conducted in Japan. We tested various respects of psychological, physiological and autonomic effects when exposed to EMFs simulating those from mobile phone base station. The purpose of this presentation is to investigate mental and psychological effects by the EMFs.
**Methods.** We randomly sampled 11 subjects with MPRS and 43 control subjects without MPRS from population based questionnaire survey of 5,000 women in Kanto area in Japan. A double blind, cross-over design randomized within participants was used. We first confirmed all subjects had no mental disorders using Mini-International Neuropsychiatric Interview (M.I.N.I.). Then we tested them with the Neo Five-Factor Inventory (NEO-FFI) to check their personality traits.

There were four exposure conditions all lasting 30 minutes: continuous EMF exposure, intermittent exposure in which EMFs were turned on or off randomly every five minutes, sham exposure without EMFs, and exposure to pink noise (65dB(A)) without EMF. The subjects were exposed to a 2 GHz W-CDMA EMFs at an intensity of 10 V/m from a horn antenna simulating a base station. Preliminary numerical simulation with a realistic human model exposed to plane wave revealed that the whole-body averaged SAR of the subject is 1.4 mW/kg. (Detailed investigation considering the reflection from the walls of the room and so on are now undertaken.)

Each subject was examined on psychological states using profiles of mood states (POMS) before and after exposure for 30 minutes. In addition, to test whether the subjects were able to perceive the EMFs, we asked them if they perceived EMFs or felt any discomfort every 5 minutes during the experiment.

A difference on NEO-FFI personality traits between two groups was determined by Mann-Whitney’s U-test. Then, a repeated-measure, mixed ANOVA with group as the between-subjects variable and four conditions, time of examination (before and after exposures) as within-subject variables was performed to determine whether POMS sub-scores differ between groups, exposure conditions or time of examination.

These research protocols were approved by the local research ethics committee in National Institute of Public Health.

**Results.** We tested 11 female subjects with an average age of 37.3 years (SD 9.7 and range 26-57 years) for the MPRS group and 43 female subjects with an average age of 38.0 years (SD 8.2 and range 21-53 years) for the control group.

There were no differences in personality traits on NEO-FFI between two groups. Both groups showed lower POMS subscale for vigor and higher POMS subscales for fatigue and confusion after any experimental conditions. However, there were no statistical differences between two groups. They also didn’t differ in their sensitivity to detect the presence or absence of EMFs.

**Conclusions.** On this randomized, double blind, crossover study in MPRS and control subjects, both groups had the same changes in psychological aspects under any experimental condition. Regarding the perception of EMFs, neither the MPRS nor control subjects were able to perceive the field more often than expected by chance. In conclusion, we found no causal relationship on psychological aspects between W-CDMA base station-like EMFs and MPRS.

**Acknowledgements.** This study was financially supported by The Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields, the Ministry of Internal Affairs and Communications, Japan.
P-58 EFFECTS OF A W-CDMA 1950 MHZ SIGNALS ASSOCIATED WITH MOBILE PHONE ON THE REGIONAL CEREBRAL BLOOD FLOW (RCBF) IN HUMANS

Yoko Mizuno 1, Takashi Ohnishi 1, Yoshiya Moriguchi 2, Toshio Nojima 3, Takashi Hikage 3, Yoshikazu Ugawa 1
1University of Tokyo, Tokyo, Japan 2National Center for Neurology and Psychiatry (NCNP), Tokyo, Japan 3Hokkaido University, Sapporo, Japan

Objectives. A large part of the energy of the pulse-modulated radio-frequency electromagnetic field (EMF) emitted by mobile phones is absorbed into the user’s head (Schönborn et al, 1998). A few studies attempted to investigate effects of EMF emitted by a mobile phone on rCBF in human by using a positron emission tomography (PET). However their claims are inconsistent and further confirmation studies are requisite for making a conclusion. The purposes of our study are to confirm previous results and to study the effect(s) of the 3rd generation mobile phone terminals rather than the 2nd ones. The 3rd generation systems have been more widely used in most countries these days. This study therefore focused on to investigate the effect of W-CDMA type EMF as one of the 3rd generation systems.

Methods. Nine healthy male volunteers participated in this study. Written informed consent was obtained prior to the experiment and the ethical committee of NCNP for research on human subjects approved the following study protocol. In order to exclude other confounding factors associated with mobile phone activation than the EMF effects, e.g., acoustic and thermal effects, a patch antenna was used instead of a real mobile phone. The antenna was prepared in order to stabilize it to the subjects’ head to minimize the aberration in PET recording due to its movement. The antenna was mounted to the right side of the subjects’ head and placed between subjects’ head and the headrest of the PET scanner. W-CDMA 1950 MHz EMF was exposed or not exposed (sham) for 30 minutes continuously under a single blind condition. The input power was adjusted to obtain 2 W/kg spatial averaged SAR over 10g mass. After 180 seconds transmission, six PET scans were obtained per experiment, 2 scans each for before, during and after the EMF or sham exposure. A radio isotope O15 water was injected via an IV line 15 seconds before each scan.

The pre-processing and statistical image analyses were performed using the Statistical Parametric Mapping software 2 (SPM2) and Matlab 6.5 for Windows. Subtraction analysis was made to investigate the decrease or increase of rCBF during and after the EMF exposure.

Results. In comparison with before EMF exposures, no significant differences were observed between real and sham EMF exposures in rCBF changes during and after exposure.

Conclusions. Neither of the claims made by previous studies rCBF decreases during the EMF exposure (Haarala C et al, 2003) or rCBF increases after the EMF exposure (Huber R et al, 2005) were obtained in our study.
Acknowledgements. This study was supported by Association of Radio Industries and Businesses (ARIB).

P-59 ELECTROMAGNETIC FIELDS EMITTED BY MOBILE PHONES AND HEART RATE VARIABILITY

Paolo Ravazzani¹, Marta Parazzini¹, Gabriella Tognola¹, Gyorgy Thuroczy², Ferenc B Molnar², Federica Sibella¹, Alessia Paglialonga¹, Luca Tommaso Mainardi³
¹Consiglio Nazionale delle Ricerche, Milano, Italy ²National Research Institute for Radiobiology and Radiohygiene NIRR, Budapest, Hungary ³Politecnico di Milano, Milano, Italy

Objectives. Aims of this study is to assess potential changes on different Heart Rate Variability (HRV) parameters during the exposure to low-intensity EMF produced by GSM cellular phones at 900 MHz. To this purpose, a group of young healthy volunteers was analysed in rest and in stand position, during real and sham exposure.

Methods. Participants are healthy young adults without any evidence of cardiac disorders. The test protocols entails cardiac measurements during exposure to EMF. The procedure is conducted twice in a double-blind design: once with a genuine EMF exposure and once with a sham exposure (at least 24 hours apart, always in the morning). Each session consists of 13 minutes in supine rest condition followed by 13 minutes in stand condition (sympathetic activation). During each session three electrocardiographic (ECG) leads were recorded. EMF exposure utilizes the normal output of a consumer mobile phone (NOKIA 6310i) at full power (2W) at 900 MHz. The phone is software controlled to set the exposure parameters to the required frequency and power. The sham or genuine exposure was realised using a 50 ohm “load” or “dummy load”, applied using the antenna connector output of the phone. The ”load” intercepts the RF signal to the internal antenna on the phone and dissipates the RF in the load, while the ”dummy load” looks identical but does nothing, allowing the RF to reach the antenna. To control the efficiency of the load a surface scanning of the phone by a near field measurements were performed. No radiated RF fields were measured using the RF load connected to the external antenna output.

To estimate the level of EMF exposure in the head and in the region of interest (hypothalamus and brainstem), measurements of absorbed radiofrequency power in the head, called Specific Absorption Rate (SAR, W/kg) were made in brain tissue equivalent liquid phantom (Antennessa GEL-900/1800, France). In these measurements 3D step motor robot system (Arrick Robotics, 3 Axis Positioning Table, USA), internal E-field probe (ER3DV4R, Schmid & Partner Engineering Ag., Switzerland) and non metallic phone positioning system were applied using the “touch position” of the phone, according to the EN 50361 CENELEC standard. The maximum SAR was below 2 W/kg, which is the limit of the European recommendation.
A system of phone fixation with the possibility of free head movement was designed. All parts of the positioning system were made of non-metallic plastic. During the exposure the phone was placed so that its longitudinal axis followed an imaginary line from the entrance to the ear canal to the corner of the mouth, in accordance with the CENELEC standard. From the ECG recorded during the genuine and sham exposure in rest and in stand condition a series of HRV parameters both in time (RR mean, SDNN, RMSSD, PNN50, TINN and triangular index) and in frequency domain (LF and HF powers, LF/HF) were calculated. In addition a set of non-linear indexes (approximate entropy, the slope values $\alpha_1$ and $\alpha_2$ from detrended fluctuation analysis, regularity, non randomness from linguistic analysis and the two standard deviations SD1 and SD2 from Poincaré plot) were evaluated. These parameters do not necessarily reflect a specific component of autonomic modulation but they testify the characteristics of heart rate behavior and its complexity, which is dependent on the functional integrity of autonomic control mechanisms.

All the parameters were statistically analyzed by a repeated measures analysis of variance contrasting sham with exposure condition ($p=0.05$). In addition, to quantify the responsiveness to the sympathetic stimulus induced by stand, the difference between stand and rest values was computed for each parameter. This difference will be indicated as $\Delta$ in the text.

**Results.** The analysis of the data shows that the most of the HRV parameters were no statistically different when recorded during a real or a sham exposure. Slight statistically significant differences were observed in a few parameters of both time and frequency domain analysis. In time domain analysis significant reductions were observed in both TINN and triangular indexes during stand condition for real exposures. In addition, the SDNN was found statistically significant when responsiveness to stand was evaluated. As to frequency domain parameters, the LF power during stand condition and the $\Delta$LF power increased in real versus sham exposure. In any case, all these differences, both in time and frequency domain, were found in the range of physiological variation, therefore they cannot be related to any adverse effect.

As to the non-linear indexes, no statistically significant difference was found.

**Conclusions.** The analysis of the RR data shows there was no effect due to EMF exposure on both main and most of the other HRV parameters. The findings of this study were obtained in a population of young subjects and additional studies should be performed in an older population, as many studies reported that autonomic nervous system (ANS) control is altered by ageing process and pathology.

A weak interaction between some minor parameters of ANS heart rate regulation and RF exposure was observed. This effect seems to be gathered around the sympathetic response to orthostatism and is represented by an accentuation of the sympathetic activation from standing up, resulting in an accelerated heart rate and a diminished variation between cycle’s lengths. All these effects are only biological and are not related to any adverse health effects. Moreover, findings such as these on minor indexes do not change the general conclusion that EMF RF exposure produces no effects on HRV. Only after additional replication/confirmation studies, together with further investigation on plausible mechanisms, any conclusion about these minor indexes can be driven.
**Acknowledgements.** The authors thanks Dr. Sakari Lang and the NOKIA Research Laboratory for their technical assistance.

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*P-60 IMAGE GUIDED MAGNETIC FIELD THERAPY*

John A. Robertson¹,², Dick Drost⁴,³, Frank S. Prato⁴,², Alex W. Thomas¹,⁴

¹Lawson Health Research Institute, London, ON, Canada ²University of Western Ontario, London, ON, Canada ³St. Joseph’s Health Care, London, ON, Canada ⁴Lawson Health Research Institute, London, ON, Canada

**Objectives.** Previously, we have described a specific pulsed magnetic field (CNP (R)) that was able to induce an analgesic effect in snails, mice, normal human volunteers, as well as chronic pain patients including those with fibromyalgia. These studies have included both whole-body exposures as well as head-only exposures. Thus, we know that the central nervous system is involved in the mechanism.

The objective of this work is to examine how the neural processing of pain is altered by the application of this pulsed magnetic field therapy.

**Methods.** Functional magnetic resonance imaging (fMRI) will be used to determine the neural activity in the brains of normal volunteers. BOLD (blood oxygenation level dependent) images will be obtained with a Siemens Avanto 1.5 T clinical MRI, and analyzed with Brain Voyager QX software (Brain Innovation B.V.).

A Peltier thermode device (1.6x1.6 cm probe, TSA-II, Medoc) will be affixed to the hypothenar region of the subject’s dominant hand. This will deliver a noxious heat stimulus (48-51°C, depending on the subject’s individual pain threshold) 10 times, each for 21 seconds in a ”boxcar” design within the MRI. The subjects will then be exposed to the CNP (R) pulsed magnetic field (peak 200 µT), or a sham condition for 20 minutes, and the fMRI/heat procedure will be repeated.

Subjects will be randomized into active or sham groups, and will not be told which group they belong to. However, the experimenter will be aware of the condition, so this will be a single-blind study.

**Results.** This experiment is presently underway and results will be presented at a later date.

**Conclusions.** With this study we hope to discover some of the neural processing changes underlying the analgesic effect of the CNP (R) pulsed magnetic field.
**Acknowledgements.** Dr. Jean Theberge, Dr. Keith St. Lawrence, Dr. Dwight Moulin, Dr. Alexandre Legros, Daron Owen, Jeff Winter, Lynn Keenliside as well as Fralex Therapeutics Inc., the Ontario Graduate Scholarship, the Natural Sciences and Engineering Research Council of Canada, the Canada Foundation for Innovation, the Lawson Health Research Institute, the Canadian Institutes for Health Research, and the Ontario Research and Development Challenge Fund for funding.

* **P-61 STUDY ON CHANGE OF SLEEP PATTERNS BY GENERATED MAGNETIC FEILDS DURING USING ELECTRONIC MAT**

Ju-Hyun Song¹, Yoon-Shin Kim¹, Sungho Choi¹, Young man Roh¹, Chul min Lee¹, Seung-Cheol Hong²

¹Hanyang university, Seoul, South Korea ²Inje university, Kimhae, South Korea

**Objectives.** This study investigated whether or not generated magnetic fields during using electronic mat lead to biological change for human.

**Methods.** In this study, considering sex, age, income in a clinical ethics’s charge, we chose volunteers consists of ten men and ten women. We observed EEG of subjects during sleep, and we analyzed sleep latency time, sleep patterns and sleep characters through results of this study. The researchers carried out experiment as separating two groups. One group was exposed above 2uT magnetic fields and another was exposed beyond 0.2uT magnetic fields. we used 8 channel device(LAXTHA.Ltd) to measure EEG during sleep.

**Results.** Table 1 showed that time from light-off to the lowest SEF-90 which was index of disillusion. In highly exposed by EMF, time from light-off to the lowest SEF-90 under using electronic mat and not using electronic mat was not found significant. Overall, the time intended to decrease. Controled group also indicated similar tendency. Hence, we assumed that this result was not because of EMF exposure, but other reasons such as subjects’s familiar mind about experience, and biological rhythm as season. We considered that subjects of second experiment was more readily fell asleep than first experiment.

Table 2 shows the difference between the highest SEF-90 point and the lowest SEF-90 point during sleep. This result illustrated that both highly exposed group by EMF and lowly exposed group were confirmed that difference between the highest SEF-90 and the lowest SEF-90 after using electronic mat was higher than controlled experiment. So, we assumed that these results was similar to that of table 1.

**Conclusions.** In this study, we assumed that it was indefinite whether EMF was the factor affecting on change of sleep patterns.
P-62 ON THE CURRENT STATE OF THE GERMAN MOBILE TELECOMMUNICATION RESEARCH PROGRAMME

Gunde Ziegelberger
Federal Office for Radiation Protection, Neuherberg/Munich, Germany

Objectives. The German Mobile Telecommunication Research Programme (DMF) was initiated to improve the data base on possible health effects of RF-fields at levels below international limit values. In the period of 2002 to 2007 a total of 52 projects are carried out in four disciplines: biology (22 projects), dosimetry (14 projects), epidemiology (9 projects) and risk communication (7 projects).

Results. Detailed information on the goal of the single projects and on current results can be found on the DMF-homepage www.emf-forschungsprogramm.de. Most of the projects will be finalized by the end of 2007. The results of single thematic topics have been or will be presented and discussed with national and international experts invited at scientific workshops. The workshop on ”Dosimetry” was proceeded in July 2006, and a second one on ”Risk Communication” in October 2006. The single presentations, a conclusion on the results and a rapporteur report are available on the website. The biological and epidemiological projects were combined in three workshops with the topics ”Acute Health Effects” in December 2006, ”Interaction Mechanisms” in May 2007 and the final one on ”Long-Time Health Effects” in September 2007.

Conclusions. Final evaluation of the DMF-results in context to results expected from other ongoing research programmes will take place at an international scientific conference early in 2008. The results are expected to improve the data base for RF-risk assessment and communication.

Acknowledgements. The Research programme was initiated by the German Federal Environment Ministry (BMU) and the Office for Radiation Protection. The total financial volume of 17 Mio Euro has been shared between the BMU and the German Network Providers.
P-63 UPDATE ON THE AUSTRALIAN CENTRE FOR RADIO FREQUENCY BIOEFFECTS RESEARCH (ACRBR)

Rodney J. Croft\textsuperscript{1,2}, Michael Abramson\textsuperscript{3,2}, Irena Cosic\textsuperscript{4,2}, John Finnie\textsuperscript{5,2}, Ray J. McKenzie\textsuperscript{2}

\textsuperscript{1}Swinburne University, Melbourne, VIC, Australia  \textsuperscript{2}Australian Centre for Radiofrequency Bioeffects Research, Melbourne, VIC, Australia  \textsuperscript{3}Monash University, Melbourne, VIC, Australia  \textsuperscript{4}RMIT, Melbourne, VIC, Australia  \textsuperscript{5}Institute of Medical and Veterinary Science, Adelaide, SA, Australia

**Objectives.** The Australian Centre for Radio Frequency Bioeffects Research (ACRBR) was established in 2004 to conduct research into possible health-related consequences of using low-level radio frequency (RF) emitting devices. To this end the ACRBR is currently engaged in a number of research programs assessing the effects of second and third generation radio technologies (and related electromagnetic fields; EMF) on endpoints ranging from molecules to human populations.

**Methods.** These include exploring RF interactions with proteins in order to investigate bioactivity changes of selected protein groups, as well as investigating the influence of inter and intra-cellular water as a medium for electromagnetic radiation and the supply of energy for molecular activation. In vitro and in vivo neurobiology feature prominently in the ACRBR research program. In mice and rat models, the effect of RF on acute genomic response (c-fos expression), blood brain barrier permeability and long-term potentiation was examined. In humans, the effects of RF on cognitive performance and neurophysiological activity has been examined in child and adult volunteers using an experimental design. Taking an epidemiological approach, we are also engaged in a cohort study of young adolescents that will determine whether there are any relationships between their phone usage patterns and measures of cognition, hearing and blood pressure, over a 3-year period. Finally, the ACRBR dosimetry research addresses a number of issues, including the effectiveness of current RF exposure compliance techniques to account for the detail variation of tissue properties and morphologies over the range of the human population.

**Results.** This presentation will describe ACRBR results to date.
**P-64 EFFECTS OF WIRELESS PHONE RF ON CELLULAR IMMUNITY AND CYTOKINES**

HeeChan Park, JaeWook Choi, SeungHyun Choi, MiRa Yoon  
Korea University, Seoul, South Korea

**Objectives.** We investigate a change of immunity effects of wireless phone RF on Human.

**Methods.** 62 female volunteers (32 cases and 32 controls) were asked to answer a questionnaire with questions on their personal data and wireless phone use in order to identify effects of wireless phone RF on a change of immunity. The subjects were exposed to RF emissions from the same type of wireless phones and during the experiment the levels of wireless phone RF energy were measured using a powermeter to ensure the consistency of wireless phone RF. Blood samples were collected before and after using a wireless phone for 30 minutes, respectively. Cellular immunity indicators, i.e. CD4+CD45RA+naive cells, CD4+CD45RO+memory cells, CD4+helper cells, CD8+cytotoxic cells, CD19+B lymphocytes, CD3-CD16+CD56+natural killer cells, and total (CD3+) T cells, were measured from the collected blood samples using the flowcytometry method. To obtain cytokines, Tumor Necrosis Factor alpha (TNF-alpha), Interleukin-1 (IL-1beta), and Interleukin-6 (IL-6) were cultured for 48 hours, and their amounts before and after the exposure were analyzed using ELISA-kit.

**Results.** There was a significant difference between cases and controls of cellular immunity and cytokines before and after the exposure, and showed significant differences in CD3-CD16+CD56+natural killer cells (p<0.001) and the concentrations of Interleukin-6 (p<0.01). Comparing the concentrations of cellular immunity indicators before and after the exposure in the case group showed significant differences in the concentrations of CD3-CD16+CD56+ natural killer cells (p<0.001) and the concentrations of Interleukin-6 (p<0.001) (Table 1, Figure 1, 2). In the comparison of the concentrations of cellular immunity indicators and cytokines before and after the exposure in the control group, there was a significant differences in CD3-CD16+CD56+natural killer cells (p<0.05) and the concentrations of Interleukin-6 (p<0.01). The case group was analyzed to identify the associations between the personal data and wireless phone use factors and the immunity. In case of the cellular immunity, the concentration of CD3-CD16+CD56+natural killer cells was significantly associated with skin dryness after wireless phone use (r=-0.699, p<0.05). In case of the cytokines, the concentration of Interleukin-6 was significantly associated with dizziness after wireless phone use (r=-0.649, p<0.01) (Table 2).

**Conclusions.** Although the method used in this study for examining the effects of wireless phone RF on cellular immunity and cytokines is widely used in immunotoxicology, it is very sensitive and has a large variation with individuals. Moreover, studying with 64 volunteers is insufficient for concluding the association between wireless phone use and a change of immunity. Therefore, this study could not conclude that wireless phone RF exposure caused a change of immunity, showing the necessity of further studies. Moreover, this study showed that there was a significant difference in some immunity indicators before and after wireless phone RF exposure, and some findings observed were identical with those in the other study. Therefore, it is necessary to carry out further studies to obtain more samples and to study a
change of immunity under various conditions of wireless phone RF exposure, e.g. different RF levels and exposure time.

![Figure 1. Distribution of CD3-CD16+CD56+natural killer cell and Interleukin 6 concentrations between before and after the mobile phone exposure in experimental groups.](image)

* P-65 THE COMPARATIVE STUDY ON LEARNING-RECOGNIZING ABILITY INDUCED BY THREE KINDS OF BAND ELECTROMAGNETIC RADIATIONS IN WISTAR RATS

Dewen Wang¹, Juan Chen¹, Hong-yan Zuo¹, Zhitao Han², Luning Wang²
¹Academy of Military Medical Science, Beijing, China ²PLA General Hospital Neurobiology Lab, Beijing, China

**Objectives.** To explore the different learning-recognizing ability alteration after the central nervous system was irradiated by the three band electromagnetic radiation.

**Methods.** Forty-eight Wistar rats was respectively irradiated by X-band microwave (100mw/cm²), S-band microwave (100mw/cm²), electromagnetic pulse (6 × 10⁴V/m). At the time of 6h.1d.2d.3d.4d.5d.6d.7d.10d.14d.21d.28d.6m.12m after the rats was irradiated, we detected their learning and memory ability by Morris water maze.

**Results.** 1. The control group and the three radiation groups both experienced learning stage (6h-3d) short-term memory stage (5d-28d) and long-term memory stage (6m12m) 2. the average escape latency of the three band radiation group was obviously shorten after the rats was irradiated 6h. At the time of 1d-3d the AEL was lightly lengthened. 3. At the time of 4d-28d the AEL extended compared to the control group and 5d-10d was most significant. 4. At the time of 6m the AEL was still significant prolongation (P<0.05, P<0.01). 5. At the time of 12m AEL was still significantly prolonged. The two microwave groups was highly significantly difference compared to the control and electromagnetic pulse groups.
Conclusions. After the rats were irradiated, spatial reference learning ability, short-term memory and long-term memory abilities were decreased. There were depressive effect and defer effect. The Wistar rats may generate stress reaction in the initial stage (6h-1d), the spatial reference memory ability obviously attenuated in the later period(3d-12m). At the time of 12m, the two microwave-radiated groups were more seriously than electromagnetic pulse-radiated group.

P-66 EFFECT OF INTERMEDIATE FREQUENCY MAGNETIC FIELDS ON GENE CONVERSION AND POINT MUTATION IN MODEL EUKARYOTIC CELL, SACCHAROMYCES CEREVISIAE.

Satoshi Nakasono1, Masateru Ikehata2, Minori Dateki1, Tsukasa Shigemitsu1, Tadashi Negishi1
1Central Research Institute of Electric Power Industry, Abiko, Japan 2Railway Technical Research Institute, Kokubunji, Japan

Objectives. We have reported that the intermediate frequency (IF) magnetic fields (MFs; 2kHz, 20kHz and 60kHz) did not have mutagenicity or co-mutagenicity for known mutagens, including radicals, DNA reactive agents or metabolically activated DNA reactive agents, in the bacterial mutation assay. In this study, we have reported the effect of the IF MFs on gene conversion and point mutation in (budding yeast) S. cerevisiae XD83 as a model eukaryotic cell. We have also investigated the effect of the MFs on mutagenesis induced by UV irradiation in the yeast cells.

Methods. Exposure System; The exposure system consists a helmholtz’s coil and an incubator with water jacket made of resin that was located in the center of the coil. The incubation temperature was controlled at 30±0.2°C. The maximum field strength depends on the MF frequency, and 0.91mTrms (146 times greater than the strength of ICNIRP guideline), 1.1mTrms (176 times) and 0.11mTrms (18 times) of MFs were generated at 2 kHz, 20 kHz and 60 kHz, respectively. This system provides a large uniform MF environment (20cm-cube, field variation below 5%), for in vitro test.

Genotoxicity Tests; The yeast test strain, Saccharomyces cerevisiae XD83, was obtained from ATCC. The plate incorporation method was used as shown by Dixon et al.. The yeast cells were incubated in 12mL of YEPD medium (1% yeast extract, 2% Bacto-peptone, 2% dextrose) at 30°C at 50rpm for 21.5h in the dark. The final cell concentration was around 1.5 x 10^8 cells/mL. The cell suspension was mixed with 0.5 ml of 0.1M phosphate buffer (pH7.0) and 2mL of the top agar (0.6% agar, 0.5% NaCl). For the gene conversion test (Arg(-)H), the final cell number was adjusted to around 10^6 cells/mL. For the test of the effect on mutagenesis by UV irradiation (UV-C, 0.15J/m^2/sec, 60sec), (Arg(-)L-UV) in the gene conversion, the final cell number was adjusted to around 10^5 cells/mL. For the base pair substitution test (Lys(-)), the final cell number was adjusted to around 5 x 10^7.
cells/mL. The mixture was plated onto the basal agar plates (90 mm diameter). For the test of effect on survival on YPD medium (YPD), the cells number was adjusted to around 100 cells/plate. Eight plates for each condition were prepared and randomly divided into two groups. One group was incubated in the MF exposure system, and the other was placed in a control incubator. The plates were incubated for 48 hr at 30°C with/without MF exposure, then revertant colonies were scored. Each experiment was conducted five times.

Results. The effects of 2kHz(0.91mTrms), 20kHz(1.1mTrms) and 60kHz(0.11mTrms) MFs on gene conversion (Arg(-)H), the effect on mutagenesis by UV irradiation (Arg(-)L-UV), base pair substitution (Lys(-)) and survival (YPD) were investigated. The results showed all of the ratios of the colony number between exposed and unexposed control groups were in the range of 0.9 to 1.6. No statistically significant difference was found between exposed and unexposed control groups in all exposure conditions.

Conclusions. We conclude that the IF MF did not affect the gene conversion, point mutation, mutagenesis by UV irradiation and cell survival in a model eukaryotic cell under the present experimental conditions.

Acknowledgements. The authors wish to thank Ms. Shiori Takai and Ms. Rie Sasaki for their technical supports.

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**P-67 ENHANCEMENT OF CYTOKINE-MEDIATED β-CELL DYSFUNCTION BY EXTREMELY LOW FREQUENCY MAGNETIC FIELDS**

Tomonori Sakurai\(^1\), Miwa Yoshimoto\(^1\), Shin Koyama\(^2\), Hitomi Ohtani\(^1\), Junji Miyakoshi\(^1\)
\(^1\)Hirosaki University, Hirosaki, Japan \(^2\)Kyoto University, Kyoto, Japan

Objectives. Cytokine-mediated β-cell dysfunction is crucial in type 1 diabetes. Inflammatory cytokines such as interleukin-1β (IL-1β) and interferon-γ (INF-γ) initiate a variety of signal cascades in β-cells that lead to β-cell dysfunction and destruction. There have been no reports studying the effects of extremely low frequency magnetic fields (ELFMFs) on cytokine-mediated β-cell dysfunction. The objective of this investigation was to evaluate the effects of ELFMFs on cytokine-mediated β-cell dysfunction.

Methods. RINm5F cells were seeded at a density of 5×10^4 cells/cm^2, and cultured in RPMI 1640 supplemented with 10% fetal bovine serum. RINm5F cells were then stimulated by IL-1β (50 U/ml) and INF-γ (100 U/ml) under exposure to ELFMF or sham-exposure conditions for 3 days, using our established system for the exposure of cultured cells to ELFMF (a sinusoidal vertical magnetic field at a frequency of 60 Hz and a magnetic flux density of 5 mT). Three different conditions of exposure to ELFMF were performed. Three conditions were as follows: 3 consecutive days of continuous exposure to ELFMF (condition 1), 2 consecutive days of continuous exposure to ELFMF starting with cytokine stimulation
(condition 2), and 2 consecutive days of continuous exposure to ELFMF starting 1 day after cytokine stimulation (condition 3). The effects of exposure to ELFMF were evaluated by measuring cellular insulin content and cell viability. To measure cellular insulin content, cells were treated with acidic ethanol solution for extracting cellular insulin. Insulin concentration in the extract was measured by enzyme linked immunosorbent assay (ELISA). Data were standardized to the total protein content in the extracts, which was measured by the DC protein assay kit (BioRad). Cell viability was determined by WST-1 cell proliferation assay, which is based on evaluating cellular mitochondrial activity.

**Results.** Cytokine stimulation for 3 consecutive days resulted in β-cell dysfunction. Cellular insulin content and cell viability were decreased by 46% and 58% in sham-exposure conditions, respectively. Three days of continuous exposure to ELFMF enhanced β-cell dysfunction. The decrease in cellular insulin content and cell viability was observed as compared to sham exposure (Figures 1 and 2, sham vs ELFMF-condition 1). Two days of continuous exposure to ELFMF did not affect cytokine-mediated β-cell dysfunction in regardless of starting on 0 or 1 day after cytokine stimulation (Figures 1 and 2, sham vs ELFMF-condition 2 or 3).

**Conclusions.** Our results suggested that the exposure to ELFMF at 60 Hz and 5 mT enhanced cytokine activity related to β-cell dysfunction.

![Figure 1](image.png)

**Figure 1.** The effects of exposure to ELFMF on cytokine-mediated decrease in cellular insulin content. Data are shown relative to cytokine (-)-sham exposure conditions (control), and presented as the mean ± SD. * $P < 0.05$ to cytokine (+)-same ELFMF-exposure condition. ** $P < 0.05$ to cytokine (-)-sham exposure conditions.
Figure 2. The effects of exposure to ELFMF on cytokine-mediated decrease in cell viability. Data are shown relative to cytokine (-)-sham exposure conditions (control), and presented as the mean ± SD. * $P < 0.05$ to cytokine (+)-same ELFMF-exposure condition. ** $P < 0.05$ to cytokine (-)-sham exposure conditions.

**P-68 EFFECT OF EXTREMELY LOW FREQUENCY MAGNETIC FIELDS ON ANTICANCER DRUG POTENCY**

Makiko Kakikawa, Shoushin Hashimoto, Masayoshi Iwahara, Sotoshi Yamada
Kanazawa University, Kanazawa, Japan

Objectives. In epidemiological research on the biological effects of magnetic fields, other factors (sunlight, food, temperature and medicine etc.) of humans have been included. On the other hand, the effects of only magnetic fields have been measured by experimental research using animals and cells.

We experimented about the combined effect of magnetic fields and medicine, and found out the tendency for magnetic fields to strengthen the DNA damage action of anticancer drug. Since magnetic fields can act on a target region by non-contact, it is thought that it becomes possible to make medicine locally effective by using it together. If magnetic fields exposure can enhance the potency of an antitumor drug only to the affected part, it may become possible to reduce amount of the drug and side effects and the medical application of magnetic fields can be expected. Objective of this study is to clarify combined use effect of magnetic fields and anticancer drugs. In this report, we investigated effects of 60 Hz magnetic fields on anticancer drug potency.
Methods. Anticancer drug, mitomycin C (MMC) was used in this study. MMC damages DNA and inhibits the DNA replication and cell growth. Measurement of effects of magnetic fields was performed by the experiment system using the E.coli bacterium and bacteriophage λ in which measurement sensitivity is good and the analyses in molecular level are also easy. The bacteriophage λ can multiply by either a lytic or a lysogenic pathway in the E.coli bacterium. When the bacteriophage λ is growing in the lysogenic state, a damage to cell (eg. DNA damage by exposure UV or MMC) causes the integrated viral DNA (prophage) to exit from the host chromosome and the pathway is shifted from lysogenic to lytic growth, regarded as bacteriophage induction. The bacteriophage λ was used as sensor of DNA damage in the cell. The cells, W3110 λ cl-857 which have λ prophage was co-exposed to MMC (10 µg/ml) and magnetic fields (1 to 100 mT at 60 Hz) and then the number of lytic growth phage (DNA damage rate) were measured by plaque assay. The coils were excited and generated magnetic fields at 60 Hz up to 100 mT by magnetic fields generator. The magnetic fields in the experimental area were uniform of 1%. To avoid the influence of the heat generated by the coil, the temperature change in experimental area was controlled within 0.1 degrees C by water’s circulating with the constant temperature device.

Results. Fig.1 shows effects of 60 Hz, 100 mT magnetic fields on MMC potency. By combined use of MMC and 100 mT magnetic fields for 3.5 to 5 hours, the bacteriophages shifted to lytic growth and induced phage titer was increased 1.5 times compared with MMC only. That is, DNA damage rates in bacterial cells treated with MMC were increased 1.5 times by exposure to magnetic fields. By co-exposure of MMC and 20 mT or 50 mT magnetic fields for 5 hours, DNA damage rate in bacterial cells were also increased 2 times compared with MMC only.

Conclusions. These results suggest that 60 Hz magnetic fields exposure strengthen the DNA damage action of MMC. However, it is not clear how the magnetic fields enhance the potency of anticancer drug. Further studies on effects of magnetic fields on other anticancer drug potency and molecular mechanisms of effect of magnetic fields on anticancer drug potency are now in progress.
P-69 LONG-TERM CONDITIONS OF LARGE-SCALE IN VITRO EXPERIMENT SYSTEM FOR 2 GHZ EXPOSURE

Takahiro Iyama\textsuperscript{1}, Teruo Onishi\textsuperscript{1}, Hidetoshi Ebara\textsuperscript{1}, Hideki Hirose\textsuperscript{2}, Hiroshi Takeda\textsuperscript{2}, Masaru Sekijima\textsuperscript{2}, Toshio Nojima\textsuperscript{3}, Junji Miyakoshi\textsuperscript{4}
\textsuperscript{1}NTT DoCoMo, Inc., Yokosuka, Japan \textsuperscript{2}Mitsubishi Chemical Safety Institute Ltd., Kamisu, Japan \textsuperscript{3}Hokkaido University, Sapporo, Japan \textsuperscript{4}Hirosaki University, Hirosaki, Japan

**Objectives.** We developed a beam-formed RF (Radiofrequency) -exposure-incubator employing a horn antenna, a dielectric lens, and a culture case in an anechoic chamber for large-scale \textit{in vitro} studies as shown in Fig. 1 \cite{1}. The combination of an open type RF exposure source operating at 2142.5 MHz and a culture case through which RF is transmitted realizes a uniform electric field (±1.5 dB) in a 300×300 mm area that accommodates 49 35-mm diameter Petri dishes. This large culture dish area enables simultaneous RF exposure of a large number of cells or various cell lines. The experiment system comprises two identical RF-exposure-incubators, one for RF exposure and the other for sham exposure, and the air circulator that provides identical air to the culture rooms. Using two sets of this system (four RF-exposure-incubators in all), a part of our group conducted \textit{in vitro} studies over five years \cite{2}-\cite{5}. The objectives of this paper are to validate long-term RF exposure condition as well as culture conditions including temperature, CO\textsubscript{2} density, and humidity, and to confirm the comparability of cell growth between the culture rooms.

**Methods.** The RF power provided to the exposure source is monitored using a bi-directional coupler and a power meter. The sensing element of a fiberoptics thermometer, which is unaffected by RF, is inserted in each culture room to monitor the temperature.

**Figure 1.** Effects of 60 Hz, 100 mT Magnetic fields on MMC Potency
The CO₂ density in the air circulator and the humidity in the culture rooms are also monitored. After 72 hours of growth in RF-exposure-incubators, the A172 and H4 cell lines are counted.

**Results.** Assuming that the 49 35-mm diameter Petri dishes are simultaneously exposed to RF, the Finite-Difference Time-Domain calculation method was used to derive that the mean SAR (Specific Absorption Rate) and the standard deviation of the SAR distribution in the culture fluid at the bottom of the 49 dishes are 0.175 W/kg/W and 59%, respectively. At the bottom of inner 25 dishes, they are 0.138 W/kg/W and 47%, respectively. The monitored RF power guaranteed that the desired SAR in the culture fluid at the bottom of the Petri dishes was provided. Table I summarizes the temperature in the culture rooms and the CO₂ density in the air circulator for 41 days, and shows that they were extremely stable. The humidity in the culture cases was checked before cell growth to confirm a level of higher than 90%. Table II summarizes the counts of cell lines after 72 hours of growth, and shows no statistically significant difference in each cell line.

**Conclusions.** The culture conditions of RF-exposure-incubators 1 and 2 were comparable to each other, as well as those of RF-exposure-incubators 3 and 4.

P-70 GENE EXPRESSION PROFILE ANALYSIS IN ELF MF EXPOSED MCF-7 CELLS

Guangdi Chen, Deqiang Lu, Huai Chiang, Zhengping Xu
Bioelectromagnetics Laboratory, Hangzhou, China

Objectives. We combined the commercial Genechip analysis system with quantitative real-time RT-PCR confirmation to explore the effects of low intensity 50 Hz MF on genome-wide gene expression in human breast cancer cells (MCF-7), with the intent to explore the biological effect of ELF MF on this organism and the underlying mechanism.

Methods. The MCF-7 cells were continuously exposed to 0.4 mT 50Hz MF for 24 hours. The total RNA from exposed or sham exposed cells was extracted by TRIzol and further purified using QIAGEN’s RNeasy mini Kit. Affymetrix Human Genome Genechip U133A Genechips including 22,000 genes (ESTs) were applied to analyze the effect of MF exposure on global gene expression. The data was analyzed with the Afymetrix Microarray Suite version 5.0 (MAS 5.0) and Affymetrix Data Mining Tool 3.0 (DMT 3.0). The differentially expressed genes screened by Genechip analysis were further examined by quantitative real-time RT-PCR.
Results. The MAS software analysis showed that the expression levels of more than 95% genes remained stable. The reproducible analysis with the DMT software identified 24 up-regulated and 6 down-regulated genes with 100% consistency change calls. These differentially expressed genes were assigned to seven different functional categories: i) signal transduction related genes (intercellular and intracellular); ii) biochemical metabolism related genes; iii) transcription factor related genes; iv) extracellular matrix protein genes; v) stress response related genes; vi) ion channel related genes, and vii) other function unknown genes.

However, most of the differentially expressed genes were not confirmed by the quantitative real-time RT-PCR analyses, indicating they were false positives.

Conclusions. The present study did not provide evidence that 0.4 mT 50 Hz MF could significantly change gene expression in MCF-7 cells.

Acknowledgements. This study was supported by the National Natural Science Foundation of China (No. 50137030), the Key Project of the Chinese Ministry of Education (No. 104092), the Excellent Young Teachers Program of MOE, P.R.C., the Science and Technology key project of Zhejiang (No. 021106135), and Zhejiang Provincial Natural Science Foundation (No. M303807).

*P-71 EFFECTS OF RADIOFREQUENCY FIELD FROM W-CDMA MOBILE RADIO BASE STATION ON CELL PROLIFERATION, DNA DAMAGE, AND GENE EXPRESSION.*

Masaru Sekijima¹, Hideki Hirose¹, Hiroshi Takeda¹, Noriko Sakuma¹, Naoko Kaji¹, Takeshi Suhara¹, Koji Nakayama¹, Toshio Nojima², Junji Miyakoshi³

¹Mitsubishi Chemical Safety Institute Ltd., Kamisu, Japan ²Hokkaido University, Sapporo, Japan ³Hirosaki University, Hirosaki, Japan

Objectives. It is important to examine the possibility of biological effects, and to obtain dependable data regarding 2-GHz band radiofrequency (RF) irradiation for deployment of the International Mobile Telecommunication 2000 (IMT-2000) cellular system. Therefore, we conducted a study that focused on a practical modulated signal for Wideband Code Division Multiple Access (W-CDMA) at 2.1425 GHz, which corresponds to the middle frequency allocated to the downlink band of IMT-2000 from mobile radio base stations. There are concerns that RF field exposure may alter cell function in a way that increases the risk of cancer. The objective was to assess the risk of cancer induced by RF fields which corresponds to the limit of the average whole body SAR for general public exposure defined as a basic restriction in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [1].
Methods. We used the large-scale in vitro exposure system with a horn antenna and dielectric lens in an anechoic chamber, which allows simultaneous exposure of 49 (7x7 array) 35 mm dishes [2]. In our studies, we performed the experiments accurately employing two pairs (exposure and sham) of this exposure system [3]. Human cell lines, A172 (glioblastoma), H4 (neuroglioma), IMR-90 (fibroblasts from fetal lungs), or CCD25SK (fibroblasts from skin) cells, were exposed to CW or W-CDMA RF fields at SAR of 80, 250 or 800 mW/kg to confirm the association between the cancer and the RF fields based on the cell proliferation kinetics, the change in the apoptotic cells number, the phosphorylation of p53 and hsp27, the change in gene expression profile, and the frequency of DNA damage. The numbers of viable cells were identified by trypan blue dye exclusion, and counting was done microscopically using a hemocytometer. Apoptosis was evaluated using the annexin V affinity assay. Induction of p53 and hsp27 protein, and their phosphorylation at each protein were detected using the bead based multiplex assay [4]. Real-time RT-PCR and microarray hybridization were used for analysis of gene expression in the cells exposed to RF fields. DNA damage was quantified immediately after RF-field exposures using three parameters (tail moment, comet length and tail length) for each comet.

Results. Under the experimental conditions tested, CW and W-CDMA 2-GHz RF field did not affect the cell proliferation. The results suggested that the exposure to RF field up to SAR of 800 mW/kg did not act as a cytotoxicant. No statistically significant difference was observed between any of the RF fields exposure groups and sham-exposed controls in the percentage of apoptotic cells, or the induction of p53 phosphorylation and p53-related gene expression [5]. The results confirm that exposure to RF fields up to SAR of 800 mW/kg does not induce p53-dependent apoptosis, DNA damage, or other stress responses in human cells. Phosphorylation and gene expression of hsp27 in human cells was not affected by exposure to the RF field [6]. The results suggest that exposure to W-CDMA and CW RF fields cannot be associated with cancer via induction of the heat shock response at up to SAR of 800 mW/kg. There is no evidence for induction of DNA single-strand breaks and alkali-labile lesions in the cells exposed to W-CDMA or CW 2-GHz RF field [7]. Low-level RF field exposures did not act as a genotoxicant at up to SAR of 800 mW/kg. In conclusion, these experimental results suggest that 2-GHz RF field from W-CDMA mobile radio base station cannot be associated with cancer at up to SAR of 800 mW/kg, which is 10 times higher than the limit of the average whole-body SAR level (80 mW/kg) according to the ICNIRP guidelines.

[7] Sakuma et al., 2006. DNA strand breaks are not induced in human cells exposed to 2.1425 GHz band CW and W-CDMA modulated radiofrequency fields allocated to mobile radio base stations. BEMS 27, 51-57.

Acknowledgements. All of the works were supported by NTT DoCoMo Inc.

P-72 EFFECT OF ELF ELECTROSTIMULATION ON ENDOCYTIC ACTIVITY OF MACROPHAGE

Muneyoshi Kagawa¹, Toshiyuki Shimooka², Koichi Shimizu¹
¹Hokkaido University, Sapporo, Japan ²Saitama Medical University, Hidaka, Japan

Objectives. If the electrostimulation due to the induced current in a body can influence immune reactions, we can control the immune function by the ELF-EMF exposure. With the view toward this application, we have studied the effects on the macrophage endocytic activity caused by capacitively coupled electrostimulation. To elucidate the mechanism of the effect, humoral factors were investigated.

Methods. A sample container was made of acrylic resin with two plane parallel copper electrodes. The electrode was insulated with a thin plate of glass for capacitively coupled electric field exposure. As the high-voltage power source, the power supply of a commercial apparatus for the electric field therapy was used (maximum supply voltage 10 kV).

For endocytosis assay, mouse peritoneal exudate macrophages (PEM’s) were prepared. The suspension of PEM (1.0-5.0×10⁶ cells/ml, RPMI 1640 with 10% FBS) was placed in the container and the electrostimulation was applied (sinusoidal waveform of 50 Hz, 0.35 A/m²).

After the stimulation, the supernatant was separated from PEM in centrifugation. In the supernatant, humoral factors to change the endocytosis was suspected, and the fluorescent latex beads were added. This case was tagged as sup.(E+). The PEM separated from the stimulated PEM solution were suspended in the culture solution (RPMI 1640) that has never experienced electrostimulation. This case was tagged as PEM(E+). Both solutions of sup.(E+) and PEM(E+) cases were kept in shaking bath of constant temperature (38 °C) and allowed the endocytosis in 30minutes(Fig.1). Then the PEM of both cases were washed in centrifugation, fixed with glutaraldehide and the fluorescent intensity was measured using a flow cytometer.

Results. Figure 2 shows the comparison of endocytic activity among the cases of sup.(E+), PEM(E+) and the sham. The abscissa is the cumulative relative frequency (CRF) of cell counts. The ordinate is the difference of fluorescent intensity at each cumulative frequency. The negative value of this difference corresponds to the suppression of the endocytic activity. The closed dot indicates the mean of difference of fluorescent intensity between the case
of sup.(E+) and sham case. The open dot indicates the mean of difference of fluorescent intensity between the case of PEM(E+) and sham case. The closed dots were negative in many cases. This suggested the endocytic activity was suppressed in the case of sup.(E+). The p-value of the paired-t test were $p<0.05$ at 5% of CRF and $p<0.01$ at 10-50% showing the statistical significance. This result shows the possibility that some humoral factor responsible for the suppression of the endocytosis is contained in the case of sup.(E+). However, the open dots were positive in many cases. This suggested the possibility of the slight increase in the endocytosis in the case of PEM(E+). The p-value of the paired-t test showed the significant difference of $p<0.05$ at 10, 20, 30 and 40% of CRF. This result suggests the possibility of the enhanced endocytosis in the PEM separated after the electrostimulation.

**Conclusions.** With the view toward the control of immune functions by ELF electrostimulation, the effect of the electro-stimulation on the endocytic activity caused by humoral factor was examined in vitro. The decrease of endocytosis due to the electrostimulation was observed with statistical significance. Further investigation is required to ascertain this mechanism of change of endocytic activity and to verify the feasibility of the immune control by electrostimulation.

![Figure 1](image-url)
P-73 EFFECTS OF A TIME-VARYING MAGNETIC FIELD ON CELL VOLUME REGULATION OF CULTURED BOVINE ADRENAL CHROMAFFIN CELLS

Toshitaka Ikehara¹, Yuki Minami², Naoko Shiota², Hisao Yamaguchi³, Masayuki Shono¹, Mitsuo Kitamura¹, Kazuyoshi Kawazoe², Kazuo Minakuchi², Kazuo Yoshizaki¹, Yohsuke Kinouchi¹, Hiroshi Miyamoto¹

¹Institute of Health Biosciences, The University of Tokushima Graduate School, Tokushima, Japan ²Tokushima University Hospital, Tokushima, Japan ³Faculty of Human Life Sciences, Tokushima Bunri University, Tokushima, Japan ⁴Institute of Technology and Science, The University of Tokushima Graduate School, Tokushima, Japan

Objectives. We have recently found that a time-varying magnetic field affected intracellular actin filaments of adrenal chromaffin cells. In this study, we tried to confirm functions of actin filaments during cell volume regulation and investigated the effects of the magnetic field on the functions of actin in chromaffin cells.

Methods. Bovine adrenal chromaffin cells were plated on 35-mm culture dishes or cover glasses placed in the same culture dishes. After the cells were attached to the dishes or cover glasses, maintained for 2-5 days in CO₂ incubator. After the cells were exposed to a time-varying magnetic field (varied intermittently from 0.07 to 1.5 T at an interval of 3 sec) for 2 hr, the culture medium were replaced with hyposmotic media. Fura 2 and calcein were
used for measurements of the concentration of intracellular Ca\(^{2+}\) ([Ca\(^{2+}\)]_i) and cell volume, respectively. Cellular F-actin was determined by actin phalloidin staining.

**Results.** When the cells were incubated in hyposmotic medium, the cell volume was sharply increased and then decreased with time. Exposure to the magnetic field increased the initial peak value and delayed the recovery to the normal value. Preincubation of cytochalasin D indicated the same volume changes as 2 hr-exposed cells. Cellular F-actin was decreased and G-actin was increased by the exposure or addition of cytochalasin D. Replacing with the hyposmotic media caused transient decrease in cellular F-actin and then the content was increased instantly to the normal value within 30 sec in control cells. But, in exposed cells increase in F-actin content to normal level was delayed. These results suggested that the exposure influenced actin polymerization or depolymerization.

**Conclusions.** Exposure to the time-varying magnetic field affects distribution of F-actin fibers and its content in cytoplasm of chromaffin cells. These data are suggested that exposure to the time-varying magnetic field influence the volume regulation by affecting actin polymerization or depolymerization.

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**P-74 EFFECT OF ELECTRICAL STIMULATION ON NEURAL STEM CELL GROWTH AND DIFFERENTIATION**

Carlos A. Ariza
Iowa State University, Ames, IA, USA

**Objectives.** To successfully apply stem cells therapeutically to treat nervous system injuries and neurodegenerative diseases, control of stem cell growth and differentiation is necessary. Individual cues present in vivo which contribute to changes in stem cell behavior are best discovered and studied in vitro. The aim of this research is to characterization effects of electromagnetic, static magnetic, and electric field stimulation on neural progenitor cell growth and differentiation.

**Methods.** Adult hippocampal neural progenitor from rats and humans are used in these experiments. Electromagnetic stimulation is applied using a solenoid. The magnetic field created by the solenoid reaches a maximum of 1.3 Tesla. Static magnetic fields are applied using permanent magnets. Two methods of electric field stimulation are used. The first method uses platinum electrodes and the second uses agar salt bridges in addition to Ag/AgCl electrodes to set up a electric field within the media. We are investigating the amount of differentiation that is produced with different amplitudes. We aim to find the characteristics of an electrical stimulus that induces the greatest amount of differentiation.
Once "optimal" stimulation properties have been obtained, they will be applied to stimulate neural progenitor cells locally using a microelectrode array. We designed and fabricated the microelectrode array with the ability to combine electrical cues with chemical, physical and biological cues and investigate the effect of these cues on neural stem cells. The device allows for selective stimulation of individual cells present in microgrooves that physically confine the cells. The effect of neural stem cell growth and differentiation in response to the combination of electrical and topographical/chemical/biological cues will be investigated.

**Results.** Agar salt bridge set up was detrimental to neural progenitor cell health for long term studies (1 week) and the use of this set up was discontinued in these experiments. Electromagnetic stimulation has shown to increase the amount of cell differentiation.

**Conclusions.** The use of electrical stimulation in combination with other cues that guide differentiation will be useful in the development of stem cell based therapies.

**Acknowledgements.** Dr. Surya Mallapragada, Dr. Gary Tuttle, Dr. Don Sakaguchi, Dr. James Bloedel, Undergraduate Research Assistants: Aaron Seitz and Josh Bird, Funding: NIH and NSF-AGEP

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*P-75* EXTREMELY LOW FREQUENCY (ELF) MAGNETIC FIELDS INCREASE HYDROGEN PEROXIDE-INDUCED MUTATIONS IN PTN89 PLASMIDS

Shin Koyama¹, Tomonori Sakurai², Takehisa Nakahara², Junji Miyakoshi²

¹Graduate School of Human and Environmental Studies, Kyoto University, Kyoto, Japan
²Faculty of Medicine, Hirosaki University, Hirosaki, Japan

**Objectives.** In recent years increasing urbanization has led to increased exposure to extremely low frequency (ELF) magnetic fields, which may be induced by many different electrical appliances, by power lines, and by other sources. Since Wertheimer and Leeper (1979) suggested a correlation between exposure to ELF magnetic fields and childhood leukemia, there has been increasing concern regarding the effects of ELF magnetic fields on human health. Many experiments have been performed in an attempt to clarify these effects, but contradictions still remain. In the current study, for reasons of simplicity we used *Escherichia coli* (E. coli) and pTN89 plasmids to evaluate the direct and indirect effects of ELF magnetic fields on DNA. We detected mutations that occurred in the supF gene carried by pTN89 plasmids in *E. coli* to examine the effects of ELF magnetic fields and/or Hydrogen peroxide (H₂O₂) to the plasmids. This *E. coli* system was developed by Obata et al (1998) and can detect a mutation at the single base level in the supF gene.
**Methods.** The plasmid DNAs were treated with H$_2$O$_2$ with or without exposure to ELF magnetic fields and then transformed in *E. coli*. The mutated plasmids were propagated and subsequently extracted, and a sequence analysis was performed. The mutation frequency caused by treatment with H$_2$O$_2$+ELF exposure was compared to that caused by treatment with H$_2$O$_2$ alone, and was found to increase with the combined treatment.

**Results.** The mutation frequencies of the pTN89 plasmids carrying the *supF* gene treated with H$_2$O$_2$ alone and H$_2$O$_2$+ELF exposure were $2.28 \times 10^{-4}$ and $5.81 \times 10^{-4}$, respectively (Fig. 1). Hence, the mutation frequency for plasmids treated with H$_2$O$_2$+ELF exposure was about 2.5-fold higher than that for treatment with H$_2$O$_2$ alone. There was a statistically significant difference ($p<0.01$) between the mutation frequencies for the two treatments, as determined by a Student-t-test. No mutant colonies were detected with ELF-exposure alone, or in the sham control. Following both treatments, the majority of changes were single base pair substitutions. Double base pair substitutions occurred in two mutants with H$_2$O$_2$ alone and in three mutants with H$_2$O$_2$+ELF exposure. The other mutations that occurred in the *supF* gene were single base deletions. G:C→A:T transitions and G:C→T:A and G:C→C:G transversions were identified with G:C→T:A transversions being slightly increased with H$_2$O$_2$+ELF treatment, compared to treatment with H$_2$O$_2$ alone. Base substitutions occurred only at G:C sites. All frameshifts were due to single base −C or −G deletions. Frameshifts due to a −C deletion were detected at position 172~176 for both treatments, and a −G frameshift occurred at position 102~105 with H$_2$O$_2$ alone. The number of frameshifts increased slightly with H$_2$O$_2$+ELF exposure, compared to treatment with H$_2$O$_2$ alone. Several mutational hotspots were apparent (160, 168 and 169) and the mutated sites were similar for both treatments.

**Conclusions.** We could not detect direct effects of ELF magnetic fields on DNA, but exposure to ELF magnetic fields with H$_2$O$_2$ may enhance the mutations.
Figure 1. Mutation frequency in the supF gene caused by treatment with H₂O₂ and H₂O₂+ELF exposure. The supF gene was replicated in E.coli. KS40/pOF105 cells. Columns represent the means and bars represent the standard deviation from experiments that were replicated six times. The asterisk represents a statistically significant difference (p<0.01) between the treatment with H₂O₂ and that with H₂O₂+ELF exposure using Student-t-test.

* P-76 MAGNETIC FIELDS GENERATED BY AN INDUCTION HEATING (IH) COOKER DO NOT CAUSE GENOTOXICITY IN VITRO

Junji Miyakoshi, Takehisa Nakahara, Tomonori Sakurai
Hirosaki University, Hirosaki, Japan

Objectives. Replacement of gas and electric cookers with induction heating (IH) cookers has become popular in Japan and Europe. IH cookers generate intermediate frequency (IF) magnetic fields of 20 to 90 kHz from heating coils, with induction of currents in metal pans that cause heating of the pans. Evaluation of potential carcinogenesis at the cellular level requires assessment of cellular genotoxicity associated with IF magnetic fields. In the present
study we focused on evaluation of cell growth, bacterial mutation, micronucleus formation, DNA strand breaks and HPRT gene mutation, using an IF magnetic field-exposure unit with a built-in CO₂ incubator.

**Methods.** The experimental system for IF magnetic field exposure supplies ELF electric power (100V, 50 Hz) to an IH cooker and supplies IF electric power (23 kHz) to a magnetic field-generating coil in an incubator via an electronic circuit inside the IH cooker. The magnetic field generation level of the system was set to 532 $\mu$T$_{rms}$ with spatial field uniformity of less than 3.8%. The temperature of the medium in the dishes was maintained at all times during the experiment and was maintained at 36.5±0.5 °C.

For routine Ames testing, strains of Salmonella typhimurium (TA98, TA100 and TA1537) and *Escherichia coli* (WP2 uvrA and WP2 uvrA pKM101) were used. For micronucleus (MN) formation and comet assay, Chinese hamster ovary (CHO)-K1 cells were used. These methods were done as described elsewhere (Koyama et al., 2004, Koyama et al., 2003, Miyakoshi et al., 2002, Miyakoshi et al., 2000). For the mutation analysis, the HPRT gene-mutation assay, which is a well-established method based on selection of clones that are resistant to purine analogs such as 6-thioguanine (6-TG), has been done. Details of the HPRT gene mutation assay have been described elsewhere (Ding et al., 2001, Ding et al., 2000).

**Results.** Exposure to the IF magnetic field at 532 $\mu$T for 2 hours did not affect the growth of CHO-K1 cells and caused no mutagenic effects in bacterial mutation assays (Figure 1). Exposure to the IF magnetic field for 2 hours induced neither single nor double DNA strand breaks in comet assays, and caused no significant change in the mutation frequency at the HPRT locus compared to sham exposure (Figure 2).

**Conclusions.** These results suggest that exposure to an IF magnetic field for 2 hours does not cause cellular genotoxocities, such as mutation and DNA strand breaks. However, the possibility of effects on other cellular functions remains, and further studies on the cellular effects of IF magnetic fields are required.

**References:**
Figure 1. Results from bacterial mutagenicity tests in cells exposed to the IF magnetic field, using the plate incubation method for five bacterial strains: (a) *S. typhimurium* TA98, (b) TA100, (c) TA1535, (d) *E. coli* WP2 *uvrA*, and (e) WP2 *uvrA* pkM101. Data represent means with standard deviation from at least three independent tests with at least triplicate plates.
**Figure 2.** 6-TG$^r$ mutation frequency in V-79 cells exposed to an IF magnetic field at 532 $\mu$T for 2 hours, sham exposed, or treated with EMS (0.2 $\mu$g/ml). Data represent means with standard errors from three separate experiments. *p$\leq$0.0001, compared with sham and IF-field exposure.
**P-77 EFFECTS OF EXPOSURE TO ELF EF IN HEK CELL TRANSFECTED WITH CALCIUM RECEPTOR**

Shinji Harakawa\(^1,3\), Susan Anderson\(^2\), Noboru Inoue\(^3\), Jacqueline Nearing\(^2\), Marlies Betka\(^2\), William Harris\(^2\)

\(^1\)Hakuju Institute for Health Science, Tokyo, Japan \(^2\)MariCal Inc., Portland, ME, USA \(^3\)Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Japan

**Objectives.** In order to study if CaR could be one of molecule target of EF effects, the present studies have comparing changes in apparent \([\text{Ca}^{2+}]_c\) as measured by FURA2 imaging in untransfected vs. CaR-transfected HEK cells after sham control vs. EF treatment.

**Methods.** HEK cells were stably transfected with human parathyroid calcium receptor (HuPCaR cells) and responses to alterations in extracellular Ca\(^{2+}\) were quantified by using FURA2/AM based assay as described. The HuPCaR on the membrane surface and are responsive to addition of CaR agonists to the external medium. Cell suspensions consisting of a total volume of 3 ml were analyzed in a PTI fluorimeter within approximately 20 min after exposure to experimental buffers. Selected aliquots were exposed to EF at the various conditions of field. Subsequent to either EF exposure or sham control treatments, aliquots of cells were used for standard ratio imaging fluorimeter analysis to measure changes in \([\text{Ca}^{2+}]_c\). Aliquots of cell suspensions were placed in EF device and either exposed to a single 10 min EF interval or treated as a sham control, eg., at frequency of 60 Hz and intensity of 6, 60 or 600 mA/m\(^2\). Samples were then analyzed within 15 min after completion of EF exposure. Data was acquired using standard ratio image analysis using a data acquisition rate of 1.3 sec. for 500 or 1000 sec intervals. At least 1 aliquot of a group of cells was not exposed to EF and was designated as the non-EF treated control. This non-EF control was analyzed identically as EF treated samples in order to provide an “internal standard” for FURA-2 values.

**Results.** After the stimulating cells with additions of CaCl\(_2\), the ionomycin is added in selected experiments to obtain a maximal FURA2 signal from increases in \([\text{Ca}^{2+}]_c\). In contrast to the response displayed by HuPCaR cells, HEK cells do not display rapid changes in their \([\text{Ca}^{2+}]_c\) after additions of extracellular Ca\(^{2+}\). The Bonferroni post hock tests appeared no differences in comparison among used conditions of EF intensity in each typed cell. In comparison between HuPCaR cell and HEK cell, all normalized values in HuPCaR cells exposed to various intensity EF were higher than those of EF intensity matched HEK cells (P< 0.01 at 6 mA/m\(^2\); P<0.005 at 60 mA/m\(^2\); P<0.01 at 600 mA/m\(^2\)).

**Conclusions.** The studies described below here directly implicate the G-protein coupled receptor family of CaRs as molecular targets for EF effects in cells. These data are consistent with recent publications (Stanfield, P. Nature 8:1323-1325, 2006) which suggest that G-protein coupled receptors are affected by the voltage across the membrane in which they sit. Our data are the first to directly link observations of the effects on EF on \([\text{Ca}^{2+}]_c\)
to a protein that "senses" extracellular Ca2+ concentrations in cells that express CaRs. Further studies will be required to determine the exact nature of these EF-based molecular interactions.

**P-78 RADIO FREQUENCY RADIATION DO NOT AFFECT CELL CYCLE, MIGRATION, AND INVASION**

Joong-Won Lee¹, Hee-Jin Kwak¹, Yun-Mi Lee¹, Je-Jung Lee¹, Myung-Jin Park¹, Hyung-Do Choi², Nam Kim³, Jeong-Ki Pack⁴, Seok-Il Hong¹, Jae-Seon Lee¹

¹Radiological & Medical Research Center, Seoul, South Korea ²Electronics and Telecommunications Research Institute, Daejeon, South Korea ³Chungbuk National University, Cheongju, South Korea ⁴Chungnam National University, Daejeon, South Korea

**Objectives.** Although the in vitro studies were conducted to elucidate biological effect of radio frequency (RF) radiation, it has not been concluded yet if RF radiation has a potential hazard or not. The objective of this study was to investigate whether RF radiation exposure had effects on cell cycle distribution, cellular invasion, and migration.

**Methods.** NIH3T3 mouse fibroblast cells were exposed to 849 MHz RF radiation at SAR values of 2 or 20 W/kg for either 1 h or 1 h per day for 3 days. During exposure, the temperature in the chamber was maintained isothermally by circulating water within the cavity. After exposure, the cells were immediately transferred to a cell culture incubator for the indicated time for cell cycle assay, or seeded for invasion and migration assay and then transfer to a cell culture incubator. Cell cycle distribution was analyzed with Flow cytometry. Cellular invasion and migration were analyzed with in vitro Matrigel invasion and Transwell migration assays.

**Results.** Cell cycle distribution was analyzed at 24 h and 48 h after exposure (SAR values: 2 or 20 W/kg, exposure duration: 1 hr or 1 hr per day for 3 days). There was no statistically significant difference between sham-exposed and RF radiation-exposed cells. When cells were analyzed their motility and invasiveness under the same exposure conditions as cell cycle analysis, RF radiation-exposed group did not show any significant change comparing with sham-exposed groups. Whereas, ionizing radiation-exposed cells as positive control group showed dramatic alteration in their cell cycle distribution, cellular invasion, and migration.

**Conclusions.** RF radiation exposure did not affect cell cycle distribution, cellular migration, and invasion.
**Acknowledgements.** This work was supported by research fund from The Ministry of Information and Communication of Korea (2006-P20-60)

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**P-79 PROTEOMIC ANALYSIS OF MOBILE PHONE RADIATION-EXPOSED MCF7 BREAST CANCER CELLS**

Ki-Bum Kim¹, Na-Kyung Han¹, Hyung-Do Choi², Nam Kim³, Jeong-Ki Pack⁴, Seok-Il Hong¹, Jae-Seon Lee¹

¹Korea Institute of Radiological and Medical Sciences, Seoul, South Korea ²Electronics and Telecommunications Research Institute, Daejeon, South Korea ³Chungbuk National University, Cheongju, South Korea ⁴Chungnam National University, Daejeon, South Korea

**Objectives.** According as the use of mobile phones has been exponentially increased nowadays, public concerns regarding potential harmful effect of radio frequency (RF) radiation emitted from the mobile devices are also growing. However, recent studies about biological effect of mobile phone radiation are somehow conflicting. To elucidate biological effect of RF radiation, if any, we monitored the change of protein expression profile in MCF7 human breast cancer cells which were exposed to RF radiation, using two dimensional electrophoresis.

**Methods.** MCF7 cells were exposed to either 2 W/Kg or 10 W/kg of average SAR value of 849 MHz RF radiation for either 1 h or 1 h per day for three days. During exposure, the temperature in the exposure chamber was isothermally maintained by circulating water within the cavity. Twenty-four hours after RF exposure, whole cell lysates from MCF cells were prepared and conducted the isoelectric focusing on a linear wide-range immobilized pH gradient (pH 3 - 10; 24 cm-long immobilized pH gradient [IPG] strips) with a total focusing time of 81,780 Vhr, using the IPGphor system in accordance with the manufacturer’s instructions (Amersham Biosciences, Piscataway, NJ). The second dimension was performed on lab-made SDS-PAGE gels (11% polyacrylamide, 0.26% 1,4-Bis(acryloyl)piperazine (PDA) / 25.5 cm X 19.6 cm X 1 mm), under constant current, in three steps (Step 1: 5 w/gel; Step2: 10 w/gel; Step 3: 15 w/gel), using an Ettandalt 6 system (Amersham Biosciences). The analytical gels were stained and visualized by silver nitrate.

**Results.** Protein expression profile of MCF cells was not significantly changed due to exposure to 2 W/kg or 10 W/kg average SAR value of RF radiation for 1 h. The change in protein expression profile was negligible in spot distribution, number, and density. Although some minor spot changes were found in repeated experiments, none of them showed reproducible change. Multiple exposure groups (exposure condition: 1 h per day for 3 days, average SAR value: 2 W/kg or 10 W/kg) also showed no reproducible alteration in protein expression.
profile comparing to sham-exposed groups. In contrast, ionizing radiation-exposed MCF7 cells showed dramatic changes in their protein expression profile.

**Conclusions.** We could not observe any significant and reproducible change of protein expression profile in RF radiation-exposed MCF7 cells. Therefore, there might be little possibility that RF exposure modulate cellular function via change of protein expression profile.

**Acknowledgements.** This work was supported by research fund from The Ministry of Information and Communication of Korea (2006-P20-60).

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**P-80 EFFECTS OF EXTREMELY LOW FREQUENCY MAGNETIC FIELDS ON OSTEOCLASTS AND OSTEOBLASTS: DEVELOPMENT OF A NEW MODEL SYSTEM USING FISH SCALE**

Makiko Kakikawa\(^1\), Yuta Oda\(^1\), Satoshi Sunata\(^1\), Nobuo Suzuki\(^1\), Kei-ichiro Kitamura\(^1\), Atsuhiko Hattori\(^2\), Masakazu Iwasaka\(^3\), Shoogo Ueno\(^4\), Sotoshi Yamada\(^1\)

\(^1\)Kanazawa University, Kanazawa, Japan  \(^2\)Tokyo Medical and Dental University, Ichikawa, Japan  \(^3\)Chiba University, Chiba, Japan  \(^4\)Kyushu University, Hukuoka, Japan

**Objectives.** It is well known that magnetic fields enhance bone formation. However, basic data concerning its mechanism is a few because no good model system of human bone is available. Human bone consists of osteoblasts, osteoclasts, and bone matrix. Bone matrix such as hydroxyapatite and type I collagen is an important function in the response to physical stress. Few technique for the co-culture of osteoclasts and osteoblasts including bone matrix has been developed yet. The fish scale is a calcified tissue that contains osteoclasts, osteoblasts, and bone matrix similar to those found in human bone. Therefore, we recently developed a new in vitro assay system using the fish scale, and then examined the effects of extremely low frequency (ELF) magnetic fields on bone metabolism in the present study.

**Methods.** Goldfish (female, n=40) were anesthetized with ethyl 3-aminobenzoate, methanesulfonyl acid salt (MS-222, Aldrich Chemical Company Inc.), and scales in the both side of the body were then removed. Thereafter, the scales were put into a 1.5 ml micro tube to which 700 \(\mu\)l of Eagle’s minimum essential medium (ICN Biomedicals, Inc.) containing HEPES (Research Organics Inc.) (20 mM, pH 7.0) and 1% penicillin-streptomycin mixture (ICN Biomedicals, Inc.) was added. The scales were exposed at 15 degrees C under ELF magnetic fields (3, 5, 10 and 30 mT at 60 Hz) for 24 hours. The one direction coil of orthogonal oriented was excited and generated the magnetic field of a constant frequency (60 Hz) by a magnetic field germinator. After exposure, these scales were fixed in 10 % formalin in a 0.05 M cacodylate buffer (pH 7.4) and then kept in a 0.05 M cacodylate buffer at 4 degrees C until analysis. The measurements of TRAP and ALP activities were described.
in previous report (Suzuki and Hattori, J. Pineal Res., 33:253-258, 2002). TRAP and ALP activities of culture media were also measured.

**Results.** Osteoclastic activity decreased by exposure to 3 mT magnetic fields at 60 Hz during 24 hours. Also, TRAP activity in the medium significantly decreased. Osteoblastic activity did not change. However, ALP activity in the medium increased. This suggests that osteoblastic activity was tendency of increase by exposure to 3 mT magnetic fields. In the 5 mT exposure as well as 3 mT exposure, osteoclastic and osteoblastic activities changed similarly (Table 1).

By the treatment of 10 and 30 mT, both osteoclastic and osteoblastic activities increased at 24 hours exposure (Table 1). The interaction between osteoclasts and osteoblasts has been recently noted in mammals because it is necessary to differentiate them. In addition, the receptor activator of NF-κB (RANK) and the receptor activator of the NF-κB ligand (RANKL) have been identified in osteoclasts and osteoblasts, respectively. It was found that osteoclasts were activated by binding RANKL to RANK, and then mature osteoclast of multi-nucleolus type were induced. In the scale, therefore, we presume that RANK-RANKL system exists and induces activation of osteoclasts.

**Conclusions.** 1)Our in vitro assay system is useful for analysis of bone metabolism by magnetic fields.
2)Osteoclasts are more sensitive to ELF magnetic fields than osteoblasts.

**P-81 LEARNING BEHAVIORS OF THE NEMATODE C. ELEGANS EXPOSED TO ELECTRIC MAGNETIC FIELDS ARE GREATLY AFFECTED**

Makiko Kakikawa¹, Syuichi Maeda¹, Ryuji Hosono², Sotoshi Yamada¹
¹Kanazawa Univ, Kanazawa, Japan ²Kanazawa Univ, Kanazawa, Japan

**Objectives.** Highly advanced electro technological equipment has given rise to previously unexperienced environments in which strong electromagnetic fields are encountered. Although the biological effects of extremely low frequency magnetic fields have been well studied, assessments remain contradictory. Therefore, we have tested effect of EMFs on development, gene expression and behaviors with the nematode Caenorhabditis elegans. C. elegans is very desirable for inquiring into effect of EMFs on organisms, because its vital function has been clarified enough. We strongly hope to focus our research activity to the relationship between EMFs and learning system.

**Methods.** Usually the nematode C. elegans was grown at 20 degrees as described by Brenner (1974) with E. coli OP50 as food source. Behavioral assays were performed with young adults. For chemotaxis to diacetyl, animals were placed at one end of the plate and one µl of diacetyl at the opposite end of the plate. Maze assay was performed as described by Brockie et al., (2001). To record Electropharyngeograms (EPGs), Animals were placed in a
bath containing 10 mM serotonin to stimulate pumping. EPGs were recorded as described by Avery et al., (1995). To test the lacZ activity, transgenic animals were exposed to EMFs, lyophilized, treated by acetone and incubated in X-gal overnight (Fire et al., 1990, 1991). The apparatus for generation of EMFs consists of two E type cores. A peak flux density of 0.5 T was generated by 100 A current. Temperature of the apparatus was kept constant by cooled water.

Results. We firstly studied influence of EMFs on life-cycle of C. elegans including reproductive system, embryonic and post-embryonic development. We found that these phenotypes are slightly affected. We then examined influence of EMFs on expression of hsp-16-lacZ as a model system of gene expression. We found that expression of the hsp-16-lacZ gene was enhanced when transgenic animals were exposed to magnetic fields. The hsp-16 promoter was more efficiently expressed at the embryonic stage than at the post-embryonic stage irrespective of exposure. Promoter activity was more sensitive to the stimulus in the intestine at the post-embryonic stage. However, we could not detect significant impairment on DNA synthesis, transcription, or DNA repair, using in vitro model systems with defined sequences. We are especially interested in influence of EMFs on neural integration. We therefore tested chemotactic ability. C. elegans shows normal chemotaxis to diacetyl and avoids Cu ion after the exposure to EMFs. However, the exposed animals are defective in the avoidance ability of Cu ion when tested chemotactic ability to diacetyl in the presence of Cu ion (maze assay) (Fig. 1). These results suggest that animals lost the ability to integrate two stimuli by the exposure to EMFs. We further investigated synaptic transmission with an extracellular recording technique, electropharyngeograms (EPGs). This method permits to determine the direction of postsynaptic action potentials in the pharyngeal muscle results from the action of both excitatory and inhibitory motor neurons. Pumping activity was not influenced by EMFs. However, EPGs was greatly affected, that is, both depolarizing transient and inhibitory post synaptic potentials disappeared, indicating that the neuronal function was greatly impaired by exposure to EMFs. The impairment of synaptic transmission by exposure to EMFs may reflect defectiveness neural integration of two stimuli. We then tested the effect of EMFs on long-term memory (LTM). Animals maintain LTM at least 48 hr when they are given 20 tap stimuli at 60-s ISI five times with 60-min interval. We found that animals exposed to EMFs are unable to acquire the LTM. We are now in progress to investigate how animals acquire the memory by the associative learning. C. elegans shows chemotaxis to NaCl but avoids NaCl when cultured in the presence of high concentration of NaCl under starved condition. The experiments provide desirable model system to know how organisms integrate different stimuli.

Conclusions. Effect of EPGs on development, behavior and gene expression was studied with C. elegans. Both embryonic and postembryonic development slightly affected. However, expression of the gsp-16 gene and complicated behavior including integration of avoidance and attraction were greatly affected. Based on the electrophysiological effect, synaptic transmission is also affected by EMFs.
P-82 EFFECTS OF MOBILE TELEPHONY SIGNALS EXPOSURE ON RADICAL STRESS IN THE RAT BRAIN

Isabelle Lagroye\textsuperscript{2,1}, Emmanuelle Haro\textsuperscript{1}, Elodie Ladeveze\textsuperscript{1}, Bernard Billaudel\textsuperscript{1}, Murielle Taxile\textsuperscript{1}, Bernard Veyret\textsuperscript{1,2}

\textsuperscript{1}University of Bordeaux 1, IMS Laboratory, site ENSCPB, 33607 PESSAC Cedex, France
\textsuperscript{2}EPHE Bioelectromagnetics Laboratory, ENSCPB, 33607 PESSAC Cedex, France

**Objectives.** Radical stress is involved in neurodegenerative diseases, such as Alzheimer disease or amyotrophic lateral sclerosis. In the last few years, it has been suggested that radiofrequency radiation (RFR) could play a role in the generation of radical stress in cells or animals, but observation of this phenomenon has not been confirmed.

The objective of this work was to investigate radical stress in the brains of rats exposed to GSM-1800 (2.8 W/kg brain averaged SAR: BASAR) or UMTS (2.6 W/kg BASAR), after single or repeated exposure. Oxidative damage is evaluated at the level of DNA, proteins, and lipids using specific markers and immunohistology.
Methods. We used 8 male Wistar-Han rats (12 weeks old) for each condition: cage-controls, sham exposure, RFR exposures, and positive controls. Exposure duration was 2 hours (single exposure) or 2 hours/day, 5 days/week, for 4 weeks (repeated exposure) in a head-only configuration using a loop antenna. In all cases, rats were progressively habituated to the exposure setup (rockets) over two weeks to avoid restraining stress. At the end of exposure, rats were immediately sacrificed under anesthesia (isoflurane 5%) and paraformaldehyde-fixed brains were removed and coded. They were then cryopreserved with sucrose (20% in PBS), frozen in isopentane and stored at $-80^\circ$C.

Cryosections (10 µm) were prepared on superfrost gold-plus slides. Three zones were chosen based on both distance to the antenna and brain structure: post bregma: $-0.8$mm for the motor cortex, $-3.8$mm for the cortex and hippocampus, and $-8.0$mm including the visual cortex.

Three markers were used to investigate radical stress in rat brain by immunohistochemistry: anti 4-HNE, anti 3-Nitrotyrosine and anti 8-oxo-dG antibodies for revealing lipid peroxidation, protein nitration, and DNA oxidation, respectively. Positive-control rats were submitted to intraventricular injection of LPS or quinoloinic acid for the identification of the presence of 3-Nitrotyrosine and 4-HNE, and 8-oxo-dG, respectively. Rats were kept for 24 hours before sacrifice, and their brains were handled as previously described.

Results. Staining of the brain slices is in progress. Data will be reported at the meeting.

Acknowledgements. This project is supported in part by the Swiss Research Foundation on Mobile Communication and the French Ministry for Research under grant No 03 5 326, and Bouygues Telecom.

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**P-83 EFFECTS OF TESTICULAR GERM CELL APOPTOSIS IN MICE EXPOSED TO 60 HZ ELECTROMAGNETIC FIELD OF 14 UT**

Yoon-Won Kim$^{1,2}$, Jin Sang Lee$^{1,2}$, Hee Sung Kim$^{1,2}$, Sang Kon Lee$^3$, Kyeong Cheon Jung$^4$, Youn-Myoung Gimm$^5$

$^1$College of Medicine, Hallym University, Chuncheon, South Korea $^2$College of Medicine, Hallym University, Chuncheon, South Korea $^3$College of Medicine, Hallym University, Chuncheon, South Korea $^4$School of Medicine, Seoul National University, Seoul, South Korea $^5$School of Electrical, Electronic and Computer, Dankook University, Seoul, South Korea

Objectives. We recently reported that continuous exposure to extremely low frequency (ELF) electromagnetic field (EMF) of 0.1 mT or 0.5 mT might induce testicular germ cell apoptosis in BALB/c mice for 8 weeks [Lee et al., Asian J Androl 2004, 6: 29-34]. In that report, the ELF EMF exposure did not significantly affect the body weight and the
testicular weight, but significantly increased the incidence of testicular germ cell death. In the present study, we aimed to further characterize the effect of continuous exposure to ELF EMF of 14 uT or 200 uT on testicular germ cell apoptosis in mice for 16 weeks.

**Methods.** Male BALB/c (7 weeks of age) mice were divided at random into 3 groups of 20 animals each. Mice were exposed to a 60 Hz MF of 14 uT and 200 uT continuously, 24 hr/day, for 16 weeks. Apoptosis of germ cell in the testis was analyzed by histopathological examination, the TdT-mediated dUTP-biotin nick end labeling (TUNEL) and electron microscopy examination, and the hormone effects were assessed by the testosterone in serum.

**Results.** There were not significant effects on the body weight and testosterone levels of mouse exposed to MF. Histopathologic examination showed significant incidence of the death of testicular germ cells and disorganization of germinal epithelia in the exposed BALB/c mice groups. In TUNEL-stain, germ cells showed a significantly higher apoptotic rate in the exposed mice than that in the sham controls ($P < 0.001$), but the difference between two exposed groups was not statistically significant. TUNEL-positive cells were mainly spermatogonia. When examined by electron microscopy, degenerating spermatogonia showed condensation of nuclear chromatin, which was appearance similar to apoptosis.

**Conclusions.** Apoptosis may be induced by the effect of continuous exposure to 60 Hz MF of 14 uT on spermatogenic cells in mice.
Figure 1. Effects of exposure to 60 Hz MF on the apoptosis of testicular germ cells. a; Most of TUNEL-positive cells (arrow) were spermatogonia. b; Frequency of apoptosis was increased in mice of exposed groups. The data are means ± S.E. *P < 0.001 vs sham control. x400.

Figure 2. Electron micrographs of spermatogonia in the seminiferous tubule from mice exposed to 14 uT (b) or 200 uT (c) magnetic field for 16 weeks. Note the degenerating spermatogonia with an amorphous electron-dense chromosomal aggregation in the central portion of nucleus (b,c). Spermatogonia in the sham control was (a). x7,000
**P-84** MRET ACTIVATED WATER AND ITS SUCCESSFUL APPLICATION FOR PREVENTION AND ENHANCED TUMOR RESISTANCE IN ANIMAL ONCOLOGY MODELS

Igor V. Smirnov\(^1\),\(^2\)
\(^1\)Global Quantech, Inc., San Marcos, CA, USA \(^2\)Kohoku Kogyo Co., Ltd., Takatsuki-cho, Ika-gun, Japan

**Objectives.** The goal of this investigation was to study the effect of MRET water as a potential agent for the prevention and treatment of two kinds of oncology diseases on mice (laboratory models of Ehrlich’s ascites tumor and Sarcoma ascites form).

MRET Water is produced with the help of patented (US Patent No. 6,022,479), non-chemical Molecular Resonance Effect Technology (MRET). The anomalous electrodynamic characteristics and viscosity of MRET water provide some evidence regarding the possible effect of MRET water on electrical activity and proper function of the cells.

**Methods.** The ability of animals for tumor resistance was studied in the experiments conducted on 440 mice (22 groups with 20 mice in each) with the help of the following methodology:

a) study of possible anti-tumor effectiveness of ”preventive” administration of different fractions of MRET water; mice received MRET water during 2 weeks before tumor cell transplantation and after transplantation;

b) study of possible anti-tumor effectiveness of ”therapeutic” administration of different fractions of MRET water; mice received MRET water after tumor cell transplantation;

c) investigation of functional citotoxic activity of lymphocytes containing natural killer cells (NK-cells) isolated from spleens of mice (without tumors) which received MRET water; lymphocytes were incubated with tumor target cells.

**Results.** The experimental results confirm that consumption of all types of MRET water leads to the significant inhibition of tumor growth observed in mice. The best results were observed in the groups of mice on MRET water activated for 30 minutes (optimal regime). Particularly, the average total volume of tumor cells for mice in ”preventive treatment” group which received water activated at the optimal regime decreased 4.2 times compared to the control group of mice on non-activated water.

Pic. 1

The observed average survival time of mice which received optimal activated water in ”preventive treatment” regime increased by 61.7% compared to the control group. Remarkable increase in life span (about 45%) was observed when mice were treated with other fractions of activated water in ”preventive treatment” regime (activation time 15 minutes and 45 minutes).

Pic. 2

The positive effect of optimal fraction of MRET water on cytotoxic activity of mice lymphocytes containing NK cells (increase by 30%) in ”preventive treatment” regime was observed in this investigation.

Fig. 1
**Conclusions.** The significant positive effect of MRET water was observed in all groups of mice on different fractions of MRET water, with higher level of efficacy for "preventive treatment" regime and the best results on MRET water activated for 30 minutes. The significant anti-tumor effect of MRET water on mice was close to the action of the chemotherapy agents without side effects.

**Acknowledgements.** The research was conducted under supervision of Prof. V. Vysotskii (Kiev State University, Ukraine), S. Olishevsky, Ph.D., Y. Yanish, Ph.D. (Kiev Institute of Experimental Pathology, Oncology and Radiobiology, Ukraine), and A. Kornilova, Ph.D. (Moscow State University, Russia).

![Figure 1](image1.png)

**Figure 1.**

The appearance of mice from “control” (A) and “preventive treatment” (B) on the 18th day after ascitic Ehrlich carcinoma cell inoculation.

![Figure 2](image2.png)

**Figure 2.**

The dead mice of “control” group (left side) and alive mice from "preventive treatment" group (right side). Photo was making on the 21st day after mice were inoculated with cells of ascitic Ehrlich carcinoma.
Objective. Electrical injuries often result in burns, which can lead to dermal scarring, sometimes severe. However, as there are not yet any suitable methods for routine clinical evaluation of dermal scars, determining the efficacy of treatment remains subjective and imprecise. Many techniques have been proposed to bring objectivity to the evaluation process; one frequently used scale for scar evaluation is the Vancouver Scar Scale, which relies heavily on the patient and the clinician, introducing subjectivity into the evaluation. Ultrasound, which can measure the thickness and density of scar lesions, may provide an objective, efficient and readily available method for the monitoring of scar progression. This study validates the utility of ultrasound as an objective method for the monitoring of scar progression, shows the correlation between ultrasound measurements to patient symptoms and validates the efficacy of the treatment method in place at the University of Chicago.

Methods. A group of 20 subjects with keloid and hypertrophic scars were studied, 14 treated and 6 untreated. The treated subjects underwent the standard scar treatment protocol used at the University of Chicago Scar Treatment Center. All participants completed a scar survey and ultrasound assessment (conducted with a high frequency GE Pro Series...)
ultrasonography machine) at each appointment during the study. A consistent imaging site was ensured by the tracing of scars onto a transparency and a skin marker followed by photography. To validate the scar thickness measurements, 5 subjects were studied pre- and intra-operatively and actual scar thickness compared to the ultrasound measurements.

**Results.** In order to assess the progression of the scars over time, the slope of each measured variable over time was calculated. A mixed-effects ANOVA model was used to analyze the changes in pruritis frequency and amount and the ultrasound thickness and area measurements over time between the control and treated groups. For each of these variables, the change over time for the treated groups was negative, indicating and improvement, while the change over time for the untreated groups was slightly positive, indicating no change or a regression. For all four variables, p < 0.01.

**Conclusions.** This study offers strong evidence of the correlation between scar symptoms and thickness and their ultrasound measurements. This suggests the potentially significant role that this imaging modality can play in scar management. In addition, this study shows that ultrasound can be non-subjectively used to monitor treatment, as shown by its ability to differentiate treated and untreated subjects with the same effectiveness as monitoring clinical variables such as pruritis frequency and amount. In addition, this study shows that the scar treatment protocol in use at the University of Chicago is efficacious.

![Figure 1](image_url)
**P-86 MICROWAVE TREATMENT OF WOOD ARTISTIC SAMPLES. EXPOSURE OF WOODEN HANDICRAFTS**

Francesco Augelli³, Bruno Bisceglia¹, Maurizio Boriani³, Nicola Diaferia², Federica Foppiani¹, Elisa Italiano⁴, Federica Magli⁴, Roberta Mastropirro⁵, Roberta Tessari⁴

¹University of Salerno, Fisciano (SA), Italy ²Emitech srl, Molfetta (BA), Italy ³Politecnico di Milano, Milano, Italy ⁴Restorer, Milano, Italy ⁵Architect free lancer, Milano, Italy ⁶ICVBC – CNR, Milano, Italy

**Objectives.** The preservation of works of art is not only a preventive operation but also a fact-finding/cognitive one. The results deriving from applications of non-invasive methods are presented. For this purpose chemical methods such as fumigation, application of chemical products and anoxic treatments in controlled atmosphere are generally used. These are mostly toxic, polluting and often invasive methods whose application is difficult; in some cases they cannot grant the neutralization of eggs.

Mi.Sy.A. (Microwave System for Art), is a device working at the microwave frequencies that neutralizes deteriorating agents. Microwaves interact with the biological forms making increase their inner temperature up to their lethal temperature, which ranges from 53 to 55°C for xylophagous insects and from 65 to 70°C for fungi and mouldings. The temperature increase is a significant element for the safeguard of wooden handicrafts whether they are polychromatic or not.
**Methods.** The traditional finishes that were tested, are included in the categories of natural resins whose filmogenic, adhesive and water-repellent properties are well-known since ancient times.

The $MW$ exposure is realized in a reverberation cavity that assures a uniform irradiation of the object under treatment.

Volume: $2.5 \, m^3$,

Signal: $CW \, 800 \, W \div 6 \, kW$,

$f = 2.45 \, GHz$.

The treatment was carried out on handicrafts made of *poplar* $(20 \times 20 \times 4.5 \, cm)$ and *fir* $(20 \times 14 \times 3.3 \, cm)$, obtained by coupling and fixing two slabs of $20 \, cm$ each one. Prior to the treatment some cavities for larvae were created in the slabs.

The samples for the experimentation were realized using the materials listed in the table below and were conditioned into appropriate climatic chambers at $12\%$ humidity for $2$ minutes.

Data relative to chemical-physical analysis were recorded through:

- Morphologic survey
- Photograph in visible light with colorimetric scale
- Macro-photograph
- Fluorescence induced by UV radiation
- Microscopic Examination
- Reflectance colorimetry
- Gloss
- Contact angle
- FTIR

**Results.** The mortality of larvae was of $100\%$ at the end of the experimentation.

There were not rapid or excessive humidity losses in the object, whose moisture content was always $< 1\%$.

Microscopic analysis, before and after the treatment, showed very good results because no chinks, detachments and deterioration of the pictorial layer were found.

The temperature rise was more rapid in the fir samples which were smaller and lighter than the poplar samples.

The golden parts were covered with a metallic film (the common tin foil) that adhered perfectly on the conductive surfaces to be safeguarded.

Both samples, that presented the gilding technique, were heated up to $56^\circ C$ (lethal temperature for the insects) and no combustion was provoked.

Spectral variations determine a negative result: it is remarkable that there were no relevant changes provoking variations in the performance of the product.

**Conclusions.** Misya’s treatment system was tested in order to evaluate the possibility to be used for wooden handicrafts with or without polychromy and not exceeding the temperature threshold of $50-60^\circ C$.

The results are encouraging and represent a significant repetition of previous experiments, but further trials should be carried out.
Sound samples were treated. According to the monitoring of the experimental protocol the treatment does not provoke damages or deterioration in the materials.

**Acknowledgements.** Thanks to Dr Luzie Zaza for the accuracy in translating and reviewing the English text.

This work was sponsored by Emitech.

**Figure 1.** Resistant glue: green before the irradiation; red after the irradiation

**Figure 2.** Industrial wax: green before the irradiation; red after the irradiation
P-87 DEVELOPMENT ON TISSUE-EQUIVALENT PHANTOM WITH CAPILLARY BLOOD FLOW FOR EVALUATION OF TEMPERATURE RISE DUE TO MICROWAVE RADIATION

Kazuyuki Saito\textsuperscript{1}, Atsushi Hiroe\textsuperscript{3}, Masaharu Takahashi\textsuperscript{1}, Koichi Ito\textsuperscript{2}
\textsuperscript{1}Chiba University, Chiba, Japan \textsuperscript{2}Chiba University, Chiba, Japan \textsuperscript{3}Chiba University, Chiba, Japan

Objectives. In recent years, there are various types of devices, which radiate EM (electromagnetic) wave and are used in close vicinity of human body. The SAR (specific absorption rate [W/kg]) is the most important index for evaluation on the EM energy absorption of the human body. However, in the case of investigation on high power devices, not only the SAR analysis but also consideration of temperature rise in the body is necessary. The temperature rise inside the body can be calculated numerically under several assumptions. However, it is difficult to estimate the temperature rise inside the body by experiment and a few studies were performed (N. Terada and Y. Amemiya, "The performance of the dipole array applicator for radiofrequency hyperthermia," Trans. IECE, vol. J67-B, pp. 163-170, Feb. 1984 (in Japanese)). Consequently, in this study, tissue-equivalent phantom with capillary blood flow for evaluation of temperature rise due to microwave radiation is developed.

Methods. In this study, the tissue-equivalent phantom with capillary blood flow is fabricated and is heated by antenna for interstitial microwave hyperthermia, which is an example of the high power EM wave radiator. Figure 1 shows the fabricated phantom model. The tissue-equivalent solid phantoms processed in short corded (diameter: approx. 2 mm, length: several tens of millimeter) are filled to an acrylic shell and are sprinkled saline water uniformly. The blood flow rate can be controlled by varying the amount of sprinkled saline water. Moreover, the coaxial-slot antenna (operating frequency: 2.45 GHz) for the interstitial microwave hyperthermia is inserted to almost center of the above mentioned phantom. In addition, three fiber optic thermosensors are placed around tip of the antenna and record temperature rises by microwave radiation.

Results. Figure 2 shows measured temperature rises around the antenna tip. The position of the fiber optic thermosensors (A, B, and C) are indicated in Fig. 2. In addition, the measured temperature rises without the sprinkled saline water are also shown for comparison. Here, the net input power of the antenna (incident power - reflection power) with and without sprinkled saline water are 7.8 W and 9.0 W, respectively. In addition, the amount of sprinkled saline water is $7.5 \times 10^{-6}$ m$^3$/s. From the results, the maximum temperature rises of the observation points A, B, and C are 18 °C, 14 °C, and 7 °C, respectively. Meanwhile, in the case of without sprinkled saline water, the temperature rises are 47 °C, 43 °C, and 30 °C (after 300 s heating). Thus, differences between them can be obviously observed.

Conclusions. In this study, the tissue-equivalent phantom with capillary blood flow was developed. By using this phantom, cooling effect due to the capillary blood flow could be observed. As a further study, relations of the amount of sprinkled saline water and the blood flow rate must be investigated.
Figure 1. Tissue-equivalent phantom with capillary blood flow.

Figure 2. Temperature transitions during microwave radiation.
**P-88 CALIBRATION OF CLAMP-TYPE INDUCED CURRENT METER IN THE LOW FREQUENCY (100KHZ-10MHZ) USING LUMPED PARAMETER CIRCUIT**

Jin-Kyu Byun\(^1\), Hyung-Do Choi\(^1\), Young-Seek Chung\(^2\), Ji-hyun Kim\(^3\)

\(^1\)Electronics and Telecommunications Research Institute, Daejeon, South Korea
\(^2\)Kwangwoon University, Seoul, South Korea
\(^3\)Myongji University, Yongin, South Korea

**Objectives.** Induced current (100 kHz~110 MHz) in the human body due to EMF from the high power broadcasting transmitters, induction heating cookers, etc. can have effects on nervous system functions or cause SAR values greater than protection guidelines. Compared to the strict international standards regarding measurement of SAR from mobile telephones, assessment of low frequency induced currents has been only covered in a few general standards, mainly due to the difficulties associated with the measurement of in-situ induced current.

However, some broadcasting transmitters in the urban area have input power as high as 100 kW, and there have been increasing needs for accurate assessment of induced current in the vicinity of such transmitters. In this paper, calibration method for widely used clamp-type induced current meter is presented.

In the frequency range of 100 kHz~10 MHz, calibration of induced current meter using human-equivalent monopole antenna is very difficult because of huge size of semi-anechoic chamber required associated with the large wavelength. To overcome this difficulty, we propose calibration method using lumped parameters in the low frequency range (100 kHz~10 MHz).

**Methods.** The calibration method is based on the conventional circuit theory that the current in the circuit is only determined by the lumped parameters when the dimension of lumped parameter is much smaller than the wavelength (\(D<\frac{1}{\lambda}\)). Fig. 1 shows the schematic picture of proposed calibration circuit using signal generator. In Fig. 1, the signal generator acts as a source of specific frequency and voltage. For circuit analysis, 50ohm internal resistance must be considered which is common for signal generators. As mentioned above, in this low frequency, the circuit current is only determined by internal resistance and load resistance. The load voltage is measured by oscilloscope, and the current is obtained by dividing the voltage with load resistance. We assume that the load current measured by oscilloscope is the accurate current, and use it to calibrate the induced current meter.

The characteristics of the lumped parameters such as resistance, inductance and capacitance are accurately measured by multi-tester. It is assumed that these values remain constant in the low-frequency range. With this assumption, the input voltage and current can be predicted accurately using Ohm’s law. The procedures for calibration is as follows:

1. Choose the known load resistance value. This value can vary depending on the assumed ground condition of human feet.
2. Connect the load to the signal generator through the induced current meter.
3. Choose the desired frequency and input voltage of signal generator, and measure the voltage across load resistance using oscilloscope. The load current is the voltage divided by
the load resistance.
4. Compare the load current with the current measured by induced current meter. The difference is the error of induced current clamp.
5. Repeat 1-4 with various resistance values and fixed frequency and extract the error boundary function.
6. Connect the unknown load resistance, and using the error boundary function from 5, estimate the error boundary.

**Results.** Fig. 2 shows the error of induced current clamp with various load resistance and frequency. It can be seen that the error gradually increases as the measured current becomes larger. With known frequency and measured current value, the error boundary for unknown impedance can be predicted by linear approximation of error data.

**Conclusions.** In this paper, we proposed the calibration method for clamp-type induced current meter using lumped parameter circuit. The error boundary with unknown load can be predicted by the linear approximation of error function.

![Figure 1. Calibration circuit using signal generator and load resistance.](image)
**Figure 2.** Error distribution of current measured by induced current meter.

**P-89 DESIGN OF COIL SYSTEMS AND BUILDINGS FOR GENERATING WIDE INTENSIVE UNIFORM MAGNETIC FIELD AT INTERMEDIATE FREQUENCIES.**

Keita Yamazaki\(^1\), Akira Haga\(^2\), Koichiro Kobayashi\(^3\), Kazuhiro Muramatsu\(^4\), Izumi Nishimura\(^5\), Satoshi Nakasono\(^5\), Tsukasa Shigemitsu\(^5\), Tadashi Negishi\(^5\)

\(^1\)Takenaka Corp., Inzai, Japan \(^2\)Tohoku Gakuin Univ., Tagajo, Japan \(^3\)Iwate Univ., Morioka, Japan \(^4\)Saga Univ., Saga, Japan \(^5\)Central Research Institute of Electric Power Industry, Abiko, Japan

**Objectives.** In order to investigate whether magnetic fields at intermediate frequencies affect the materials and functions of a living body, two kinds of coil systems and buildings, which generate wide, intensive, and uniform magnetic fields at 20kHz and 60kHz, were designed and realized. In these coil systems and buildings, the magnetic flux densities in a space of 1m x 1m x 1m are required such that the amplitudes at the center point are 200µT at 20kHz and 100µT at 60kHz and the uniformities are within ±5%. Moreover, magnetic fields outside the building should be less than 6.25µT, which complies with approved guidelines [1].

**Methods.** In order to generate uniform magnetic fields, a four-square coil system similar to that presented by E. Merrit [2] was employed. The coil system was connected to the
capacitance \( Co \) in series for reducing the impedance by series resonant circuit. By the experiment using the prototype coil system, the problems, such that the coil current leaked by the distributed capacitance \( Cd \) between adjacent turns, between turns that are not adjacent and between turns and walls, and the ultrasonic noise occurred by the vibration of turns due to electromagnetic force, were found. It can be easily understood that these problems are overcome by reducing the sizes and numbers of turns in the coil system [3]. For example, leakage current from turns to adjacent turns and wall can be reduced when inductive reactance of coil is less than capacitive reactance of \( Cd \). This means that the resonant frequencies \( RFs \) of inductance of coil and \( Cd \) should be larger than 20kHz and 60kHz, respectively. However, it is difficult to obtain \( Cd \) analytically. Therefore, the effects of sizes and numbers of turns in the coil system on these problems were investigated experimentally. As a result, these were determined to be 1.6m x 1.6m x 1.616m and 26/11/11/26 turns for 20kHz, 7/3/3/7 turns for 60kHz, respectively.

**Results.** On the other hand, the effect of eddy currents in the reinforcing bars of buildings on the uniformity of the magnetic field, the shielding effect of leakage flux outside the buildings, and temperature rise were also investigated by 3-D magnetic field analysis taking the eddy currents and nonlinearity into account. As a result, both coil systems were located 1.5m and 1.3m away from concrete floor slabs and walls, respectively.

**Conclusions.** After completion of the buildings and coils shown in Fig. 1, the measured \( RFs \) for 20kHz and 60kHz were 130kHz and 580kHz, respectively. Moreover, all specifications mentioned above were satisfied as shown in Fig. 2.

References
FIGURE 1. Four-square coil system at 20 kHz installed in new designed house.
**Figure 2.** Overview of designed new building and distribution of magnetic field inside and outside building, and inside coil system when magnetic field of 200µT at 20 kHz is applied to the center point of coil.
P-90 MAGNETIC FIELD MEASUREMENT NEAR POWER FACILITIES BASED ON IEC PT62110 IN KOREA

Yunseok Lim¹, Kooyong Shin¹, Seongho Myeong³, Jaejoon Kim², Dongil Lee¹, Jayoon Koo⁴

¹KEPRI (Korea Electric Power Research Institute), Daejeon-shi, South Korea ²KEPCO (Korea Electric Power Corporation), Seoul, South Korea ³KERI (Korea Electric Research Institute), Changwon-shi, South Korea ⁴Hanyang University, Seoul, South Korea

Objectives. This work aims to evaluate the exposure levels of the human body to the magnetic fields generated by power apparatus by use of newly proposed IEC PT62110.

Methods. For this purpose, statistical treatment has been conducted with the measured data for the uniform and non-uniform magnetic field exposure.

Results. Throughout this work, the measurement procedures and evaluation method of human exposure level for the magnetic field generated from AC power systems based on IEC PT62110. For this purpose, averaged human exposure level to the magnetic field and non-uniformity for the two typical power systems, pad-mounted transformer and vertical cable, have been presented as typical examples in Korea.

Conclusions. 1) Human exposure level should be evaluated by spatial average exposure level measured from three different heights as indicated in IEC PT62100 rather than spot measurement evaluation for the non-uniform field.
2) Human exposure level can be evaluated by spot measurement at the height of 1.0m according to IEC PT62100 for the uniform field.

Acknowledgements. The financial support was made by the research fund of the KEPRI grant (No.R-2002-1-080-0-00).
Figure 1 Measurement magnetic field generated from pad-mounted transformer

Figure 2 Measurement magnetic field generated from vertical cable
P-91 IN SITU ANALYTICAL SYSTEM TO STUDY EFFECTS OF EXPOSURE TO ELF EF ON TRANSPARENT TISSUE

Koji Tochio1,2, Shinji Harakawa2,3, Fuyuki Doge2, Haruyuki Minamitani1
1Keio University, Yokohama, Japan 2Hakuju Institute for Health Science, Tokyo, Japan 3Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Japan

Objectives. The aim of this study is developing new system to observe effects of an exposure extremely low frequency electric field (ELF-EF) on transparent tissue, e.g. mesentery, in a condition of “in situ”.

Methods. The device system was composed of a parallel mesh electrode, a voltage generator and a proper microscope with a CCD camera unit.

Results. In applying of such the system to a quantitative measurement in microvasculature kinetics, i.e. blood flow rate and an internal diameter of vessel, under the presence of EF, treatment of noradrenalin via both intravenous injection and direct-dropping to mesentery showed immediate effects. Alterations induced by intravenous injection of noradrenalin were not influenced due to EF. While, effect of EF upon direct-dropping-induced changes were inhibitory, compared to those in sham EF exposure.

Conclusions. It seems such the present system may be useful in investigating phenomena, what were not yet studied in situ condition, due to EF exposure.
P-92 FREE SCANNING METHOD FOR MEASURING THE MAGNETIC FIELD DISTRIBUTION

Naoki Miyata, Yoshitsugu Kamimura, Yoshifumi Yamada
Utsunomiya Univ., Utsunomiya, Japan

Objectives. Conventionally, it is general that the spatial field distribution is serially measured with the coordinates lattice points decided in advance, and displayed. The scanning of the field sensor is performed manually using the jig, or is automatically performed with a special scanning machine or the robot. However, an accurate movement to three-dimensional coordinates is difficult in a manual scanning, and the system seems to become massive in the machine scanning. Then, this study proposes the free scanning method for the field distribution measurement by recording the position of the moved sensor automatically,
without scanning the sensor to the coordinates lattice point decided in advance. Our final objective is an easy and interactive visualization of a hazardous electromagnetic field.

**Methods.** The configuration of the free scanning system for the field distribution measurement is shown in Figure 1. The field sensor is set on the tip of nonmetal rod, a position sensor is set on the butt, and then the position of the field sensor is indirectly recorded automatically. A position sensor can obtain coordinates \((x,y,z)\) and three kinds of angles (yaw, pitch, roll) using the magnetic field radiated from the transmitter located in the origin. When magnetic field distribution measurement, it is necessary for separating a position sensor enough from the field sensor, for reducing the interference due to the measured magnetic field and the influence of a surrounding metal. The relative distance between both sensors is determined from the changes in the coordinates and the angles of a position sensor when the rod angle is changed keeping the tip of rod. The position of the field sensor is obtained from coordinates and the angles of the position sensor and a relative distance between both sensors, and it is recorded with measured value of the field sensor. The specification of two kinds of sensors that we used is shown in Table 1. The magnetic field sensor has two kinds of range of the measurement frequency, low frequencies (30 Hz to 1 kHz), and high frequencies (1 kHz to 100 kHz). The sampling duration of the magnetic field sensor is 1.1 seconds and the shortest sampling duration of a position sensor is within 0.1 seconds. The sampling speed of the magnetic field sensor is a bottleneck at the measurement speed. An effective radius of a position sensor is about 150 cm.

**Results.** A relative distance in coordinate unit of a position sensor was about 80 cm according to a preliminary experiment. In this study, two dimensional magnetic flux density distribution in the vicinity of the induction heating (IH) cooker was obtained as shown in Figure 1. The pan that put water in on the IH cooker was set, an acrylic plate was located upward horizontally, and the magnetic flux density on the surface of the plate was measured with the magnetic field sensor. To obtain two dimensional distribution of the magnetic flux density, about 180 points were measured in about 200 seconds. The measurement result was interpolated, and the magnetic flux density distribution was shown in the color map (Figure 2). According to this figure, it is found that the peak of H-field is at the center of the IH cooker.

**Conclusions.** In this study, we proposes the measurement method of the distribution of a hazardous electromagnetic field easily by combining the field sensors with a position sensor, and two dimensional measurement of magnetic flux density distribution demonstrated the usefulness. The problems in the future are the development of the display method in real-time as for the measurement result, and of an appropriate display method of three dimensional field distribution.

**Acknowledgements.** This study has been sponsored by Grants-in-Aid for Scientific Research (C) No.17560246 of JSPS.
Figure 1.

Figure 2. Magnetic flux density distribution of IH cooker.
P-93 COMPARISON OF FREE SPACE CALIBRATION TECHNIQUES OF A SAR-PROBE

Lira Hamada\(^2\), Hideo Kurokawa\(^1\), Kenichi Sato\(^2\), Shinobu Ishigami\(^1\), Soichi Watanabe\(^1\)

\(^1\)National Institute of Information and Communication Technology, Tokyo, Japan \(^2\)NTT Advanced Technology, Tokyo, Japan

Objectives. International standards of SAR measurement methods recommend one-step procedure and two-step one for calibration of a SAR-probe or electric field (E-field) probe with dedicated waveguides. In the two-step procedure, the absolute sensitivity of the probe is evaluated in free space (1st step), and the relative sensitivity in liquid to free space is evaluated (2nd step). In the one-step procedure, the absolute sensitivity is evaluated only in liquid. In the two-step procedure, the absolute sensitivity in free space can be evaluated in the uniform E-field while the absolute sensitivity in the liquid must be evaluated in steeply gradient E-field in the one-step procedure. This is one advantage of the two-step procedure against the one-step procedure, which may result in reduced uncertainty of the calibration. Although calibration methods for E-field probes in free space have been investigated, calibration methods for the SAR-probe, i.e., very small size isotropic E-field sensor, have not been investigated yet. In this paper, therefore, we investigate two techniques of free space calibration for the SAR-probe.

Methods. The SAR-probe has three dipole sensors in the tip. The each sensor is connected to a detector through the high resistance line in it. The detection voltages \((V_i = 0, 1, 2 <i>[\mu V])\) of it are relative to the square of the E-field \((E_i = 0, 1, 2[V/m])\) which are exposed to the sensors. As shown in Eq. (1), the total E-field \((E_M[V/m])\) can be evaluated as the RSS of the three E-field components \((E_i = 0, 1, 2[V/m])\). And \(E_M\) can be replaced as the right side of Eq. (1) with \(V_i\) and \(Norm_i\), where \(Norm_i = 0, 1, 2[\mu V/(V/m)^2]\) are the sensitivity in free space for each sensor. The standard E-field \((E_T[V/m])\) is needed for free space calibration of the probe. We chose the two methods (Method-A & Method-B) to make the standard E-field for free space calibration. As shown Fig. 1, Method-A uses the E-field generated inside the waveguide and calibration position is a center of it. The \(E_T\) at the calibration position is determined by Eq. (2). As shown in Fig. 2, Method-B uses the E-field generated by the open-ended waveguide and calibration position is a point of distance \(r[m]\) away from the aperture of open-ended waveguide. The \(E_T\) at calibration position is determined by Eq. (3).

In free space calibration for the SAR-probe, the direction of each sensor should be adjusted to the direction of E-field. But it is very difficult for us because we can not find the actual internal structure from outside of the SAR-probe. Therefore, we used a characteristic of SAR-probe, the sensors are installed in cylindrical symmetry, so that the accurate calibration can be performed as follows.

1. The SAR-probe is vertically inserted in the direction of the E-field at the calibration position.
2. \(V_i\) is measured by rotating 360 degree every 10 degree.
3. \(Norm_i\) is optimized by the least square method so that the deviation between \(E_T\) and each \(E_M\) can be minimized.

This procedure has also been adopted by some SAR-probe companies.
Results. As shown in Table, the calibration factors evaluated by Method-A are corresponding to those provided by the manufacturer of the SAR-probe, and the maximum deviation is about 3%. However, the calibration factors evaluated by Method-B are 33% smaller than those provided by the manufacturer. And the frequency characteristics are nearly constant (about 3%) in Method-A, while those are relatively variable (about 27%) in Method-B. In Method-A, only the tip of the probe is exposed to the E-field. In Method-B, the whole probe and the detector is exposed to the E-field. Therefore the deviation of each method is caused by the difference of the parts which is dominated by the E-field.

Conclusions. In this paper, we investigated the two techniques for free space calibration of a SAR-probe. One is closed environment (Method-A), and the other is open-space one (Method-B). Both result were different.

In the SAR measurement in the liquid, only the tip of the SAR-probe is usually exposed to the E-field, and other parts are little exposed. For this reason, in free space calibration, we recommend the use of the Method-A. In future, we will investigate the uncertainty of SAR-probe calibration by two-step calibration procedure using Method-A.

<table>
<thead>
<tr>
<th>Measured Electric Field</th>
<th>Method-A</th>
<th>Method-B</th>
</tr>
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<tbody>
<tr>
<td>$E_M = \sqrt{E_0^2 + E_1^2 + E_2^2} = \sqrt{\frac{V_0}{Norm_0} + \frac{V_1}{Norm_1} + \frac{V_2}{Norm_2}}$ (1)</td>
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<tr>
<th>Theoretical Electric Field</th>
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<tr>
<td>$E_T = \sqrt{377 \times \frac{P_{in}}{\alpha} \left[1 - \left(\frac{\lambda}{2\alpha}\right)^2\right]^2}$ (2)</td>
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<tr>
<td>$E_T = \sqrt{\frac{30 \times G \times P_{net}}{r^2}}$ (3)</td>
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</table>

$P_{in}$: Net input electric power to waveguide [W], $\alpha$: The length at the long axis of the waveguide [m], $\lambda$: Wavelength [m], $G$: Absolute gain of the waveguide [dBi], $r$: Distance between waveguide and probe sensor [m], Norm: Sensitivity in free space [$\mu W/(V/m)^2$]

Figure 1.
P-94 DEVELOPMENT OF CALCULATION PROGRAM KMAGEXPO ON PERSONAL MAGNETIC FIELD EXPOSURE OF KOREANS IN LIVING ENVIRONMENTS

Kwangho Yang, Munno Ju, Sungho Myung
Korea Electrotechnology Research Institute, Changwon, South Korea

Objectives. To predict and evaluate personal MF exposure in general living environments

Methods. At first, we developed four types of 12 personal MF exposure prediction formulas for developing KMAGEXPO. Those are a 24-hr exposure prediction formula of Korean, 2 formulas during the period at work and in bedroom and 9 formulas by occupations which were developed by applying evolutionary computation method to the measured database. Specially, genetic algorithm and genetic programming were used among the evolutionary computations. After tuning database with the above methods, the best formulas with small estimation error were selected. The target of estimation error is about 0.3 mG. The 7 parameters of each formula include gender(G), age(A), residence type(H), residence size(HS), distance between residence and power line(RD), occupation(O) and the usage and condition of electric appliances(RULE) except power line voltage class.

Results. For example, the following formula, developed using genetic programming method, calculates 24-hour average MF exposure.

\[ 24\text{hrMFExpo} = ((4.33/G)\log(RD)) - ((0.84/H)\log(HS)) + 0.045((O*G)/(A+O)) + \]
RULE
Where, RULE is a calibrating constant that represents key factor which influence MF exposure such as the usage of electric appliances in work and home. The calibrating constant significantly increases reliability of the estimation. In this study, average MF exposure of all participants was 1.3mG and absolute average estimation error calculated by prediction formula was 0.26mG. This result shows that the 24-hour average MF exposure of an individual can be predicted with estimation error below target value, 0.3mG using the above 24-hour formula. In the bedroom formula, occupation (O) was not included as the parameter. The absolute average estimation error for the work place formula and bedroom formula were 0.37mG and 0.36mG, respectively. The above formulas will be further developed into a prediction formula that can calculate MF exposure in case and control groups for subjects below middle school students. The KMAGEXPO will be used in epidemiological survey on correlation between magnetic field and tumors found in Koreans.

Conclusions. The human health problem caused by ELF magnetic field has become one of Korea’s most debated social issues. Therefore, this paper proposed the KMAGEXPO software that can estimate personal MF exposure levels of Korean people in general living environments.

The key features and significance of this software development are as follows:
1) The data used to develop estimation formulas were collected from 466 participants.
2) The program chose gender, age, house type, house size (square footage), radial distance between residence and power lines and occupation as parameters. This research revealed that the distance and occupation parameters are highly relative to the MF exposure level.
3) First time in the world, the evolutionary computation suitable for this problem was used as an optimization method. This computation showed that these estimation formulas yielded approximately 0.3mG mean average errors.
4) KMAGEXPO can serve as a valuable tool in estimating 24-hour personal MF exposure without directly measuring and it will provide an effective means to study MF’s effects on human health.
**Figure 1.** Main menu of KMAGEXPO

**Figure 2.** A calculation module for 24-hr MF exposure of Korean
Objective. Due to the increase of application of electromagnetic wave in recent years, higher frequency spectrum such as millimeter wave bands are employed. In order to confirm the safety of EM-wave exposure to a human body, we should evaluate the power absorption in the human body in these high frequency bands. These Evaluations need electrical properties of biological tissues and organs.

As a way to measure electrical properties of biological tissues in millimeter wave bands, we focus on ellipsometry method which is widely used in optical region for measuring thickness and complex refractive index.

It is known that electrical properties of biological tissue depend on amount of water content. Therefore permittivity of the biological tissue contain high rate of water is similar to water value.

In this study, complex relative permittivity of de-ionized water was measured to confirm that ellipsometry method can be used to measure permittivity of biological tissues.

Methods. If the sample’s thickness and ellipsometry parameters are measured, we can determine complex relative permittivity using computing technique such as Newton method.

Results. De-ionized water was measured on the condition that the incident angle was 56.7 degrees and the source frequency was 60GHz. Water was poured into The hollowed foamed polystyrene as the sample holder and the top surface of the sample holder’s edge was cut away to prevent an obstructive reflection from the sample holder.

The reflection power was obtained by detector antenna for the polarization angle range of 0 to 360 degrees by 5 degrees interval step. Figure 2 shows the detector polarization angle dependence of the reflected power from water sample (21.2 degree C).

The Fourier Analysis Correction Ellipsometry (FACE) method [1] is used to calculate ellipsometry parameters. The FACE method can reduce an uncertainty due to the free space method. Then complex relative permittivity was calculated on the assumption that sample thickness is infinity, because almost all reflection occur only water surface due to the large loss tangent of water.

Table 1 shows these calculated ellipsometry parameters and complex relative permittivity of de-ionized water (21.2 degree C) as well as reference’s value of water.

Conclusions. We measured complex relative permittivity of de-ionized water using ellipsometry method to confirm that ellipsometry method can be used to measure permittivity of biological tissues. The measurement result of water was in good agreement with reference value of water. Therefore this method may have an ability of permittivity measurement for biological tissues.

Figure 1. Ellipsometry System

Figure 2. Polarization dependence of power
P-96 SIMPLE CUBIC-3 COIL SYSTEM

Kunihisa Tashiro, Hiroyuki Wakiwaka
Shinshu University, Nagano, Japan

Objectives. Well-controlled, uniform magnetic field generation over a considerable volume is necessary technique in geomagnetic field canceling system and magnetic fields exposure system. From practical advantages for the construction and the usefulness, several kinds of square coil system have been already proposed. While number of square coils allows the axial field to have good uniformity in large volume, the size of the entrance area is limited by the coil crossing for the three orthogonal coils sets. In order to drive one power supply for one direction, the ratio of the current in the coils should be integer, and it is relatively tolerant of small design imperfection. For the reasons mentioned above, this paper proposes "SimpleCubic-3" coil system which consists of three square coils, same coils’ distance and simple integer ampere-turn ratio.

Methods. Several kinds of square coil system with integer ampere-turn ratio are summarized in Table 1. They are designed based on two approaches. First approach considers the Taylor-series expansion of the axial field with respect to the center. The symmetry configuration vanishes all odd-order terms, and then number of square coils N allows N+1-th-order term to be deleted. Since ampere-turn ratio for the three or four coils is rational number (Kakuno et. al, 1976), the similar integer ratios have been proposed (Merritt et. al. 1983). Helmholtz-2 with two square coils, Merritt-3 with three square coils, and Merritt-4 with four square coils are in the category. Second approach discusses the uniformity at an evaluation area inside the coils placing same distance each other. Cubic-3 with three square coils (Sasada, 2003) and Rubens-5 (Rubens, 1945) with five square coils are in the category. Same placement of Cubic-3 has been also proposed (Grisenti et. al., 1981), but the ampere-turn ratio is real number (1: 0.51 : 1). Our proposed SimpleCubic-3 accepts this with simple integer ampere-turn ratio. For the square coil systems, the axial field can be calculated by using the Biot-Savart law.

Results. Comparison of the axial field along the axis is shown in Fig. 1. Vertical axis represents the absolute value of deviation from the value of center, and the practically important range of those is shown. Horizontal axis represents the distance from the center, which is normalized with the side length of square coil. As several papers proposed (eg. Kirschvink, 1992), Merritt-4 can achieve the best uniformity in largest area. However, when the coil cannot change the position, the cubic volume corresponding to the entrance size is smaller than that has side length of 0.39 d, where d is the side length of square coil. Although the deviation within 1 % area is small, Helmholtz-2 has practical advantages which are large entrance having the side length of 0.5445 d, same ampere-turn-ratio, and short total coil length. Cubic-3 has the entrance size having side length of 0.5 d, and the corresponding area has the deviation within 1 %. In contrast, SimpleCubic-3 has the deviation within 2 % for the area corresponds to the entrance size. In order to evaluate the available volume, the uniformity is also calculated along a line parallel to the axis. An example is shown in Fig. 2. It seems that SimpleCubic-3 achieves the deviation of 2.6 %
field uniformity at the sphere volume of 0.5 d diameter. It is better value compared with other relatively simple coil system, such as 3.7 % of Cubic-3 and 7.7 % of Helmholtz-2.

Conclusions. Practical performance of several coil systems for use in uniform magnetic field generation to three-dimensional direction has been studied. It was found that SimpleCubic-3 has both of practical advantages of Helmholtz-2 and Cubic-3.

![Figure 1](image.png)

**Figure 1.** Comparison of the uniformity along the axis
Objective. Public concern has focused on the effect of exposure to the magnetic fields produced from household appliances on human health [1]. Recently, induction cooking appliances (IHs) have begun to be widely used in homes and restaurants. More knowledge is needed to better understand the leakage magnetic fields produced by IHs.

Methods. In this paper, the effects of the size and material of pan and the shape and material of chassis of IH on the amplitudes and direction of leakage flux density vectors were investigated 3D nonlinear magnetic fields analysis taking account of eddy currents. Moreover, the experimental verification was also carried out. In order to obtain the distribution of leakage magnetic flux densities produced from a general type of an induction cooker for home use, which has two IHs of 2kW with 20kHz, a nonlinear steady eddy current analysis with the finite element method and the measurement using the magnetic field probes (HP 11941A) were carried out.
**Results.** Fig. 1 shows an analyzed model for IH with small pans. In the analyzed results, the magnetic flux leaks to the front of IH through the pan and returns to the corner of chassis. Fig. 2 shows the effective value $B_e$ of leakage flux density at the line $x = z = 0$ produced by IHs with the several type of pans. The analyzed result of small pan almost accords with the measured one.

**Conclusions.** The distributions of the leakage flux densities are much affected by the type of pan due to the difference of the flux paths and eddy current effects, which become clear by numerical analysis in this paper.

Reference

**Figure 1.** A model for induction cooking appliance (half region).
P-98 IMPROVEMENTS TO A WAVEGUIDE BASED EXPOSURE SYSTEM FOR STUDYING MICROWAVE FIELD EFFECTS ON THE CONTRACTILE FORCE OF SKELETAL MUSCLE

Paulo Vandenberg¹, Robert Wiese², Indira Chatterjee¹, Dana McPherson¹, Gale Craviso²
¹University of Nevada, Reno, Reno, NV, USA ²University of Nevada, Reno, Reno, NV, USA

Objectives. The potential exists for developing medical applications of microwave fields that target physiological processes such as skeletal muscle contraction in a controlled, mechanistic manner. Preliminary experimental studies using the microwave exposure system described in Lambrecht et al. (2006) and the mouse hindfoot flexor digitorum brevis (FDB) muscle have indicated decreases in tetanic contractile force, but not peak twitch force, when the muscle is exposed to microwave fields in the frequency range 0.75 – 1 GHz. However, due to certain limitations in the design of the experimental apparatus, it is not possible to completely rule out thermal effects as a possible cause of the changes in muscle behavior. The goal of this work is to improve the design of the exposure system to eliminate the possibility of thermal effects occurring during skeletal muscle contraction studies.

Methods. The exposure system consists of an organ bath within a waveguide, with the muscle suspended vertically within the inner chamber of the organ bath and Tyrode solution

FIGURE 2. Effect of pan on flux distribution (z=0).
continuously perfusing the muscle from the bottom of the chamber. During microwave exposure, temperature monitoring within the organ bath demonstrated that the Tyrode solution in and around the muscle was maintained to within ±1°C of the physiologically relevant value of 35°C for FDB muscle. However, the Tyrode solution in the inlet tubing to the inner chamber of the organ bath was being significantly heated before it reached the organ bath. As a strategy to reduce the heating of the Tyrode solution in the inlet tube, a Tyrode filled cylinder was constructed out of polypropylene and positioned such that it surrounded the inlet tube and lower portion of the organ bath. Finite Difference Time Domain (FDTD) modeling using the commercially available software package XFDTD (Remcom, Inc.) as well as thermal modeling (using CosmosFloWorks) are being used to compute the detailed E field and SAR distributions, and temperature distribution in the organ bath and inlet tubing. FDTD and thermal modeling are also being employed to redesign the organ bath and increase the ability of the system to prevent heating of the incoming Tyrode solution.

**Results.** Experimentally it was observed that the temperature of the Tyrode solution in the inlet tubing to the inner chamber of the organ bath was in excess of 45°C in the presence of the microwave field. This increase in temperature was consistent with FDTD modeling results indicating the presence of a very high E field. Preliminary experiments with the Tyrode filled cylinder surrounding the inlet tubing and lower part of the organ bath demonstrated a significant decrease (by up to approximately 50%) in the extent to which the temperature of the Tyrode solution inside the inlet tubing increased. FDTD modeling further showed that the SAR and E field decreased significantly with the addition of the Tyrode filled cylinder. FDTD and thermal modeling results will be presented to show the effect of refinements to the organ bath design on the temperature in the inlet tube.

**Conclusions.** The increased temperature of the Tyrode solution inside the inlet tube could result in a number of phenomena including a decrease in oxygen tension of the Tyrode solution as well as possibly the destruction of heat-sensitive components of the serum that are present in the Tyrode solution and which are important for optimal/maximal contractile force. Whereas our original organ bath design and the corresponding FDTD modeling results were mostly concerned with producing homogeneous nonthermal levels of E field in the vicinity of the muscle, it has now become apparent that attention also needs to focus on redesigning the organ bath to reduce the E field and hence the heating of the Tyrode solution that occurs in the inlet tubing. Both experimental and numerical techniques are being utilized to accomplish this objective.

**REFERENCES:**
Acknowledgements. This research was supported by the Air Force Office of Scientific Research grants F49620-03-1-0262, FA9550-04-1-0194 and FA9550-05-1-0308.

* P-99 APPLICATION OF GIS AND LAND REGISTER FOR ESTIMATION OF MF EXPOSURE POPULATION AROUND 154KV POWER LINE  
Seung-Cheol Hong¹, Kim Keun-young¹, Jung Joon-Sig¹, Kim Nam²  
¹INJE University, Gimhae, South Korea ²Chungbuk National University, Cheongju, South Korea  

Objectives. The aim of this study is the usefulness of 2D Geographical information system (GIS) and land register system for estimation of MF exposure population under 154kV power line in the south metropolitan area of Korea.

Methods. The possible exposure area of magnetic field, which is emitted from the 154kV power line, is calculated to the total four hundred meters, expanding two hundred meters toward the left and right sides each directly under the power line, and the area is classified according to the purposes of land in the land register. The layers of administrative districts (Dong, lot number), buildings, population, and the location of the power line (acquisition of GPS coordinates) on a digital topographic map (1:7500) of the object area are collected to make a basic geographical data for the realization of 2D GIS map. The object area of the research, as the south metropolitan area, has facilities (parks, neighboring facilities, arcades and so on) scattered evenly through the area, and several land uses (58.06 percent of forests and fields, 34.6 percent of residential district and 7. 48 percent of paddy and ordinary fields, and others) according to the land register. The exposure area of magnetic field is indicated on the 2D GIS, and the number of household within the area is determined by using a resident registration book to calculate the coefficients per purpose of land use.

Results. The actual population inhabited in the magnetic field exposed area, which is calculated via a resident registration book, is fifty five hundred and four, and in case assuming that the number of residents in mountains and greens is zero and the number of members per household is four in residential districts according to the land register, the population is presumed to be sixty two hundred eighty, and in the case of three members per household, the presumed population is forty seven and ten. The difference between actual number and presumed number of residents is based on the fact the mean value of a family member is under four, which is a value of general household, and it is also thought that the social economic status of the object area is relatively inferior, so there are a lot of households with one member such as old people living alone.
Conclusions. If classifying the types of dwelling houses in the object area, it is divided into single-family houses (two lots), row and multi-family houses (eleven lots); the resident population coefficient per household can be set as two point seven-two and two point nine-three each. In case calculating the exposure population in thirteen lots by applying the resident population coefficient above, the number is forty five hundred and eighty five point zero-five and it shows the most approximate value with the error of eighty one point zero-five (1.8%).

Figure 1.

P-100 MEASUREMENT OF INTERMEDIATE-FREQUENCY MAGNETIC FIELDS EMITTED FROM ELECTROMAGNETIC COOKERS USING A LARGE-SIZE LOOP COIL ANTENNA

Isao Kayano\textsuperscript{1}, Seiichi Mochizuki\textsuperscript{2}, Yasuo Ogasawara\textsuperscript{2}

\textsuperscript{1}Kawasaki College of Allied Health Professions, Kurashiki, Japan \textsuperscript{2}Kawasaki Medical School, Kurashiki, Japan

Objectives. Using a large-size loop coil antenna with a surface area equivalent to an adult trunk, we aimed at measuring an intermediate-frequency magnetic field emitted from an electromagnetic cooker.
Methods. A magnetic field was measured in the electric-wave darkroom located in the Industrial Technology Center of Okayama Prefecture, Okayama, Japan (ANSI-C 63.4; room size: length=7.9 m, width=6.0 m, height=6.7 m). The baseline magnetic field noise in the room was 2 or less pT over the measured range of 9 kHz-30 MHz. The Helmholtz type loop coil antenna (inner diameter: 560 mm) with a surface area equivalent to an adult trunk was used, and a frequency analysis was performed over 9 kHz-30 MHz. Two types of electromagnetic cookers were studied (100 V, 60 Hz for both). Each cooker was located on a wooden desk (height: 1.2 m), and the loop antenna was located at a distance of 1 m, 2 m or 3 m from the center of the cooker (Fig. 1). Both horizontal and perpendicular magnetic fields were measured. A stainless-steel kettle (inner diameter: 210 mm) filled with tap water was put on the cooker during measurement. We performed measurement at the following five states of power supply: 1) disconnect, 2) standby, 3) output level: LOW, 4) output level: MIDDLE (MID), and 5) output level: HIGH. The square root of the sum of squared values measured in both horizontal and perpendicular directions was used as the magnetic field intensity.

Results. At 1 m from the cooker, an output level was changed at three levels. In Model A, the maximum magnetic field was not dependent on the output level (11.76 nT for all three levels). The frequency for the maximum magnetic field was 31.91 kHz (LOW), 26.19 kHz (MID), and 24.05 kHz (HIGH), respectively. In Model B (Fig. 2), the maximum magnetic field was 10.36 nT (LOW), 11.76 nT (MID), and 11.89 nT (HIGH), respectively. The frequency for the maximum magnetic field was 40.96 kHz (LOW), 39.92 kHz (MID), and 25.15 KHz (HIGH), respectively.

At an output level of HIGH, measurement distance was changed to 1 m, 2 m or 3 m. In Model A, the maximum magnetic field was 11.76 nT (1 m), 2.89 nT (2 m), and 2.95 nT (3 m), respectively. The frequency of the maximum magnetic field was not dependent on the measurement distance (24.05 kHz for all three distances). In Model B, the maximum magnetic field was 11.89 nT (1 m), 3.43 nT (2 m), and 3.35 nT (3 m), respectively. The frequency of the maximum magnetic field was not dependent on the measurement distance (25.08 kHz for all three distances).

In both two models, the magnetic field frequency decreased with increasing output level. However, no noticeable change was observed in the maximum magnetic field. This may be due to the fact that the frequency/DUTY ratio of the applied current automatically adjusts the output level. In the previous studies, other groups used a minute dipole antenna and reported that the maximum magnetic field was in inverse proportion to the 3rd power of distance, while in this study the 2nd power of distance with about 1/10 intensity (Fig. 3).

Conclusions. The magnetic fields emitted from electromagnetic cookers were in inverse proportion to the 2nd power of distance with about 1/10 intensity, compared with the local magnetic field. As for the biological effects of a magnetic field, the induced current intensity in the body exposed to the field should be evaluated, and thus the present study suggests that the current induced by an electromagnetic cooker is estimated to be in inverse proportion to the 2nd power of distance, not the 3rd power.
**Figure 1.** Situation of measurement

**Figure 2.** Magnetic field (Model:B)
Figure 3. Decay curve of magnetic fields
P-101 DETERMINING THE THRESHOLD OF LIGHT EXPOSURE REQUIRED TO ELIMINATE ELECTROMAGNETIC SHIELDING INDUCED ANALGESIA IN CD-1 MICE.

Lynn D. Keenliside¹, Frank S. Prato²³, Dawn Desjardins¹, Alex W. Thomas¹²
¹Lawson Health Research Institute, London, ON, Canada ²University of Western Ontario, London, ON, Canada ³St Joseph’s Hospital, London, ON, Canada

Objectives. Previous experiments have shown in mice (Prato et al, 2005) that repeated daily exposure to a magnetically shielded environment induces analgesia that peaks at 5 days. (Koziak et al., 2006) has shown that simultaneous exposure to visible light (400-750 nm); 1.35x10¹⁸ will abolish the effect and other intensities and wavelengths have similar effects (Prato et al, 2006). This report defines the intensity threshold for blue (470nm) light and explores the effect of ultraviolet (UV, 405nm) light.

Methods. A series of experiments have been performed, starting with blue light at 250%, 100%, 50% of the intensity measured in their living quarters and UV light at the same number of photons as blue100%. Light levels were established as the total number of photons under the curve of each colour spectra. We measured light levels in the mouse living quarters with a LightSpex spectroradiometer and data were used as reference levels for the light exposures within the enclosures. We used our previously established protocols and Swiss CD-1 mice 2-4 months old. During their mid day cycle, mice were individually placed in mu-metal enclosures which reduce the ambient magnetic field by a factor of 100 or more. Enclosures are equipped with external LED sources powered by direct current. Internal electromagnetic field coils were disconnected. Mice are contained within a plastic cage that keeps them centrally located in the enclosure. Transparency of the cage and light pipes at wavelengths down to 405nm was confirmed with the spectroradiometer. Prior to being placed in the enclosure and immediately following the 1 hour exposure, mouse nociception (pain sensitivity) was measured as the latency to an aversive behaviour to a noxious thermal stimulus produced by a hot plate analgesiometer (50±0.5°C). For all experiments the 1 hour daily exposure was carried on for 5 consecutive days. Series 1 with N=100 showed the threshold to be less than 50% of their ambient light levels and 100% UV light had the same effect, so a second series of N=60 was performed with blue exposures of 25%, 12.5% and 6% (UV light exposure was not repeated).

Results. A review of figure 1 shows all four light conditions eliminated the analgesic effect while the dark condition clearly shows the analgesic response rising to day 5. Figure 2 shows results of series 2 and indicates a return of analgesia between 6% and 12.5%. Previous experiments showed red and yellow light having very little effect, with greater effect of green light and strong effect of blue. This corresponds with published data for visual acuity for rodents. These latest experiments continue to confirm a correlation of ELF magnetic field effects with visual perception of mice into the near UV range.
Conclusions. Although it seems evident the effects of light on nociception from magnetic shielding are a visual response, we could only confirm this by repeating the experiment with blinded mice. We have not studied potential confounding effects of conditioning by the ambient light intensities and frequencies in the animal housing facility which uses SP41 fluorescent lights common within the facility.

Acknowledgements. This study was funded in part by grants from the Canadian Institute of Health Research and the Ontario Research and Development Challenge Fund.

Figure 1. -Experiment 1, open circles are pre-exposure while closed circles are post exposure in mu-metal enclosure with blue light 50%, 100%, 250% & UV 100%. N=100
Objectives. In the previous reports, we note that ELF EF may improve the stress response but the elucidated mechanism remains unclear. The aim of this study is demonstrate whether the condition of EF used on our past studies is sensible or not for rat.

Methods. A conditioned place preference (CPP) paradigm was utilized in order to examine whether a 50 Hz electric field (EF), which was used in our studies, is perceptibility for rat, and whether it forms behavior of preference or aversion in rats. Twenty-one adult male Wistar rats were divided into two groups, EF and sham EF exposed group. As a place conditioning, rats were within a white area of CPP apparatus for 30 minutes in the presence of EF, subsequently they were moved into a black area of CPP apparatus for 30 minutes in the absence of EF. The condition of EF exposed to rats was 50 Hz, 17500V/m. Rats of control group were similarly handled, except for EF off. After the intervals of training for 6 days, the behavior of rats was measured by recording the residence time within the white and black area for observation times of 900 second.

Figure 2. -Experiment 2, open circles are pre-exposure while closed circles are post exposure in mu-metal enclosure with blue light 6%, 12.5%, 25%. N=60
**Results.** The residence time within white area in rats exposed to EF showed significantly longer than those of control (P<0.05).

**Conclusions.** These results indicate that intensity of EF used in this study is sensible for rat but does not cause aversion behavior in rat.

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**P-103 STUDY OF CAENORHABDITIS ELEGANS GENOME STABILITY DUE TO HIGH INTENSITY RADIOFREQUENCY EXPOSURE**

San Ming Wang\textsuperscript{1}, Eleasa Kim\textsuperscript{1}, Jun Chen\textsuperscript{1}, Yeong C. Kim\textsuperscript{1}, Sanggyu Lee\textsuperscript{4}, Howard L. Gerber\textsuperscript{2}, Charles C. Tseng\textsuperscript{3}

\textsuperscript{1}Northwestern University, Evanston, IL, USA \textsuperscript{2}Purdue University Calumet, Hammond, IN, USA \textsuperscript{3}Purdue University Calumet, Hammond, IN, USA \textsuperscript{4}Kyungpook National University, Daegu, South Korea

**Objectives.** The objective of this study is to determine the genome stability due to high intensity radiofrequency exposure in vivo using Caenorhabditis elegans.

**Methods.** The living organism model for this study was C. elegans that was synchronized at the same growth stage and exposed at 2.4 GHz (SAR~10W/kg) for 24 hrs (see BEMS abstract "A 600 Nanosecond Pulsed RF Exposure System for Caenorhabditis elegans"). The same synchronized C. elegans were placed in an identical sham control environment without an RF exposure. We then analyzed the genomic DNA structure using a Ditag Genome Scanning technology. This technology collects two short tags representing the ends of a set of restricted fragments. Essentially, the ditags represents each of the restricted fragments. By collecting sufficient ditags, we can detect genomic DNA structure at the genome level. We compare the ditag sequences between the exposed and non-exposed samples. If the genome structure changes due to the RF exposure, the ditag sequences representing the DNA fragments should be different.

**Results.** From the exposed and the control samples, we identified 50,000 ”ditags”, covering about 40% of the C. elegans genome. Of those ditags, we identified approximately 15,000 unique ditags, of which 80% can be mapped to C. elegans genome database; 3,000 ditags between the two samples were overlapping. The remaining unique ditags were present only in either sample. We have identified several hundreds of ditags present in the control but not in the exposed sample, indicating possible damages of the genomic DNA in the regions covered by these ditags.
Conclusions. The method allows the comparison of ditag sequences between exposed and non-exposed genomes and thereby infers genome stability. The detected ditag differences between the control and exposed organisms may indicate DNA damages at specific regions due to RF exposure. We are in the process of experimental confirmation to determine if these represent the broken DNA fragments.

Acknowledgements. This research is supported by an AFOSR DOD MURI grant.

P-104 EXTREMELY LOW FREQUENCY MAGNETIC FIELDS AFFECT TRANSCRIPT LEVELS OF NEURONAL GENES IN CAENORHABDITIS ELEGANS

Shin-ichi Harada$^1$, Sotoshi Yamada$^2$

$^1$Kanazawa University Graduate School of Medical Science, Kanazawa, Japan $^2$Kanazawa University, Kanazawa, Japan

Objectives. Many public concerns have been raised over the possible and health effects of exposure to extremely low frequency magnetic fields (ELFMFs). Some epidemiological studies have indicated positive correlations between magnetic fields and various types of cancer or other disease, including neurological disorders, but assessments remain contradictory. Recent data with ELFMFs showed significant morphological changes in neuronal cells, increase in single- and double-strand DNA breaks in brain cells, and altered Ca$^{2+}$ homeostasis and related signalling processes. The identification of potential hazardous effects of ELFMFs on neuronal cells is of special importance. In previous work, to investigate the biological effects of ELFMFs in nervous systems, we performed the screening of magnetic fields responding genes by differential display method in nematode Caenorhabditiselegans (C. elegans), and identified ncs-2 gene, one of the neuronal calcium sensor (NCS) genes. Moreover, we demonstrated quantitative RT-PCR analysis to confirm reproducibility of the mRNA expression levels of ncs-2 gene and related genes.

Methods. ELFMFs generator
The high magnetic field generator is composed of two E-type cores with their poles placed face to face. By supplying a 60 Hz, 190 A current, an AC magnetic fields with a peak flux density of 0.5 T can be produced. This machine was cooled by a high performance water circular system, and a quartz thermometer was used to monitor temperatures under the experiment. Wild type C. elegans were exposed into a plastic dish to the high magnetic field generator at 20 °C for 120 min x 0.5 T (exposed). As a control, worms were also incubated without exposure to ELFMFs at 20 °C for 120 min (control).

Detection of mRNA levels by quantitative RT – PCR
To determine the transcript levels of isolated genes, mRNA was quantified with a SYBR
Green assay kit by one-step reaction according to the manufacturer’s protocol. Reaction parameters were a cycle at 48°C for 30 min, 95 °C for 10 min, and followed by 40 cycles of at 95 °C for 30 sec, 60 °C for 60 sec. A sham exposed control is standardized as 100 arbitrary units and compared to exposed case. All data are expressed as mean ± S.D. obtained from at least three individual experiments. Statistical significance of obtained results was verified using Student’s t-test and p < 0.05 was considered significant.

**Results. Quantitative analysis of neuronal genes by RT – PCR**

To study the quantification of mRNAs which were screened by differential display, the expression level of ncs gene’s product between control and exposed case was compared by quantitative RT-PCR. The ncs-2 identified by differential display has reported primarily expressed in the neuronal cells, and also ncs gene exist three homologues, ncs-1, ncs-2 and ncs-3, in C. elegans. As a result of quantitative RT-PCR, no significant changes of each ncs mRNA was detected under sham exposed control. When exposed ELFMFs, three ncs genes were significantly down-regulated. (Fig. 1)

It is known that tax gene mutants have shown the abnormal thermotaxis in C. elegans. As ncs-1 mutant shows same phenotype with tax mutants, ELFMFs effect in the mRNA level of tax-2 and tax-4 was examined by RT-PCR. As a result of it, it was confirmed that tax-2 and tax-4 were also significantly down-regulated by ELFMFs exposure (Fig. 2). Since tax-2 and tax-4 genes would be expressed in AFD sensory neuron, as a thermosensory neuron, the expression of hsp-16.2, one of the heat shock proteins, was analysed by RT-PCR whether the effect of expression was occurred by eddy currents. No significant changes were observed between control and exposed case (data not shown). We considered that there is no heating effect in C. elegans cells by the eddy current.

**Conclusions.** We found that ncs-1, -2 and ncs-3 mRNAs were significantly down-regulated under ELFMFs. Both tax-2 and tax-4 gene products have coded cyclic nucleotide gated channel subunits, and considered to regulate the influx of the Ca\(^{2+}\) ion. Then expression of tax-2 and tax-4 mRNA was examined by RT-PCR, and it was detected that tax-2 and tax-4 mRNAs were significantly decreased by ELFMFs exposure. Further, we detected the unc-18, Syntaxin and unc-13 genes associated with synaptic transmission were significantly decrease their mRNA levels under ELFMFs exposure (data not shown). Based on results obtained from RT-PCR, it may be concluded that some Ca\(^{2+}\) signaling and synaptic transmission related genes on neuron will be affected the expression levels by ELFMFs in C. elegans.

**Acknowledgements.** This work was supported by a grant from the Magnetic Health Science Foundation and a Grant-in Aid for Scientific Research (C) from the Ministry of Education, Science, Culture and Sports of Japan (17500250) to S.H.
Figure 1.

Figure 2.
**P-105** EFFECTS OF LOCAL EXPOSURE TO 1,457 MHZ ELECTROMAGNETIC FIELD UNDER HIGH INTENSITY CONDITIONS ON CEREBRAL BLOOD FLOW IN THE RAT BRAIN

Hiroshi Masuda\(^1\), Akira Ushiyama\(^1\), Miyuki Takahashi\(^1\), Shogo Hirota\(^1\), So Tanaka\(^2\), Hiroki Kawai\(^2\), Kanako Wake\(^2\), Soichi Watanabe\(^2\), Masao Taki\(^3\), Chiyoji Ohkubo\(^4\)

\(^1\)National Institute of Public Health, Saitama, Japan \(^2\)National Institute of Information and Communications Technology, Tokyo, Japan \(^3\)Tokyo Metropolitan University, Tokyo, Japan \(^4\)World Health Organization, Geneva, Switzerland

**Objectives.** The possibility of radio-frequency electromagnetic fields (RF-EMF) of mobile phones to cause any adverse health effects on the brain is a subject of numerous studies and publications. Our previous studies have shown that no blood flow changes in pial microcirculation were found in the rat brain locally exposed to 1,439 MHz EMF even at 4.8 W/kg of brain averaged specific absorption rate (BASAR). On the contrary, a recent study reported that the blood flow in the human brain increased after the exposure to pulse-modulated 900 MHz EMF at 0.27 W/kg of BASAR. Therefore, it was necessary to define the intensity of local exposure of brain to RF-EMF which would affect the cerebral blood flow locally. The aim of the present study was to investigate a relationship between the exposure intensity and the changes in cerebral blood flow, considering body temperature and arterial blood pressure.

**Methods.** Male Sprague-Dawley rats (8 weeks old) were used in this experiment. The rats were anesthetized with an intramuscular injection of ketamine (100 mg/kg) and xylazine (10 mg/kg), and with a subcutaneous injection of pentobarbital (25 mg/kg). The head of each animal was fixed in the stereotaxic apparatus and locally exposed to 1,457 MHz electromagnetic near-field TDMA (time division multiple access) signal for PDC (Personal Digital Cellular, Japanese cellular telephone standard) system to simulate the exposure by mobile phones using an “8”-shaped loop antenna. The field intensity was adjusted to make 0, 26, 77, 308 W/kg in BASAR (5-6 rats each). Whole-body exposures occur concomitantly. In this case, relative value of whole body averaged SAR was 1/15.6 of the BASAR. The three parameters, cerebral blood flow, temperatures in three regions of rat (parietal, subpharyngeal, and rectal regions) and arterial blood pressure were simultaneously monitored for 18 minutes including an exposure period for six minutes. The cerebral blood flow was measured in the brain surface area via craniectomy using a Laser-Doppler flowmeter. The time-courses of each parameter were presented as those averaged values for every one minute.

**Results.** The temporal increase in cerebral blood flow was observed only in the exposed rats at 308 W/kg of BASAR. The blood flow increased throughout the exposure and returned to the basal level six minutes after the exposure. The local exposure of rat brain to RF-EMF resulted in dose-dependent increases in each regional temperature. However, significant differences in maximal temperatures were found in the exposures at 77 and 308 W/kg of BASAR but not at 0 or 26 W/kg. The parietal and subpharyngeal temperatures temporally increased depending on the exposure period, whereas the rectal temperature slowly increased to plateau value and remained it after the exposure. The arterial blood
pressure augmented during the exposure only at 308 W/kg of BASAR with the similar time-course observed the blood flow response.

Conclusions. An increase in cerebral blood flow was found only in the RF-EMF exposure at 308 W/kg of BASAR, although each regional temperature significantly rose both at 77 and 308 W/kg. In addition, a temporal increase in arterial blood pressure was also observed only at 308 W/kg of BASAR. These findings suggest that the cerebral blood flow is not modified by the local exposure to RF-EMF even at high intensity, while systemic temporal hypertension occurs due to hyperthermia.

Acknowledgements. This study was financially supported by The Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields, the Ministry of Internal Affairs and Communications, Japan.

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* P-106 MECHANISM OF PERIPHERAL SKIN TEMPERATURE CHANGE CAUSED BY ELF ELECTRIC FIELD EXPOSURE.

Masaji Yamashita¹, Kazuo Ohsaki², Koichi Shimizu³
¹Hokkaido Institute of Technology, Sapporo, Japan ²Hakuju Institute for Health Science Co.Ltd., Tokyo, Japan ³Hokkaido University, Sapporo, Japan

Objectives. In our previous study, we have found that the local exposure of 50 Hz electric field suppressed the natural decrease of skin temperature. This suggested the effect of field exposure on autonomic nerve response. To clarify this mechanism, two kinds of experiment were conducted. First the palm perspiration was measured in the same protocol as the skin temperature measurement reported previously. This result helped us to judge whether the effect was due to the sympathetic or parasympathetic nerve response. After finding the origin of this effect, we examined this effect of field exposure in the common test of the sympathetic nerve response.

Methods. In the first experiment, the temporal change of palm perspiration was measured. The sensor parts of a perspirometer and a laser Doppler flow-meter were attached at the palm of the subject. Other parameters to monitor the autonomic nerve response were also measured, such as the pulse wave, respiration, and ECG. A 50 Hz electric field was generated between circular plane parallel electrodes (50 cm dia., 10 cm separation) by applying high voltage (10 kV AC) from the power source of a therapeutic device. In the experiment, the hand and the forearm of the subject were inserted between the horizontal electrodes and kept on the lower electrode. The field strength on the hand and the forearm is estimated from 100 kV/m to 155 kV/m. This strength is in the similar level to that a patient experience with the therapeutic device. The time course of the experiment consisted of three sessions, i.e. 15 minutes rest, 30 minutes field exposure and 20 minutes rest periods. A subject sat on the chair of the therapeutic device. The electric field was applied without any noticeable
cue following the rest period. Then the electric field was switched off without any cue, as well. The physiological parameters were measured in 200 Hz sampling rate. The data were divided into 7 analyzing sections (rest 1, rest 2, expo.1, expo.2, expo.3, rest 3, rest 4) of 5.5 minutes period. The time course of the experiment and the method of data acquisition were the same as in our previous experiment in which we found the field effect on the skin temperature decrease.

In the second experiment, the skin temperature was measured at the left ring finger of a subject in the well-known Kraepelin test. The time course of the experiment was as follows. A subject sat on the chair of the therapeutic device and kept rest for 10 minutes. Then he was instructed to answer the Kraepelin test for 10min. and kept rest again for 35 minutes. An electric field was applied to him for 30 minutes from the start of the Kraepelin test. The field was exposed to the subject using the therapeutic device. With this device we could apply 30 kV to the soles of the subject through an insulating plate. As a result, the field up to 300 kV/m was exposed to his head and about 100 kV/m to his hand. Prior to the experiment, the purpose, the possible risks and the procedure of the experiment were explained to each subject, and the consent was obtained. The experiments were carried out in the double-blind method.

**Results.** Figure 1 shows the temporal change of the palm perspiration. The measured values were averaged in each time section and normalized as the ration to the value of the "rest 2" period. The subject was forced to keep same posture with his arm fixed between the electrodes. This gave physical and mental stress to subjects, and the perspiration as a mental sweating increased in the later periods, particularly in the sham-exposed case. This result of palm perspiration, with other physiological parameters, suggested that the field exposure suppressed the response from the sympathetic nerve system.

In the second experiment, the skin temperature decreased as the subject underwent the mental stress of the Kraepelin test. This decrease of the temperature was suppressed by the electric field exposure with statistical significance.

**Conclusions.** In the first experiment, the increase of the palm perspiration was suppressed by the local field exposure in the same manner as the previously reported skin temperature. This suggested that the effect on the sympathetic nerve response is one of the significant mechanisms for the suppression of the temperature decrease caused by the local field exposure. In the second experiment using the well-established test, the effect on the sympathetic nerve response was verified and the suppression of the response was confirmed in the field exposure to the whole body.
OBJECTIVES. Objective of the work was to investigate effects of mollusk neuron exposure to Electromagnetic field (EMF) irradiated by cell phone.

METHODS. Isolated nervous system of the mollusk Helix Pomatia was used in the study. Exposure to EMF and dosimetry:

Transverse electromagnetic cell (TEM Cell) was used for EMF exposure and dosimetry. After proteolytic treatment the ganglion was fixed in the foam plastic small chamber containing Ringer solution and placed into TEM Cell for EMF exposure. Selection of this material was conditioned because dielectric characteristics of this material is approximately equal to air and SAR and temperature increase calculations are simplified. Distribution of SAR and temperature increment was calculated based on FTDT method. Commercially available cell phone was used as EMF source, which was connected to the TEM Cell. Usage of the test card provided constant output power of cell phone.

Electrophysiology

After exposure to the EMF in the TEM Cell, ganglion was placed on the Petri dish and placed in the screen chamber for electrophysiological investigations. Two identified giant
neurons were selected for investigation. Standard microelectrode technique was used. Neuron was impaled with two glass microelectrodes. One microelectrode served for registration, another one - for intracellular stimulation. Stimulant (ST) intracellular impulses represented train of outward current impulses. Pair of glass suction electrodes was used for extra cellular stimulation. Stimulus was applied on Left Pallilal nerve. Stimulus represented voltage pulse train.

Neuron activities were recorded using the POWERLAB data acquisition unit "ML 866" of Adinstruments Co. accompanied with "Chart 5" software with Peak parameter extension. AP inter-spike intervals, action potential peak parameters, latency periods, thresholds of AP firing were determined. Habituation dynamics to identical stimulus of sham and actually irradiated neurons were compared.

**Results. Intracellular stimulation**

**Sham irradiation**

Neuron shortly reacts to ST with APs and very soon habituates. Habituation is expressed in decline of stimulus induced impulses by neuron. Time necessary for arising habituation varies from several seconds to 1-2 minutes. Repeat of applying of the stimulant intracellular impulses causes significant increase of latency period. The threshold augmentation is less than the rate of latency increase. Peak Parameters of AP are slightly changes due to repetition of stimulation: Rise and falling times of the APs are increased. The width of APs is augmented. Rest facilitates recovery of reactions on stimulus, although new habituation arises much sooner. If stimulant impulses amplitude is increased, reactions appear (APs) and new habituation requires longer period. A sample recordings of sham irradiate case is shown in the fig1A.

**Effects of exposure in the TEM Cell**

Exposure to EMF causes suppression of neuron habituation ability. On the stimulus slightly higher the threshold neuron reacts for several dozens minutes without habituation. Latency revealed some trend of irregular oscillations; however trend is not increasing function. The same could be said about the threshold. Peak parameters of exposed to EMF neurons were investigated also. Some components of these parameters change during stimulation. However the changes are not significant and they occur after long period of stimulation. Sample recordings of neuron reactions, which was exposed to EMF in the TEM Cell is shown in the fig1B.

**Extracellular stimulations**

**Sham irradiation**

Habituation on the nerve stimulation appears promptly - in 1-2 minutes. Nerve stimulation with train of voltage impulses causes EPSPs, amplitude of which is sufficient to generate APs. However, very soon, neuron declines the EPSPs and dos not show AP firing. Recurring of the same stimulus on the nerve after several minutes do not destroy habituation – neuron declines all STs. Slightly increased stimulus is not able to destroy habituation. Peak parameter exploration shows that AP parameters are slightly changed; Wight of AP is augmented, accordingly rising and falling times of AP are delayed. A sample recordings of sham irradiate case is shown in the fig1C.

**Effects of exposure in the TEM Cell**

Exposure of the neuron to EMF in the TEM Cell causes significant prolongation of reaction
time. Habituation does not appear for dozen minutes. Times for reaction proceedings are significant different at sham and actually irradiated cases. Peak parameters show some changes however these changes are not significant. A sample recording of neuron reactions, which was exposed to EMF in the TEM Cell is shown in the fig1D.

**Conclusions.** Cell phone irradiation suppresses neuron habituation ability.

**Acknowledgements.** The work is supported with grant of international scientific technical center ISTC # G-1187.
Figure 1.
A- Sham exposure: Neuron reactions and habituation on intracellular current impulses. Amplitude of stimulant impulse is 0.1 NA, duration-4ms.
B- Exposure to EMF in the TEM Cell. Exposure time 60 min. SAR=0.67 w/kg, ΔT=0, 1C. Stimulation with the same stimulus. Reactions without habituation were continued for 25 min.
C- Sham exposure: Neuron reactions on the nerve stimulation. Stimulant voltage impulse amplitude is 0.8 V, duration 30 ms., apply frequency 1.2 Hz.
D- Exposure to EMF in the TEM Cell. Exposure time 60 min. SAR=0.67 w/kg, ΔT=0.1C. Stimulation with the same stimulus. Reactions without habituation were continued for 17 min.
Stimulant impulse apply is not shown because each of them causes artifact on recordings.
Caliber: On the X axis is shown time in seconds, n the Y axis voltage. Each division on the Y axis corresponds to 10 MV.
P-108 NANosecond Pulsed Electric Fields (NSPEFS) CAused BCL-2 Down Regulation in Melanoma B16-F10 Tumors On SKH-1 Mice

James R. Swanson\textsuperscript{1,3}, Xinhua Chen\textsuperscript{1,2}, Richard Nuccitelli\textsuperscript{3}
\textsuperscript{1}Old Dominion University, Norfolk, VA, USA \textsuperscript{2}Zhejiang University, Hangzhou, China \textsuperscript{3}Old Domion University, Norfolk, VA, USA

Objectives. Our initial studies revealed that apoptosis and angiogenesis involved in B16-F10 melanoma reduction caused by multiple treatment of nsPEFs. In this study we examined expression of bcl-2 expression in melanomas treated with nsPEFs and analyzed its relationship with apoptotic and vascular events.

Methods. Hairless mice SKH-1 were subcutaneously implanted with B16-F10 cells. After nsPEFs treatments (40 kV/cm field strength; 30 ns rise time; 300 ns duration), the apoptosis of implanted tumor was detected by TUNEL and the angiogenesis by micro vessel density. The gene expressions of bcl-2 in implanted tumor tissues were measured by RT-PCR. 66 melanomas were detected by tissue micro-array technology under the same condition of expression of Bcl-2, Bad, and cytochrome c with immunohistochemistry in situ.

Results. Immunohistochemistry was assigned in three categories: low (<35\%), medium (35–60\%), and high (>60\%). Treated tumors showed a significantly lower micro vessel density compared with control tumors (p < 0.001) while higher apoptosis (p < 0.05). Treated tumor also had a significantly lower expression of bcl-2 (p < 0.001), the same down regulated of bcl-2 was also shown in RT-PCR.

Conclusions. The present study suggests that bcl-2, an apoptosis-related protein, may be equally important for decreased angiogenesis in vivo caused by nsPEFs.
Poster Session 447

* P-109 ESTIMATION OF MAGNETITE DENSITY BY NEEDLE TYPE GIANT MAGNETORESISTANCE PROBE

Sotoshi Yamada¹, Chomsuwan Komkrit¹, Chinthaka Gooneratne¹, Makiko Kakikawa¹, Masayoshi Iwahara²
¹Kanazawa University, Kanazawa, Japan ²Kanazawa University, Kanazawa, Japan

Objectives. The hyperthermia cancer treatment based on induction heating by directly injecting magnetic fluid with magnetite to tumor has been proposed. (K. Tazawa & et al; J. Hyperthermia Oncology, 19, p. 79, 2003) To confirm that tumor is destroyed with sufficient heat, the amount of magnetite inside the human body has to be quantified before treatment. For the purpose, we developed the evaluation method of content density of magnetite based on magnetic measurement. To confirm the measurement, we discussed two points, the relationship between the density of magnetite and magnetic field inside cavity, and a new style probe to measure magnetic fields low-invasively inside the body.

Methods. When ac magnetic fields with frequency of several hundred kHz are applied to magnetic fluid, hysteresis loss, partially eddy-current loss, is induced and the tumor with injected magnetite is heated directly. Heat capacity, Q(W/mL), generated by magnetite can be calculated as follows:

\[ Q = k_m f D_w B^2 \]  
where \( f \); exciting frequency (Hz), \( D_w \); magnetic density per weight (mgFe/mL), \( B \); applied magnetic field (T), \( k_m \); \( 3.14 \times 10^5 \) (W/Hz/(mgFe/mL)/T²/mL). Therefore, it is important to estimate the density of magnetite inside the body.

We proposed the evaluation procedure of content density of magnetite based on magnetic measurement. We considered that there is the relationship between the density of magnetite and the permeability of magnetic fluid inside the cavity. According to our previous consideration, the relative permeability, \( \mu^* \), of magnetic fluid can be estimated as follows:

\[ \mu^* = 1 + 4D_v \]  
where \( D_v \) is the volume density and has the function of \( D_w \) and the specific gravity of magnetite. The equation indicates that the shape and size of magnetic particle do not affect the relative permeability.

As shown in Fig. 1, a uniform external magnetic flux, \( B_0 \), is generated by Helmholtz coil and applied to magnetic fluid in the tumor. The magnetic flux density at the center of the tumor, \( B_1 \), is more than \( B_0 \). The change ratio, \( \delta \), between the magnetic flux densities can be rewritten as,

\[ \delta = \frac{(B_1 - B_0)}{B_0 \times 100} = 4(1-N)D_v \times 100 \% \]  
where \( N \) is the demagnetizing factor of cavity depending on the shape. The volume density of magnetic fluid can be estimated if the difference of magnetic flux density inside the embedded cavity and applied magnetic flux can be measured.

The needle-type magnetic sensor as shown in Fig. 2, was fabricated in order to measure magnetic flux density inside the human body. The magnetic probe is consisted of giant magnetoresistance sensor (GMR).

Results. Magnetic fluid is packed into the cylinder storage tank with diameter of 15 mm and length of 15 mm. An external magnetic flux density with the frequencies of 100 and
200 Hz is generated by Helmholtz coil. The external field of 100 µT is applied to magnetic fluid.

The experimental result of the estimation is shown in Fig. 3. This figure denotes the relationship between the volume density of magnetic fluid and the change ratio of magnetic field densities. The calculated results expressed by Eq.(3) are drawn for the cavity with differential shapes. The experimental result for a cylinder tank has a linear function and has the function like the cubic volume.

Conclusions. To develop the proposed hyperthermia cancer treatment, it is important to estimate the content density of magnetite injected inside the body. We investigated the relationship between the difference of magnetic fields from external field and magnetic fluid volume density containing in an embedded cavity. The use of needle-type GMR sensor enables us to directly measure the magnetic flux density inside the cavity with minimal invasive.

Figure 1. Measurement system
Figure 2. Needle-type magnetic probe

Figure 3. Estimation of density of magnetite
**P-110 ”CAPACITIVE COUPLING SYSTEM” EXPOSURE. EVALUATION OF ELECTRIC FIELD IN SPINE**

Bruno Bisceglia¹, Ruggero Cadossi⁴, Assunta De Vita³, Maurizio Sarti², Stefania Setti⁴  
¹University of Salerno, Fisciano (SA), Italy ²IREA, Napoli, Italy ³Università del Sannio at Benevento, Benevento, Italy ⁴IGEA, Carpi (MO), Italy

**Objectives.** With this non-invasive method the biological effects are linked with the sole presence of the time-varying electric field. The method foresees the use of electrodes placed in contact of the skin by means of conductive gel. The voltage applied is 40 \( V_{pp} \) at frequency of 60 kHz. The site of interaction of the electric field lies at the level of the cell membrane; an increase in \( Ca^{++} \) transport across voltage-gated channels is observed followed by an increase in cell proliferation. Furthermore, the exposure to electric field of osteoblast-like primary cells increases the synthesis of bone matrix and favours their proliferation and differentiation. Electrical stimulation is aimed at favouring early and rapid activation of the repair process, which must lead to bone healing. The combination of the aforesaid stimulation with bone grafts has achieved very favourable results in cases of spinal fusion; the success rate of bone graft alone is not very high and it takes a long time. Vertebrae interbody fusion is utilized in most instances in patients suffering from low back pain.

**Methods.** Electrical stimulation in the treatment of bone can be investigated in different forms. In this work a numeric approach by using Comsol Multiphysics code is proposed for simulating spine exposure to Capacitive Coupling System. The finite element method was chosen to solve the Maxwell’s equations using a grid model which approximates the anatomical geometry. In this model the geometry was represented as three objects which present the dielectric characteristics of the skin (\( \sigma=5*10^{-4} \) S/m, \( \epsilon_r=10^3 \)), of the muscle (\( \sigma=0.6 \) S/m, \( \epsilon_r=2*10^4 \)) and of the bone tissue (\( \sigma=0.03 \) S/m, \( \epsilon_r=10^3 \)), respectively. Each tissue is assumed to be homogenous, electrically neutral and defined by a distinct boundary. Because the wavelength of the 60 kHz sinewave is much greater than the dimensions of the model, a quasistatic approximation was used. A 60 kHz 40 \( V_{pp} \) signal was placed on a pair of external electrode in contact with the outer boundary of the geometry. As in the clinical practice, the electrodes (10 \( \times \) 5 \( \times \) 0.1 cm) are placed directly onto the skin at the sides of the spinal column (radius = 1.5 cm), at 10 cm distance from one another. Comsol Multiphysics simulation code was used to solve the model above described.

**Results.** The purpose of this work is to define an alghoritm that allows to estimate the Electric Field in the exposed tissues directly from 3D. The mechanism by which electric fields stimulate bone tissues is unknown, specific electrical characteristics are related to specific effects in biological tissues. Electric field and potential distributions are computed for each tissue. The results are showed in the figures.
**Conclusions.** The results of simulation outline the electric field distribution and amplitude in the different tissues and may help to identify the minimum electric field levels necessary to stimulate reparative osteogenesis. The outcome of our simulation should be compared to areas of osteogenesis observed in clinical experience.

**Figure 1.** Streamlines and potential distribution in the tissues
**P-111** POSSIBILITY OF FREQUENCY SPECIFICITY OF OCULAR EFFECTS BY QUASI-MILLIMETER AND MILLIMETER WAVE EXPOSURE

Masami Kojima\(^1,2\), Masahiro Hanazawa\(^3\), Yoko Yamashiro\(^2\), Soichi Watanabe\(^3\), Hiroshi Sasaki\(^1,2\), Masao Taki\(^4\), Kazuyuki Sasaki\(^2\)

\(^1\)Kanazawa Medical University, Kahoku-gun, Japan \(^2\)Medical Research Institute, Kanazawa Medical University, Kahoku-gun, Japan \(^3\)National Institute of Information and Communications Technology, Koganei, Japan \(^4\)Tokyo Metropolitan University, Hachioji, Japan

**Objectives.** To investigate ocular effect by a quasi-millimeter and a millimeter wave exposure, ocular temperature changes during exposure and ocular injury after exposure were examined.

**Methods.** Pigmented rabbits were exposed unilaterally to 18, 22, 26.5 GHz or 26.5, 35, 40 GHz quasi- and millimeter-wave with a lens antenna for 3 minutes. The focused beam was exposed to the center of the rabbit cornea. The incident power density was controlled by monitoring both forward and reverse powers with a power meter. Ocular temperature

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**Figure 2.** Electric field distribution in a section of the spine
changes (cornea, lens, vitreous, retrobulbar) during a 3 min. exposure were measured with a Fluoroptic thermometer and corneal surface temperature was measured with a thermography camera. For evaluating ocular injury, a rabbit was exposed to one frequency (18, 22, 26.5, 35, 40 GHz) with 800 mW/cm\(^2\) for 6 min. Ocular changes were evaluated by slit lamp and ocular inflammation was measured by laser flare meter immediately after and 1 day after exposure.

**Results.** Cornea and lens temperature rise were detected by exposure with all examined frequencies. The highest ocular and corneal surface temperature was 40 GHz, followed by 35, 22 and 18 (almost the same), and the lowest was 26.5 GHz. Ocular injury by 800 mW/cm\(^2\) for 6 min. exposure was seen only with 40 GHz. Miosis and iris vasodilation were seen immediately after exposure, and corneal epithelial defect at the center of the cornea and corneal opacity were seen one day after exposure.

**Conclusions.** It was suggested that thermal and biological reactions differed according to frequency, even when the maximum incident power density was the same.

**Acknowledgements.** The study was supported by a safety guideline study of the Ministry of Internal Affairs and Communications of Japan.

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**P-112 OPTIMAL COMPUTATIONAL ERRORS IN DIFFUSION SIMULATION OF NUCLEAR MAGNETIZATION IN WATER MOLECULES**

Toshikazu Imae\(^1,2\), Hiroyuki Shinohara\(^2\), Masaki Sekino\(^3\), Shoogo Ueno\(^4\), Hiroyuki Ohsaki\(^3\), Kazuo Mima\(^1\), Kuni Ootomo\(^1\)

\(^1\)University of Tokyo Hospital, Tokyo, Japan \(^2\)Tokyo Metropolitan University, Tokyo, Japan \(^3\)University of Tokyo, Chiba, Japan \(^4\)Kyushu University, Fukuoka, Japan

**Objectives.** Diffusion-weighted imaging (DWI) using magnetic resonance imaging (MRI) reflects diffusion of water molecules which are restricted by cell membranes and other microscopic structures. Tanner et al. derived analytical solutions of the diffusion equation of magnetization for diffusion barriers having simple geometries. For estimating diffusion in actual diffusion barriers within biological tissues, however, numerical analyses are essential because of the complicated shapes of the diffusion barriers. The finite-difference method is a general numerical method for solving partial differential equations in discrete space and time, and is applicable to the diffusion equation of nuclear magnetization, but, this method has computational errors due to discretization, so the relation between those errors and the time and space lengths involved is not clear.

The purpose of this study is to obtain the lengths of the time step, \(\Delta t\), and spatial step, \(\Delta x\), which minimize the computational errors in a simulation and also optical computational errors, for clinical application.
Methods. The diffusion equation of nuclear magnetization under gradient magnetic fields was derived from Fick’s second law and the Bloch equation. The equation was transformed using a finite-difference equation in discrete space and time. We call the equation the numerical solution of the diffusion equation.

The explicit solution was calculated from the diffusion equation using the Fourier transform analysis. For comparison of the numerical solution and the explicit solution under the same conditions, we substituted a rectangular initial magnetization of width $\Delta x$ into the explicit solution. The observed signals were the spatial integration of magnetization. The difference between the signals of the numerical solution and explicit solution was evaluated. We considered the product of $\Delta x$ and $\Delta t$ as a given constant, $B$, because the computational time is inversely proportional to the product ($B=\Delta x \Delta t$).

To consider computational errors that allow for clinical application, we defined the permitted computational errors as a one-tenth of difference between the apparent diffusion coefficient (ADC) of normal brain tissues ($0.79 \times 10^{-3}$ [mm$^2$/sec]) and the infarction area ($0.63 \times 10^{-3}$ [mm$^2$/sec]), and explored the condition of $\Delta x$ and $\Delta t$, which was less than the permitted computational errors.

Results. Fig.1 shows the relationship between the discrete time and computational errors, where $D$ is the diffusion coefficient, $G$ is the intensity of the gradient magnetic field, $k_0$ and $A$ are the respective position and magnitude of the rectangle. The computational errors increased as the $B$ value increased, because the increase in $B$ makes the computation approximate. Computational errors came to a minimum at optimum $\Delta t$. When $\Delta t$ was shorter than the optimum value, the reason for the increase in computational errors was that the root mean square distance of diffusion, $x_r=(2D\Delta t)^{1/2}$, was shorter than the distance between the spatial grid points. On the other hand, when $\Delta t$ was longer than the optimum value, the reason for the increase in computational errors was that the numerical solution of the diffusion equation considered only the diffusion to adjacent grid points. We calculated optimum $\Delta x$ from $B$ and $\Delta t$.

Fig.2 shows the relationship between the optimum length of the time step and the resulting spatial step. Optimum $\Delta x$ increased as optimum $\Delta t$ increased. In an actual simulation, we decide $B$ from the total simulation time which we can practically accept, and choose the combination of $\Delta x$ and $\Delta t$ from the results.

The permitted computational errors were 1.6%. The conditions under which the computational errors became less than the permitted computational errors were $G =50 \times 10^{-3}$ [mT/mm], $\Delta t =5$ [ms], $\Delta x=0.18[\mu s]$, and the computational errors came to 1.1%.

Conclusions. The results of this study were useful for efficiently carrying out diffusion simulation within a given limitation of time for computation and computational errors for clinical application.

Acknowledgements. This study was supported by a Grant-in-Aid for Encouragement of Young Scientists (A and B) from JSPS.
Figure 1. Relationship between $\Delta t$ and computational errors. The computational errors have a local minimum point.

Figure 2. Relation of $\Delta t$ and $\Delta x$ for minimization of computational errors.
RF ABSORPTION IN THE HUMAN HEAD IN ULTRAHIGH-FIELD MAGNETIC RESONANCE IMAGING SYSTEMS OF UP TO 11.7 T

Masaki Sekino¹, Dongmin Kim¹, Shoogo Ueno², Hiroyuki Ohsaki¹
¹The University of Tokyo, Kashiwa, Japan ²Kyushu University, Fukuoka, Japan

Objectives. Recent advances in superconducting magnets and radiofrequency (RF) coils have realized ultrahigh-field magnetic resonance imaging (MRI) systems of up to 9.4 T (Vaughan et al. 2006), and several research groups have plans for developing 11.7 T systems. These ultrahigh-field systems have numerous advantages, such as acquisitions of precise functional and diffusion images, and imaging of non-proton nuclei. The increase in the magnetic field strength raises the frequency of RF electromagnetic field applied to the subject during measurements. As a result, the ultrahigh-field system has a high specific absorption rate (SAR). Previous studies have shown that RF electromagnetic field in ultrahigh-field systems have severe inhomogeneity due to the skin effect and the dielectric resonance effect (Sekino et al. 2005), which complicates the estimation of SAR in such systems. The purpose of this study is to obtain electromagnetic field distributions and the SAR in the human head in ultrahigh-field systems of up to 11.7 T.

Methods. Figure 1(a) shows a numerical model of the human head and a birdcage-type RF coil for producing a circularly polarized RF magnetic field. Each tissue in the model has its own dielectric constant and conductivity. The dielectric constant and conductivity were dependent on the frequency of the RF magnetic field. The numerical simulation was based on the finite difference time domain (FDTD) method. The model was 42 cm in width and 47 cm in height, and was divided into 4-mm-square cells. Each cell had x and y components of magnetic fields, and a z component of the electric field. The birdcage-type RF coil had 8 wires and the diameter of the coil was 18 cm. The NMR frequencies ranged from 64 MHz to 500 MHz, which corresponded to magnetic field strengths ranging from 1.5 T to 11.7 T. The difference in phase between adjacent wires was $\pi/4$. The SAR was given by $\text{SAR} = \sigma E^2 / \rho$, where $\sigma$ and $\rho$ are respective conductivity and density of the tissue, and $E$ is the amplitude of electric field.

Results. Figures 1(b)(c)(d) show the amplitudes of electric field at frequencies of 64 MHz, 200 MHz, and 500 MHz (corresponding to magnetic field strengths of 1.5 T, 4.7 T, and 11.7 T, respectively). The electric field at 64 MHz monotonically increased with distance from the center of the head. An increase in frequency resulted in a severe inhomogeneity in the RF electric field. The electric field at 500 MHz had a high intensity at the center of the head. The amplitude at 500 MHz ranged from 0.0051 kV/m to 8.0 kV/m in the human head. Figure 2(a) show the SAR averaged in the head. We assumed the duty cycle of 1/50 for the evaluation of SAR. The SAR levels in ultrahigh-field systems were higher than that of the 1.5 T system. The safety standard set by the Ministry of Health, Labor and Welfare, Japan limits the average SAR in the head to 3.2 W/kg, and the Food and Drug Administration, USA limits the average SAR in the head to 3.0 W/kg. The ultrahigh field systems should be operated with low duty cycles in comparison with the low field systems. Technical developments in RF coil designs are required to reduce the SAR level in the ultrahigh-field systems. Figures 2(b)(c)(d) show spatial distributions of the SAR.
Regions having high electric field intensities and high conductivities exhibited high SAR levels, which resulted from the definition of SAR. In the 500 MHz (11.7 T) system, the SAR had high levels at the center of the head as well as at the surface of the head.

**Conclusions.** The ultrahigh field MRI systems had high SAR levels and severe inhomogeneities in SAR distribution.

**Figure 1.** (a) Numerical model of the human head and an RF coil. (b)(c)(d) Electric field distribution at frequencies of 64 MHz, 200 MHz, and 500 MHz (corresponding magnetic field strengths of 1.5 T, 4.7 T, and 11.7 T).
Objectives. It is well-known that there are considerable strain differences in the relative copulation rates between male and superovulated female mice. In particular, the C57BL/6J strain of mice has a lower rate of successful copulation. We examined the effect of exposure to an electric field on sexual behavior in C57BL/6J male mice.

Methods. The electric field exposure system was composed of three major parts, namely, a high voltage transformer unit, a constant voltage unit and electric field exposure cages. The exposure cage was comprised of a cylindrical plastic cage (diameter: 200 mm, height: 200 mm) and two electrodes made of stainless steel (400 x 400 mm) were placed over and under...
the cylindrical cage. In order to establish the electric field (50 Hz, 45 kV/m) in the cage, a stable alternating current (50 Hz, 9000 V) was applied to the upper electrode. C57BL/6J male mice (n=30) were exposed to 50 Hz, 45 kV/m electric field in the electric field cage for 30 minutes per day for 11 days. After the final electric field exposure, each male mouse was placed in a cage with a superovulated female mouse. Superovulation was induced by intraperitoneal injections of 5 i. u. equine chorionic gonadotrophin and 5 i. u. human chorionic gonadotrophin 48 hr apart. As a control, a similar male mouse was placed in the electric field cage for 30 min per day for 11 days without the electric field exposure and subsequently mated with a superovulated female mouse (n=30). Establishment of copulation was determined by detection of a vaginal plug the morning after overnight mating.

**Results.** When C57BL/6J males were exposed to a 50 Hz, 45 kV/m electric field for 30 min per day for 11 days and placed in a cage with a superovulated females of the same strain, the successful copulation rates of males was significantly improved compared with unexposed males (P<0.05). To identify the essential periods of electric field exposure to improve copulation rates, C57BL/6J males were exposed to a 50 Hz, 45 kV/m electric field for 30 min per day for 1, 3 and 11 days and subsequently mated with superovulated C57BL/6J females. When C57BL/6J males were exposed to the electric field for 11 days, the copulation rates with the superovulated C57BL/6J females were significantly improved (P<0.05), a finding similar to the previous experiment. However, exposure of C57BL/6J males to the electric field for 1 or 3 days did not significantly increase the copulation rates with the C57BL/6J superovulated females compared with the unexposed control.

**Conclusions.** These results suggest that the exposure of C57BL/6J mice to an electric field improves their sub-fertility activity in mating with superovulated females and cumulative electric field exposure is required for improvement of the copulation rates in C57BL/6J male mice. Further studies across species will also importantly determine whether this is a conserved phenomenon or one peculiar to certain strains of mice; if conserved, there is potential for its application to human beings.
P-115 AN ASSESSMENT METHODOLOGY OF IMPLANTABLE MEDICAL DEVICE EMI DUE TO RFID READER/WRITERS BASED UPON THE EMF DISTRIBUTION ANALYSIS

Shunichi Futatsumori¹, Shunsuke Taguchi¹, Takashi Hikage¹, Toshio Nojima¹, Ben Koike², Hiroshi Fujimoto³, Takeshi Toyoshima³
¹Hokkaido University, Sapporo, Japan ²Japan Automatic Identification Systems Association, Chiyoda-ku, Japan ³Medtronic Japan Co., Ltd., Minato-ku, Japan

Objectives. The implantable medical device EMI is one of the most important issues to investigate for the improvement of their patients’ quality of life. Moreover, the use of implantable medical devices has become more widespread and more than 50,000 devices are implanted in Japan in one year of 2005. It is required to ensure safe environments regarding the EMI from various kinds of radio devices and electronic devices, which emit electromagnetic fields around. A lot of research is being carried out to find out the EMI [1]. We have carried out detailed in-vitro experiments to assess the EMI due to RFID reader/writers for implantable medical devices (RFID/IMD-EMI) [2]. In this paper, a novel RFID/IMD-EMI assessment methodology based upon the electromagnetic field distribution from the RFID reader/writer antenna is proposed. In addition, the applicability of the proposed methodology is examined by the experimental results.

Methods. Firstly, detailed in-vitro EMI test experiments have been carried out to obtain fundamental EMI characteristics of implantable cardiac pacemakers and implantable cardioverter-defibrillators (ICD) due to RFID reader/writers. EMI characteristics of 27 types of pacemakers and ICDs from 30 types of commercially available antennas are examined so far. In addition, to apply the RFID/IMD-EMI assessment methodology, electromagnetic field (EMF) distributions form antennas are measured precisely as shown in Figure 1.

Secondly, the RFID/IMD-EMI assessment methodology based upon the electromagnetic field distribution is proposed. It is supposed that ”one turn coil” is connected between different electrode and indifferent electrode of pacemakers as shown in Figure 2. By following Faraday’s law of induction, an electromotive force arises between the electrodes when they are exposed to alternating magnetic field. To estimate this disturbing noise level, the methodology calculates the total magnetic flux integrated across the pacemaker and lead cross-section.

Results. Figure 3 shows the estimated induced voltage based on magnetic flux distributions from 4 types of 125 kHz RFID reader/writer antennas. The induced voltages are compared with maximum interference distance (distance where EMI disappears) obtained from the experiments. Estimated induced voltages at each maximum interference distance are almost the same. More than a thousand test modes are examined. Detailed evaluations of the methodology are conducted by statistical processing. The results are shown in the congress.

Conclusions. The novel experimental RFID/IMD-EMI assessment methodology based upon the total magnetic flux integrated across the pacemaker and lead cross-section was proposed. The result calculated from the methodology was compared with the experimental
results to confirm the applicability of the proposed methodology. By using the methodology, there is a possibility that the EMI on specific pacemakers or ICDs can be assessed by measuring the EMF distributions from the RFID reader/writer antennas.

References

Acknowledgements. The authors would like to thank the members of the Pacemaker Committee of Japan and Japan Automatic Identification Systems Association for their cooperation and support.

\[\text{Figure 1. An example of magnetic field distributions from a 125 kHz RFID reader/writer antenna.}\]
**Figure 2.** The human torso phantom.

**Figure 3.** Estimated relative induced voltage (Normalized) by magnetic flux from 125 kHz RFID reader/writer antennas compare with experimental results. (Maximum interference distance is indicated as white marker.)
**P-116 CHANGES IN DIFFUSION PROPERTIES OF BIOLOGICAL TISSUES ASSOCIATED WITH MECHANICAL STRAIN.**

Kenichiro Tanaka¹, Toshikazu Imae¹, Masaki Sekino², Shoogo Ueno³, Hiroyuki Ohsaki², Kazuo Mima¹

¹University of Tokyo Hospital, Tokyo, Japan ²The University of Tokyo, Chiba, Japan ³Kyushu University, Fukuoka, Japan

**Objectives.** DWI (diffusion weighted imaging) is a recently developed method for imaging diffusion of water molecules in living bodies using MRI (magnetic resonance imaging). The diffusion of water molecules is disturbed by diffusion barriers such as cell membranes and other microstructures, which results in a restricted diffusion of water. A mechanical strain in the biological tissue causes a deformation of the cell membrane. The deformation affects the effective diffusion coefficient and the principal direction of diffusion. Therefore, quantitatively clarifying this phenomenon potentially leads to a new imaging technique of strain in biological tissue or deformation of subvoxel-scale structures. In this study, we investigate the influence of strain in muscular tissues on DWI signals and the self-diffusion tensor. In addition, we propose a method for estimating unknown diffusion parameters such as the diffusion coefficient and the cell size by fitting a model function to the MRI signals.

**Methods.** Measurements were carried out on five samples of chicken skeletal muscles. The sample consisted of muscle fibers aligned to a specific direction (Z axis), and had a dimension of 20×10×30mm³. The sample was sandwiched between a pair of acrylic plate to be uniformly compressed in the vertical direction (Y). Compression was added until the width of the sample became half (width became to 5mm from 10mm). The measurement used 4.7T UNITY INOVA magnetic resonance imaging spectrometer (Varian Associates, Palo Alto, CA) for the compressed and uncompressed samples. The signal was measured by the STEAM (stimulated echo acquisition mode) sequence [1]. The measurement parameters were as follows: TR=4000 ms, TE=35 ms, and TM=80,180...2480 ms (25 points). The intensity of MPG (motion probing gradient) was G=3×10⁻² T/m, δ=5 ms, ∆=100, 200...2500 ms (25 points). The MPGs were applied in six directions in order to investigate anisotropy in diffusion. A theoretical model of the diffusion of water molecules in muscle fibers was derived based on Tanner’s equation [2,3]. Diameter of the muscle fibers was estimated by fitting the model equation to the measured signals.

**Results.** Changes in the mean diffusivity (MD), the fractional anisotropy (FA), and diameter of the muscle fiber did not have any statistical significance. The intracellular diffusion coefficient (Dint) decreased due to the mechanical strain (p<.05). This theory enabled us to easily estimate the cell diameter and intracellular diffusion coefficient from the MRI signals by using our model function.

**Conclusions.** We have simplified the cell as a square prism for this experiment. However, an actual cell has complicated shapes, and the cell membrane has finite water permeability. Our model equation remains to be improved to consider the permeability of the cell membranes and the shapes of cells. The direction of the muscle fiber was estimated in a three-dimensional coordinate. The parameters of MD and FA are effective measures of the anisotropy in diffusion. Diffusion tensor of MRI was useful for a quantitative evaluation...
of the distortion. This method has potential applications in the quantitative evaluation of strain in biological tissues, though the method still poses several technical challenges.


P-117 ANALYSIS OF A DEVICE FOR DETECTING BREAST CANCER IN DISPERSIVE CHARACTERISTICS OF BIOLOGICAL TISSUES

Jeong-Lan Kim¹, Chea-Ok Ko¹, Tae-Hong Kim¹, Hyung-Do Choi², Ae-Kyoung Lee², Jeong-Ki Pack¹
¹Chungnam National Univ., Daejeon, South Korea ²Electronics and Telecommunications Research Institute, Daejeon, South Korea

Objectives. The objective of this study is to analyze the accuracy of a cancer-detection system, which is based on the dielectric characteristics of cancer tissue and the time delay of the backscattered response. To detect a small breast-cancer tissue at short distance, pulse signals in the cancer-detection system should have a narrow bandwidth in time-domain. For a prototype system, we have fabricated an experimental model and an UWB (ultra-wideband) antenna. However, the study to improve the detection accuracy has not been performed yet. To investigate the factors for better accuracy, the effect of dispersive characteristics of biological tissues on the detection accuracy was analyzed in this paper, by FDTD simulation.

Methods. We performed a feasibility study for breast-cancer detection system using CMI (confocal microwave imaging) technique before, and the feasibility was confirmed both by numerical simulation and measurement[5]. The breast-cancer detection system involves illuminating the breast with an UWB pulse from a number of antenna locations and collecting the backscattered signals. In the numerical simulation shown in Figure 1, an UWB antenna was realized as the resistively loaded bow-tie antenna. The UWB antenna produces a very narrow pulse in time domain. So, the performance of the detection system will be influenced by the dispersive characteristics of biological tissues, and thus the dispersive characteristics of biological tissues should be taken into account for detection algorithm. To find the dispersive characteristics of cancer tissue, it was cultivated in mouse, and the complex permittivity was measured using a coaxial probe, as shown in Figure 2[2]. Figure 3 shows the difference in dielectric constant between breast tissue and cancer tissue. To model the dispersive characteristics, we used the Debye model. Even the 1st-order model led to good fitted result in 1-5 GHz range. The values for the key parameters, $\epsilon_\infty$, $\epsilon_s$, relaxation $\tau$, $\sigma$, for skin, breast-cancer and fat are (43.23, 97.46, 5.01e-9, 0.4132), (61.32, 144.9, 6.809e-9, 1.853)
and (5.097, 7.856, 3.885e-9, 0.06652), respectively. To analyze the dispersive characteristics of tissues, we compared the difference between dispersive and no dispersive algorithm. The simulation conditions are as follows: discretization parameters \( \Delta x = \Delta y = \Delta z = 1 \text{ mm}, \Delta t = 1.926 \text{ ps}; \) modulated Gaussian input pulse with the center frequency of 6 GHz, pulse width of \( 220 \times \Delta t; \) PML (8 layers) boundary condition.

**Results.** The converted time-domain signals at all scan positions were calibrated, and then processed by the proposed detection algorithm to construct 3 dimensional images. The scattered signal from the breast phantom without cancer was used as a calibration signal. The results demonstrated a good detection capability of a cancer tissue, even with 2D scanning. To investigate the influence of the dispersive characteristics of the biological tissues, dispersive and non-dispersive cases were simulated. The results show a difference between two cases.

**Conclusions.** We demonstrated that the prototype system can detect and localize a cancer tissue with a good resolution. It was found that key elements to improve the performance of the detection system are to consider the dispersive characteristics as well as a good UWB antenna and a proper calibration signal. To model the dispersion, the 4th Cole-Cole method is better, but it requires a large memory size. The study for an efficient algorithm such as a hybrid method is under way.

**Acknowledgements.** "This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute of Information Technology Advancement)” (IITA-2006-(C1090-0603-0034))
Figure 2. (a) Nude mouse with cultivated cancer (b) Extracted cancer tissue (c) Measurement of the cancer tissue
Figure 2. Photo of the measurement (counterclockwise from the top)

Figure 3. Permittivities of breast and breast tumor-tissue
**P-118 EFFECS OF RF ELECTRIC FIELDS IN THE RAT ADIPOCYTE**

Hirofumi Funamizu\(^1\), Ayaka Sugino\(^1\), Norihiko Mitsumune\(^1\), Takuji Hara\(^2\), Toshiro Saito\(^3\)

\(^1\)Tokyo University, Tokyo, Japan \(^2\)BESTEC Corporation, Wako-shi, Japan \(^3\)Hitachi Life Science Corporation, Kawagoe-shi, Japan

**Objectives.** We did covering gene analysis research on the influence of radio frequency electric field exposure by using rat’s cell adipocyte in this time.

We regularly executed the energizing exposure during the fixed time with the special exposure device that had originally developed this cell culture eight days later in the incubator. The above-mentioned device made by radio frequency electric field exposure BESTEC corporation’s V was used.

The hall rat gene analysis did an analytical request to the Hitachi life science Corporation with DNA microarray made by use the Agerent Corporation in covering gene analysis. As a result, a significant expression reinforcement or decrease was seen in the gene related to the growth promoting substance and the signal transduction and the gene related to film protein etc. Moreover, a significant change was not seen about the expression of HSP.

We suggested that the enough possibility of influencing the gene expression in the cultured cell by the low frequency electric field exposure made by research BESTEC Corporation’s V. The application to the medical treatment field will be considered by a further examination in the future.

**Methods.** We regularly executed the energizing exposure during the fixed time (60min x3) with the special exposure device that had originally developed this cell culture eight days later in the incubator. The above-mentioned device made by radio frequency electric field (10-80kHz) exposure BESTEC corporation’s V was used.

The hall rat gene analysis did an analytical request to the Hitachi life science Corporation with DNA microarray made by use the Agerent Corporation in covering gene analysis.

Details are announcement schedules in patent fillings by the symposium now.

**Results.** As a result, a significant expression reinforcement or decrease was seen in the gene related to the growth promoting substance and the signal transduction and the gene related to film protein etc. Moreover, a significant change was not seen about the expression of HSP.

Details are announcement schedules in patent fillings by the symposium now.

**Conclusions.** We suggested that the enough possibility of influencing the gene expression in the adipocyte by the radio frequency electric fields exposure made by research BESTEC Corporation’s V.
**P-119** WEAK PEMF SIGNALS ARE FIRST MESSENGERS FOR TISSUE GROWTH AND REPAIR: APPLICATION TO TENDON REPAIR.

Arthur A. Pilla1,2

1Columbia University, New York, NY, USA 2Mount Sinai School of Medicine, New York, NY, USA

**Objectives.** The author predicted in 1972 that weak bioeffective EMF signals could be configured to modulate ion binding at electrified cell membrane/aqueous interfaces. This gave rise to the electrochemical information transfer model in which ion binding kinetics were depicted in terms of electrical equivalent circuits to allow the frequency bandpass of the EMF target to guide the choice of signal parameters. This led to the configuration of signals now in routine clinical use for recalcitrant fracture repair. As the biological signaling pathways for tissue growth and repair became elucidated, it was obvious that, while the original bone repair signal was within an effective dosimetry range, it was far from optimal. One indication of this is the requirement for several hours of daily treatment for several months to reach a satisfactory clinical outcome. This work shows how effective EMF signals may be configured *a priori* to be first messengers by evaluation of signal to thermal noise ratio (SNR) in a two step pathway involving Ca2+ binding to calmodulin (CaM). Application is made to Achilles’ tendon repair in a rat model.

**Methods.** The EMF target is considered to be Ca2+ binding to CaM followed by CaM binding to an enzyme such as nitric oxide synthase (NOS) which controls the release of the signaling molecule nitric oxide (NO). Analysis of the kinetic equations describing this two step process yields a two time constant electrical equivalent circuit analog which contains the time constants for Ca2+ binding to CaM, and CaM binding to, e.g., NOS, respectively. Knowledge of the actual time constants, allows any EMF signal to be assessed in the frequency domain with respect to its ability to produce a detectable (i.e. SNR≈1) voltage in the target. This is shown in the figure, wherein SNR for pulsed radio frequency (PRF) signals consisting of a 2000 µsec burst of 27.12 MHz sinusoidal waves repeating at 5/sec, configured *a priori*, a 65 µsec burst at 600/sec (a diathermy based signal in clinical use for soft tissue repair), and the original PEMF bone healing signal consisting of a 5 msec burst of 200/20 µsec pulses repeating at 5/sec, are shown. Both PRF signals are predicted effective, the 65 µsec signal significantly less so since it was not frequency matched to the kinetics of Ca2+ binding. The PEMF bone repair signal is predicted ineffective.

**Results.** This approach was tested using the PRF signals described on a well established Achilles tendon repair model in the rat (Strauch, 2006). The Achilles tendon of male adult Sprague Dawley rats was transected and stabilized with a single suture. There was no additional mechanical stabilization. Animals were divided into sham exposed and active groups. Active animals were treated in individual plastic cages with the 2 msec PRF signal 1 a predicted effective peak amplitude of 0.05 G, the 65 usec PRF signal at the standard clinically employed peak amplitude of 1 G. Sham exposed animals were treated identically. PEMF exposure was 30 min twice daily until sacrifice at 21 days. The tensile strength of the isolated tendon was determined using a standard laboratory tensiometer. Pull rate was 0.45mm/sec. Tendons treated with the 65 µsec PRF signal were 24% stronger than sham
treated (NS). In contrast, tendons treated with the 2 msec PRF signal were 69% higher than sham treated (p<.001).

**Conclusions.** The results suggest that EMF signals configured via SNR analysis to match the bandpass of a second messenger target can act as a first messenger to modulate biochemical cascades related to tissue growth and repair. In the particular case of tendon repair the likely second messenger is Ca\(^{2+}\) binding to CaM followed by CaM binding to NOS. The objective was to produce sufficient electric field amplitude (dose) within the frequency response of Ca\(^{2+}\) binding. The model predicted that millisecond range burst durations for the PRF signal would satisfy these objectives at amplitudes in the 0.05 G range. The model also showed that the 65 \(\mu\)sec PRF signal would produce lower amplitude in the Ca/CaM pathway, despite inducing significantly higher electric field in tissue rendering it only marginally effective, in accord with the experimental results. Certainly the results in this rat model suggest PEMF dosimetry can be optimized *a priori* to act as a first messenger for biological cascades relevant to tissue repair. It is of interest to note the PEMF signal used routinely for bone repair failed to have a significant effect on tendon repair in this model (Wei, 2006), as predicted by this analysis. The approach presented in this study is a general one applicable to any signal configuration or target pathway. Its accuracy will depend upon knowledge of the kinetics of the transduction step.

P-120 DEVELOPMENT OF JELLY-TYPE POLYMER BASED SIMULATING HUMAN BRAIN FOR RESEARCH ON HYPERThERMIA BY HIGH FREQUENCY MAGNETIC FIELD

Yoon-Myoung Gimm\(^1\), Ohyoung Kim\(^2\), Koichi Ito\(^3\)
\(^1\)Dankook University, Yongsangu, South Korea \(^2\)Dankook University, Yongsangu, South Korea \(^3\)Chiba University, Chiba-shi 263-8522, Japan

Objectives. Development of jelly type simulating internal human organs to check the temperature changes in strong magnetic field for the possibility study of hyperthermia.

Methods. A variety of polymer based jelly phantoms simulating human organs were synthesized in order to confirm the applicability of hyperthermia. As the first tentative step, using the appropriate material compositions including polyethylene, jelly phantoms for artificial homogenous brain were prepared and their electrical properties were characterized at cellular frequencies. Each simulating human organ in the chest and abdomen will be developed later by jelly type together with the strong magnetic field generator at 100 kHz band and with the compound of magnetic fluid for thermal excitation. Recipes are shown in Table 1 and target values of electrical properties for SAR measurement and measured jelly phantom values are shown in Table 2. Manufactured head shape jelly phantom and its weight loss characteristic by storage time are shown in Fig.1.

Results. We tried to develop various jelly phantoms of artificial homogenous human organs for the temperature change examination to be exposed to strong external magnetic field. As an interim step, brain jelly phantoms were developed and their electrical properties were measured at mobile frequency band. The electrical characteristics were confirmed to be close to the target values in dielectric constants and electrical conductivities for SAR measurement. Also long-term storage characteristics of the jelly phantoms were also evaluated to apply the corresponding experiments.

Acknowledgements. This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (No.R01-2006-000-11338-0).
**P-121 MORPHOLOGIC CHANGES OF MITOCHONDRIA AND METABOLIC EFFECTS OF MICROWAVE RADIATION ON RAT HIPPOCAMPUS**

Peng Ruiyun  
Beijing Institute of Radiation Medicine, Beijing, China

**Objectives.** To investigate the injury effect of microwave radiation on morphologic changes of mitochondria and metabolic of rat hippocampus

**Methods.** 30 male rats were exposed to microwave which average power density was 30mW/cm² and were sacrificed at 6h, 1d, 3d and 7d after radiation. Electron microscope, enzymatic activity staining and spectrophotometer were used to study the change of the ultrastructure of hippocampus mitochondria and activity of ATPase, SDH and MAO. Mitochondrial ATP, ADP and AMP contents were measured with high performance liquid chromatography (HPLC).

**Results.** At 6h after microwave radiation, the sizes and shapes of hippocampus mitochondria were abnormal, and the injury of mitochondria was aggravated at 1d and 3d after radiation. The mitochondria presented swell, cavitation including disorder, shortness and decrease of crest. The activity of SDH and the content of ATP were decreased at 6h, most serious at 3d(P<0.01),and getting back at 7d after radiation. The changes of ATPase and MAO were consistent. The increase of activity was most notably at 1d and 3d after radiation(P<0.01).
Conclusions. Microwave can injury the structure and function of mitochondria in rat hippocampus, and cause abnormal energy metabolic of enzyme.

* P-122 EXPOSURE OF 20 KHZ TRIANGULAR MAGNETIC FIELD TO RATS FOR 18 MONTHS

Yun-Sil Lee¹, Soo Yong Choi², Youn Myung Gimm³, Jeong Ki Park⁴, Hyung Doo Choi⁵, Hae-June Lee¹
¹Korea Institute of Radiological and Medical Sciences, Seoul, South Korea ²Korea Institute of Radiological and Medical Sciences, Seoul, South Korea ³Dankook University, Seoul, South Korea ⁴Choongnam National Univ, Daejon, South Korea ⁵ETRI, Daejon, South Korea

Objectives. A carrousel exposure system to 20-kHz intermediate frequency (IF) magnetic field at 30 mT rms were exposed to rats for long term of 12 months or 18 months and serological, serum biochemical, urinary and histopathological analysis were performed.

Methods. Sprague Dawley rats (20 each of male and female in sham and magnetic field exposed groups) were exposed to triangular magnetic field for 8 hrs/day for 12 and 18 months. Urinalysis (pH, serum glucose, protein, ketone bodies, RBC, nitrogen, bilirubin, urobilinogen, and specific gravity), hematological analysis (RBC, hemoglobin, hematocrit, thrombocyte count, and leucocyte count), blood biochemistry (total protein, blood urea nitrogen, creatinine, glucose, total bilirubin, total cholesterol, aspartate aminotransferase, alanine aminotransferase, and alkaline phosphatase), and histopathological analysis of organs (thymus, stomach, intestine, liver, kidney, testis, ovary, spleen, brain, heart, and lung) were performed.

Results. No significant differences between IF magnetic-field exposed and sham rats, except for some changes of blood nitrogen urea (BUN) in female rats.

Conclusions. Long term exposure of rats to 20 kHz triangular magnetic field (30 uT) affected some leukocytes numbers, and more detailed examination at higher intensity is underway.
P-123 ABSENCE OF EFFECT OF POWER-FREQUENCY MAGNETIC FIELDS EXPOSURE ON MOUSE EMBRYONIC LENS DEVELOPMENT.

Ke Yao¹,², YiBo Yu¹, KaiJun Wang¹, Juan Ye¹, Deqiang Lu³, Huai Jiang³
¹Eye Center, Affiliated Second Hospital, College of Medicine, Zhejiang University, HangZhou, China ²Ophthalmology Institute of Zhejiang University, HangZhou, China ³Bioelectromagnetic Laboratory, College of Medicine, Zhejiang University, HangZhou, China

Objectives. With the increase of occupational exposure to power-frequency magnetic fields and general exposure to sources such as electric power lines or electric appliances, more attention has been paid to the related biological effects. There are no reports in the literature investigating the biological effect of power-frequency (50/60 Hz) magnetic fields on embryonic lens development. The present study was designed to determine whether power-frequency magnetic fields act as an environmental insult and induce changes in morphology or protein and/or transcription factor mRNA expression levels in developing mouse embryonic lenses.

Methods. Three groups of pregnant mice were exposed to magnetic fields (50 Hz) of varying intensities (0.0, 1.5 and 4.5 mT) for 3 hours per day from Gestation Day (GD) 0 to 18. The embryonic lenses were enucleated on GD 18, and the transparency of the lenses along with the ultrastructure of lens epithelial cells (LECs) was observed. The lens is rich in a group of proteins which are composed of water soluble protein (WSP) and water insoluble protein (WIP). The remaining lenses were examined for quantity of WSP and WIP, the ratio of WIP to total protein, and mRNA expression levels of four well known developmentally-regulated DNA-binding transcription factors, Pax6, Prox1, Sox1, and c-maf. We preserved one pregnant mouse per group and fed the neonatal mice until 2 weeks of age to observe the transparency of lenses.

Results. The lenses in the three groups were found to be transparent and the LECs from the experimental groups exhibited normal ultrastructure comparable to the control. No significant differences were found among the three groups in protein fractions(Table), and the mRNA expression levels of transcription factors(Figure) (p>0.05).

Conclusions. In this study we did not detect any effects on the development of embryonic lenses in mice exposed to power-frequency magnetic fields.
Figure 1. Pax6, Prox1, Sox1, and c-maf relative mRNA expression level in three groups. Embryonic lenses were enucleated at GD 18 and the mRNA expression levels of the four transcription factors were detected in each sample. Data are the mean of one experiment carried out in duplicate. The error bars represent the standard error (n=5). The values for each transcription factor were not significantly different among Group 1.5 mT (dense grid), Group 4.5 mT (black), and Group 0.0 mT (blank) (p>0.05).

* P-124 INVESTIGATION OF THE MITIGATION COST RELATED TO THE MAGNETIC FIELD GUIDELINE IN KOREA

Sungho Myung¹, Yeongyu Cho¹, Yunseok Lim², Kooyong Shin², Dongil Lee², Jaejoon Kim³

¹Korea Electric Research Institute, Chwang Won, South Korea ²Korea Electric Power Research Institute, Daejeon-shi, South Korea ³Korea Electric Power Coorporation, Seoul, South Korea

Objectives. It is well known that power transmission lines is major EMF exposure sources. This work aims to calculate the mitigation cost related to the magnetic field guideline in korea.

Methods. In this study the mitigation cost caused by the reduction of the magnetic field was calculated. The construction cost for new facilities for each voltage as calculated, then the additional construction cost for each case guideline. The ratio with the base height was multiplied to the additional construction cost. The percentage of the total amount
compared to the base construction cost is shown. In this calculation, the definition of mitigation cost is limited to the additional input cost needed to follow the new magnetic field guideline from the current operating environment. All the calculation was done under the assumption that the electric current is fixed for each voltage.

**Results.** If we only take into consideration newly installed transmission lines, we will need every year for the next five years a budget equal to 0.11% (approx. 25.6 billion won) of electric power sales in order to maintain the magnetic field at 100[mG], 0.82% (approx. 191.1 billion won) to maintain the magnetic field at 30[mG], 6.4% (1.4912 trillion won) to maintain the magnetic field at 4[mG], and 235% when installing transmission lines of 345k and under underground. The above calculation is based on the assumption that transmission lines of 345kV and over are operated at 60% of the regular capacity and lines of 154kV are operated at 100%.

**Conclusions.** Analysis of this paper is based on the assumption that the magnetic field of all the transmission lines is reduced. In reality, reduction of the magnetic field will be limited to sensitive areas such as schools and hospitals, in which case more cost will be incurred and this matter will undergo intensive analysis.

**Acknowledgements.** The financial support was made by the research fund of the MOCIE grant

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**P-125 STUDY ON ELECTROMAGNETIC EFFECTS OF IH COOKER ON A METAMORPHOSIS OF XENOPUS LAEVIS**

Azusa Chuman, Atsuo Nuruki, Seiichi Tsujimura, Kazutomo Yunokuchi
Kagoshima University, Kagoshima, Japan

**Objectives.** In recent years there has been renewal of interest in the study of effects of electromagnetic fields on living bodies by a spread of electromagnetic equipments such as IH cookers and a radio. Although numerous attempts have been made by researchers there is still little knowledge in mid-temporal frequencies. In the previous study, we focused on the effect on fertilized eggs of frogs under the exposure of the electromagnetic field in mid-temporal frequencies generated by an IH cooker and showed that the date of metamorphosis was earlier than that of the sham-exposure frogs. The IH cooker produced an umuniform magnetic field. The strength of the magnetic field varied approximately four times in space. The question now arises that the strength of magnetic field could be a critical factor to influence the date of metamorphosis.

In this study we compared the date of metamorphosis of the frogs influenced by the electromagnetic fields with both short and long exposures. Subsequently, we measured the date of metamorphosis influenced by the magnetic fields from a Merritt coil that produced a uniform magnetic field in space.
Methods. During the fertilized eggs grow up the mature frogs, they were exposed electromagnetic fields using IH cooker and a Merritt coil. Their subjects were exposed every day. We compared the tail lengths of frogs exposed to the electromagnetic fields to those of sham-exposure frogs.

Frogs were grown in the beaker filled with saline (concentration 0.3 %, 1500 ml). Frogs exposed to the electromagnetic field from the IH cooker classified into IH-group. Frogs exposed to the electromagnetic field of a Merritt coil classified Merritt coil-group. Frogs un-exposed to the electromagnetic field classified sham-group.

(1) Electromagnetic fields exposure using IH cooker
Fig.1 shows an exposure using an IH cooker. Induction frequency of an IH cooker was 20 kHz, and maximum output was 3 kW.
Magnetic field strength was increased by approaching an IH cooker. Maximum strength of magnetic field using an IH Cooker was 17 $\mu$T. The duration of exposure was 90 min of every day or 5 h of every day.

(2) Electromagnetic fields exposure using Merritt coil
Induction frequency of a Merritt coil was 20 kHz. The strength of magnetic field using a Merritt coil was 17 $\mu$T. The strength of magnetic field wasn’t changed by location in the beaker. The duration of exposure was 90 min of every day or 21 h of every day.

Results. (1) IH Cooker
Fig.2 shows change of median tail length at sham-group, IH (90 min)-group and IH (5 h)-group. Frogs exposed for 5 hours using IH Cooker sped up metamorphosis compared to sham-exposure frogs. Frogs exposed for 90 minutes using IH Cooker slowed up metamorphosis compared to sham-exposure frogs.

(2) Merritt coil
Fig. 3 shows change of median tail length at sham-group, Merritt coil (90 min) -group and Merritt coil (21 h)-group. Frogs of exposure using a Merritt coil sped up metamorphosis compared to sham-exposure frogs. And frogs exposed for 21 hours sped up metamorphosis compared to frogs exposed for 90 minutes.

Conclusions. In this study we compared the date of metamorphosis influenced by the magnetic fields under conditions of both short and long exposures using the Merit coil that produced a uniform magnetic field. The results showed that the date of metamorphosis in long exposure condition was earlier than in short exposure condition (Fig.3), indicating that the strength influence the date of metamorphosis. These results are consistent with those in the previous study in which the date of metamorphosis of the frogs with exposure was earlier than that of the sham-exposure frogs. There is a contradictory note to make in connection with the Sham data in Fig.2 where the date of metamorphosis in Sham was earlier than in the 90-min exposure. Since the IH cooker generates an ununiform magnetic field the difference might be due to a difference in strength in space of the magnetic field. On the basis of these findings we would conclude that the date of metamorphosis of the frogs varied depending on the duration of the exposure.
**Figure 1.** Exposure using IH Cooker

**Figure 2.** Change in tail length
Figure 3. Change in tail length
P-126 DOES WHOLE BODY EXPOSURE OF RATS TO MICROWAVES EMITTED FROM A CELL PHONE AFFECT THE TESTES?

Ashkan Mowla
Shiraz Univ of Medical Sciences, Shiraz, Iran

Objectives. To determine the effects of radiofrequency radiation emitted from cell phones on the lipid composition, malondialdehyde concentration, p53 immune reactivity, sperm count, morphology, histological structure of testes, and on rectal temperature of rats exposed to microwave radiation emitted from cell phones.

Methods. Twenty-two Sprague-Dawley rats were separated into two groups of 11, sham exposed (control) and experimental. The rats were confined in plexiglas cages specially designed for this study, and cellular phones were placed 0.7 cm under the cages. For the experimental group, cell phones were activated 30 min per day (7 days a week) for 1.5 months. For the control group, the cell phones were placed beneath the cages for 20 min a day, but the phones were turned off. Rectal temperatures were measured weekly. For the control group, the cellular phones were placed beneath the cages for 20 min a day, but the phones were turned off. Rectal temperatures were measured weekly. For 250 mW radiated power, the whole body average SAR (rms) is 0.51 W/kg and 1 g averaged peak SAR (rms) is 3.11 W/kg. The Mann-Whitney U-test was used for statistical comparisons of groups.

Results. No statistically significant alteration in any of the endpoints was noted.

Conclusions. This study found no evidence suggesting an adverse effect of cell phone exposure on measures of testicular function or structure.
**P-127** RADIOFREQUENCY ELECTRIC FIELD EXPOSURE ANALYSIS ACCORDING TO TIME IN INDOOR ENVIRONMENTS OF DOWNTOWN

Jung-hun Choi, Nam Kim, Sang-Myeong Park, Seung-Cheol Hong, Sungho Choi

1Chungbuk National University, Cheong-ju, South Korea
2Inje University, Kimhae, South Korea
3Hanyang University, Seoul, South Korea

**Objectives.** The paper analyzes how continually increasing RF electromagnetic wave exposure, in light of the development of wireless communication technologies, varies according with time, with the aim of determining the variations in RF electromagnetic wave exposure to which persons living in specific facilities might be subject to during the time they spend at such facilities. As a result of these studies, it has been proposed that variations in the exposure, according to time, may become a key variable in implementing a prediction model for RF electromagnetic wave exposure. This is expected to become available as a key data item in implementing a prediction model for RF electromagnetic wave exposure, approximating an actual measurement value in the future.

**Methods.** In this paper, an elderly welfare facility located in the downtown area was selected as the object to be measured. RF sources used in a band of 75MHz to 3GHz were then measured by operating an SRM-3000, available from Narda Co., in order to analyze exposure sources of RF electromagnetic waves introduced into the measurement point. Exposure in the range of 3MHz to 18GHz was measured by using an EMR-300, made available by Narda Co., so as to analyze variations in the exposure according to time. This measurement method adopts a spot measurement, and performs repeated measurements in the same point in order to remove any variations in radio environment due to space variations. The measurement time was 24 hours. Equipment was established and operated to collect data every two seconds. These repeated measurements were performed five times in order to assure the reliability of the data.

**Results.** According to the measurement results, for an indoor environment of the downtown area, the exposure sources are distributed as indicated in Table 1. The exposure sources indicating a relatively higher level of exposure in the measurement facilities are analyzed as representing frequencies used for broadcasting, a cellular phone base station, a wireless LAN, digital broadcasting, and the like. FIG. 1 is a graph illustrating the variations in exposure levels according to time, and Table 2 indicates the analysis of the variations in exposure levels in 30-minute units. Reviewing the variations in the RF electromagnetic wave exposure between 3MHz and 18GHz, based on the analyzed results of the variations in exposure according to time, we found that exposure levels between 0 o’clock and 1 o’clock were at the lowest levels, at 0.25V/m on average, with exposure levels between 22 o’clock and 23 o’clock revealing relatively high rates of exposure, at an average of 0.62V/m. As a result, it has been found that variation levels in RF electromagnetic wave exposure according to time are 2.4 times or more.

**Conclusions.** According to research results, it has been determined that RF electromagnetic wave exposure in this indoor environment of the downtown area indicates different values, from a minimum of 0.01V/m to a maximum of 0.99V/m, according to variations
over time. This suggests that the variation variable in exposure levels according to variations of time, not considered until now in implementing a prediction model for RF electromagnetic wave exposure, may, in fact, have a significant impact on the prediction of RF electromagnetic wave exposure. Consequently, in implementing a prediction model for RF electromagnetic wave exposure in the future, this study suggests that an improved method for implementing a prediction model approximating the actual measurement values should include a consideration of the variation variable in exposure according to the time of day.

**Acknowledgements.** This research work was supported by ECO2 Research Grant No. 2005-09001-0038-0 from the Korea Ministry of Environment (2005~2006).

*P-128 ANALYSIS OF ELECTRIC FIELD EXPOSURE ON THE NEW RF SERVICE IN KOREA*

Sang-Myeong Park¹, Nam Kim¹, JungHun Choi¹, SeungWoo Lee¹, Yoon-Shin Kim²
¹Chungbuk National University, Cheongju, South Korea ²Hanyang University, Seoul, South Korea

**Objectives.** In November 2006, the number of subscribers to satellite DMB is estimated at around nine hundred thousand, with the estimated number of subscribers to terrestrial DMB services at roughly 2.4 million. The number of subscribers to both is continually
increasing as they expand their offerings and range. In the case of terrestrial DMB or Wibro, since the services are currently only operated in metropolitan areas, the number of users is anticipated to increase enormously when they are expanded to cover the entire country. Accordingly, as the interest of the general public in new services increases, disputes over the potential harmfulness of electromagnetic waves, with reference to mobile phone services and any new service are inevitable. This research therefore forms part of an evaluation on the harmfulness of electromagnetic waves in relation to a new RF service being executed in Korea. The purpose of this research is to analyze the strength of electric field of the frequency band for the new service to which the general public will be exposed, at locations where there is a large floating population, and the strength of electric field to which users of environment-sensitive facilities are exposed, based on those areas in which the new RF service is currently being provided.

**Methods.** This research has measured those levels for the Seoul and Seongnam areas, in which such a service is currently being offered. This is done in order that we may analyze the strength of the electric field for new RF services. To test areas with high floating population numbers, Gaepo-dong, Samsung-dong, Seocho-dong, and Suseo-dong of the Seoul metropolitan area were selected. To conduct the test in environment-sensitive facilities, Yatap-dong of Seongnam City, which is home to child-care facilities, secondary education facilities, and elderly welfare facilities are located. In terms of measurement equipment, an SRM-3000 (Narda), able to measure the strength of electromagnetic waves per frequency at a location coexisting with a number of frequencies was used. The objects of the measurement were the corresponding frequency bands of the respective Terrestrial DMB (Digital Multimedia Broadcasting), satellite DMB, Wibro (Wireless Broadband Internet), IMT-2000 (International Mobile Telecommunication 2000) services, and they were measured with a mean value of 6 min for a single measurement. In order to measure points with large floating populations, the object areas were divided into five measurement points to measure the strength of the electric field at each point. In the case of environment-sensitive facilities, the measurement regions thereof were divided into three measurement points in order to measure the strength of the electric field.

**Results.** As a result of the measurements of 180-186 MHz and 204-210 MHz of terrestrial DMB, 2630-2655 MHz of satellite DMB, 2331.5-2358.5 MHz of Wibro, and 2110-2170 MHz of IMT-2000, the strength of the mean exposed electric field of each new RF service band in the corresponding areas and environment-sensitive facilities is as shown in Table 1 and 2. In the case of the terrestrial DMB service of two bands, it was found that the strength of the mean exposed electric field was far lower than 28 V/m, the Technical Requirements for the Human Protection against Electromagnetic Waves. This was found across all measurement areas. It is noteworthy that satellite DMB, Wibro, and IMT-2000 services, in which the Technical Requirements for the Human Protection against Electromagnetic Waves are at 61 V/m, did not reach 1/100 of this reference in any of the four areas.

**Conclusions.** As a result of the measurement of the strength of electric field with reference to the areas where new services are being executed, we have confirmed that the strength of the electric field in all the areas was far less than the Technical Requirements for the Human Protection against Electromagnetic Waves. As new RF services such as Wibro,
Terrestrial DMB, satellite DMB, IMT-2000 etc. are coming online, it is believed that various studies of mobile phone services, as well as of these fields, needs to continue to proceed.

Acknowledgements. This research work was supported by ECO2 Research Grant No. 2005-09001-0038-0 from the Korea Ministry of Environment (2005~2006).

**Figure 1.** The electric field strength comparison of each measurement spot at Samsung-dong

**Figure 2.** The electric field strength comparison of each measurement spot at environment-sensitive facilities
THEORETICAL AND EXPERIMENTAL BIOEFFECTS RESEARCH FOR HIGH-POWER TERAHERTZ ELECTROMAGNETIC ENERGY

Jill McQuade1, Semih Kumru3, Nichole Jindra3, Ronald Seaman4, Alex Salazar4, Victor Villavicencio5, Clifton D. Clark5, Kalyn Yaws2, Jason Payne2, Robert Thomas3, William Roach2

1AFRL/HEDR, Monument, CO, USA 2AFRL/HEDR, Brooks City-Base, TX, USA 3AFRL/HEDO, Brooks City-Base, TX, USA 4General Dynamics-AIES, Brooks City-Base, TX, USA 5Northrop Grumman, Brooks City-Base, TX, USA

Objectives. Historically, safety analyses for radiofrequency emission and optical laser exposures have been designed to define the threshold level for tissue damage. To date, no experimental studies have documented damage thresholds to living tissues in the Terahertz (THz) range of electromagnetic frequencies (0.1 – 10 THz). Exposure limits exist as extrapolated estimates at the extreme bounds of current occupational safety standards for lasers and radiofrequency sources.

THz frequencies have many potential applications including communications, high resolution imaging, and locating improvised explosive devices. Additionally, the unique spectra of many materials in the THz band allow for detection and identification of chemical, explosive, and biological agents. Currently available portable THz energy systems are capable of producing power in the micro-watt to low milli-watt range. Technology has been developed to use electron accelerators to produce high-power, focused electromagnetic energy beams in the THz range. High-power THz beams provide higher speed data acquisition for imaging purposes. Although high-power THz beams are presently available only at a few accelerator sites, there are several current proposals for the construction of affordable compact to micro-sized electron-accelerators systems.

Due to present the lack of published data on the safety of THz emissions, an understanding of the bioeffects of tissue exposures to THz beams is necessary. It is important to establish safety margins in power density and dwell time for exposures to humans. The traditional approach to establish safe exposure limits has been systematic examination of experimental damage thresholds over a parameter space of wavelength, exposure time, beam size, and pulse properties. These studies often require several years of data collection and the establishment of a theoretical understanding of the mechanisms and endpoints of injury.

Methods. Scientists at AFRL/HED have conducted theoretical modeling of the interaction of both optical radiation and radiofrequency radiation with tissues for the past several decades. The existing theories and methods differ somewhat due to the wavelength scales involved (sub-micrometer to meters). The THz frequency band represents an intermediate range in which both methods can be selectively employed and compared for consistency. Work has recently been completed to reconcile methods of optical and radio-frequency radiative transport modeling. Additionally, preliminary theoretical estimates of damage thresholds to skin tissue from THz energy has been performed.

AFRL/HED and Jefferson Laboratory have formed a collaboration, allowing HED scientists to use the high-power THz emissions of the Jefferson Laboratory Free Electron Laser. The use of this facility enables tissue damage threshold studies in the THz range of the spectrum which can be used to validate the theoretical predictions. An initial pilot study involved the
exposure of a chamois cloth (a skin surrogate) and two tissue phantom materials. Further experimental studies will use the hairless guinea pig to test skin damage thresholds and plasma proteomic changes.

**Results.** AFRL/HED and Jefferson Laboratory have formed a collaboration, allowing HED scientists to use the high-power THz emissions of the Jefferson Laboratory Free Electron Laser. The use of this facility enables tissue damage threshold studies in the THz range of the spectrum which can be used to validate the theoretical predictions. An initial pilot study involved the exposure of a chamois cloth (a skin surrogate) and two tissue phantom materials. Further experimental studies will use the hairless guinea pig to test skin damage thresholds and plasma proteomic changes.

**Conclusions.** The overlap of the two standards within the terahertz range of frequencies leads to many complications. For instance, skin damage threshold data will either validate or establish new safety standard guidelines for the laser safety standards. Psychoperception thresholds will also need to be established for comparison to the radiofrequency radiation standards.

**Acknowledgements.** We would like to thank the scientists at the Jefferson Laboratory, especially Dr. Gwyn Williams and Mr. Mike Klopf.

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**P-130 EFFECTS OF GESTATIONAL EXPOSURE TO 1.95-GHZ W-CDMA SIGNAL OF IMT-2000 CELLULAR PHONES: EMBRIOTOXICITY AND TERATOTOXICITY IN RATS**

Tomoyuki Shirai, Mayumi Kawabe, Soichi Watanabe, Kanako Wake, Osamu Fujiwara, Jianqing Wang, Seiko Tamano
Nagoya City Univ Graduate School of Medical Sciences, Nagoya, Japan

**Objectives.** The present experiments were designed to evaluate effects of exposure to EMF from cellular phone on embryonic development when pregnant mother use it.

**Methods.** The 1.95GHz high frequency EMF was exposed on maternal nose area from gestational days 7 to 17, the period of embryogenesis, and the conditions of fetuses were examined. The levels of the exposure set with the maximum permissible dose, as advised by the Telecommunications Technology Council, the Ministry of Posts and Telecommunications, in 1997. Therefore, the specific absorption rate (SAR) of 0.67 or 2.0 W/kg was applied. EMF (the signal of the W-CDMA system) exposure was carried out during gestational day 7 to 17 at the head of the mother restrained in the holder individually for 1.5 hours every morning. Two control groups were also prepared, one was complete control which was not placed in the exposure box and another was sham exposure control which was set in the exposure box but without actual EMF exposure. The exposure box is 90 x
90 x 60 cm³, and except the ceiling of a metal side, it is covered with the wave absorber in order to prevent the leak of an electric wave. The 1/4-wave monopole antenna was installed in the center of the ceiling. In the experiment, five pregnant rats were set in a radically with direction of the nose to the center. The distance from the antenna to the nose was 3 cm and from a ceiling to a rat back was 0.5 cm. Precise analysis using mathematical model obtained from MRI picture taken form pregnant rats at gestational days 7, 14 and 16 demonstrated that the actual exposure levels were lower than expected. The SAR values were about 1/3 time of the expected values, either high dose groups or low exposure group. It turns out that actual exposure level in the high dose group was 1.2 W/kg instead of SAR 2.0 W/kg. The whole body average SAR of a pregnant mother rat or an embryo was less than the value of 0.4 W/kg appointed in order to prevent arising the tissue temperature. Maternal weight and diet intake were measured during the gestational 7 to 20, every day, and the cesarean section was performed after euthanasia under anesthesia on gestation day 20. The macroscopic pathological examination was conducted at the time of a cesarean section, and the number of corpus luteum of pregnancy, implantation marks, alive embryos, and absorbed embryo and dead embryo were counted. In case of alive embryos, sex of embryos, placental weights, external abnormalities as well as internal and skeletal abnormalities were investigated.

**Results.** Maternal general condition, body weight gain, diet intake was not changed during EMF exposure period. Examinations at cesarean section revealed that although the number of survival embryos in the sham exposure control group was larger than that in the exposed group, there was no statistical difference. There were no influences of the EMF exposure on either the number of corpus luteum pregnancy, fetal loss, alive fetuses, placental weights, or fetal external abnormalities. Visceral and skeletal abnormalities of fetus were not evident either.

**Conclusions.** Gestational local exposure to 1.95GHz high-frequency EMF (W-CDMA) used for cellular phones around the head did not influence to mothers reproduction ability and embryo-fetal development.

**Acknowledgements.** This work was supported by a Grant from the Ministry of Internal Affairs and Communications, Japan.
P-131 THE DOSIMETRY SIMULATION PIPELINE

Allen R. Curran¹, Deborah Silver², David A. Nelson³, Mark A. Hepokoski¹
¹ThermoAnalytics, Inc., Calumet, MI, USA ²Rutgers, Piscataway, NJ, USA ³University of South Alabama, Mobile, AL, USA

Objectives. Voxelized anatomical models are widely used to simulate exposures of biological systems to radio frequency (RF) and other forms of directed energy. A voxelized model is made up of volume elements that completely describe internal anatomical structures. Developing a model is a labor-intensive process of converting two-dimensional MRI or CT images into a three-dimensional voxelized description. This involves "segmenting" or identifying the tissue type or organ for each pixel in a two-dimensional data slice. Furthermore, once the model is segmented it needs to be repositioned into a "realistic" pose. The goal of this project was to assemble a toolkit capable of converting medical imaging data into a voxelized model suitable for exposure simulation studies of humans or laboratory animals. The toolkit was assembled from existing voxel editing software and also includes the FDTD (Finite Difference - Time Domain) and Thermoreg codes, creating a direct path from two-dimensional image data to three-dimensional tissue temperature maps (Figure 1).

Methods. After acquisition, the next step in the process is segmentation. There are a number of freeware and commercial toolkits that are available for segmentation. While many of them are specific to different organ types (such as the brain or heart) there are a number that can handle full animal body datasets as are used in dosimetry studies. One of the main difficulties in segmentation is compensating for noise or acquisition issues such as partial scans or overlapping segments. However, many of the segmentation programs allow the user to perform manual segmentation so that corrections can be done slice-by-slice. We have experimented with a number of different freeware codes including ITK Snap, Kitware’s VolView and 3Dslicer. While no one code has all the required features, it is possible to use them in tandem since there are other image based software codes that convert between the different codes and supplement some of the functionality that these codes do not provide (e.g., merging different segmentations, etc.).

The next step in the process is repositioning. Computer graphics and CAD tools are currently unable to reposition voxelized data since these tools operate on polygons. Most existing volumetric deformation algorithms are not suitable for this application since they can not handle the large deformations nor the kinematics associated with repositioning. Repositioning and segmentation are independent, i.e., the segmentation can be performed before or after manipulation. However, it is better to perform the segmentation before repositioning, since it is helpful to segment the bones before choosing the articulated (IK) skeleton that is used for repositioning. Furthermore, image acquisition and segmentation are done only once for each dataset, but the dataset may need to be repositioned many times for each different scenario or experiment that is conducted. In previous work we have described a methodology that can be used for repositioning, however, it is a difficult task and there is no generic code available. The lack of an efficient method for repositioning a voxel model is still a major impediment to more realistic exposure simulations of humans and animals.
Results. We have performed a partial segmentation (bones + fat) of pig imagery using the free software described above. An IK-skeleton was identified and the voxel model of the pig was repositioned to a standing pose. A voxel model of a goat was also repositioned to a standing position and subsequently used as input to the FDTD and Thermoreg computer codes.

Conclusions. Initial experiments have shown that full animal segmentation is possible using existing free software in tandem. There are many existing segmentation code development efforts supported by the medical community (NIH, NSF, commercial enterprises, etc.), with regular software updates. While one program may not have all of the functionality necessary, it is not difficult to transfer data between the different applications. It has also been shown that a repositioned model can be used for both FDTD and Thermoreg. Although the repositioning codes work well, the current interface is difficult to use and poses an impediment to a seamless transition between two-dimensional image data and dosimetry solvers. Current efforts focus on improving the usability of the interface.

Acknowledgements. This work was supported by AFRL/HEDR (M Haeuser, 2dLt) and funded by the DoD SBIR program.
**P-132** MODELING THE BRAIN FOR THE CALCULATION OF INDUCED CURRENTS: SEGMENTED VS. MEASURED DATA

Andreas Barchanski¹, Masaki Sekino², Erjon Gjonaj¹, Thomas Weiland¹, Shoogo Ueno³, Hiroyuki Ohsaki²

¹Technische Universitaet Darmstadt, Darmstadt, Germany ²The University of Tokyo, Tokyo, Japan ³Kyushu University, Fukuoka, Japan

**Objectives.** The Transcranial Magnetic Stimulation (TMS) is the non-invasive application of a short, localized magnetic field pulse of high intensity to the surface of the head. This magnetic pulse induces currents of a magnitude large enough to cause a depolarization of neurons, predominantly in the cerebral cortex. Using numerical methods, the distribution of the induced current densities inside the brain can be computed, promising a prediction of the area of neural excitation. In such calculations, anatomically realistic models of the brain are used. Up to now, the most common procedure to create brain models is the segmentation of standard magnetic resonance imaging (MRI) data. Recently, Sekino et. al. have proposed a novel approach to measure the conductivity distribution directly, by exploiting the proportionality between the conductivity and the diffusion coefficient of water, obtained from MRI measurements [1]. In this paper, we analyze and compare the calculated current densities in a typical TMS treatment, obtained using a segmented and a measured brain model.

**Methods.** The segmentation of the MRI data is performed using the Statistical Parametric Mapping (SPM) software. It is based on a hybrid method called unified segmentation, that is a mixture of tissue classification based on voxel intensities and a registration of the data to a template brain [2]. During the segmentation process, each voxel is assigned to one tissue type: white matter, gray matter and cerebro-spinal fluid (CSF). The conductivity value of each tissue type can then be estimated using e.g. the parametric Cole-Cole equation proposed by Gabriel et. al.

In Sekino’s method, the diffusion coefficients are estimated from the relation between the b-factor and the signal intensity of MRI. Using the Einstein-Stokes equations, the viscosity of the extracellular fluids can be estimated, from which the conductivity can be obtained. This procedure can be applied in the three orthogonal directions, allowing to measure the spatial distribution of the anisotropic conductivity.

The induced currents are calculated using the Ex-SPFD approach, that is an extension of the classical SPFD method originally proposed by Stuchly and Dawson [3]. The Ex-SPFD approach is a two step algorithm, that allows to use arbitrarily shaped field sources and also highly conductivity material in the computational domain. In the first step, an approximative vector potential is calculated using the curl-curl equation, or alternatively a vector Poisson system when the shielding effect of the induced currents can be neglected. In the second step, a scalar correction potential is calculated from the SPFD equation, using
the approximative vector potential on the right-hand-side. The induced currents can then
be obtained from the ohmic law applied to the corrected potential.

**Results.** In order to compare the current densities calculated using the different models,
a typical TMS treatment is simulated. The excitation if performed by a figure-of-eight coil with 2 x 9 windings. We have recently showed that due to the short duration of the magnetic field pulse, the actual value of the induced current densities can be higher by a factor of approximately seven than the time-harmonic solution at 1000 Hz [4]. However, the comparison between both models can be performed for a single frequency component, which significantly reduces the computational time. The computational domain was discretized using an equidistant mesh with a resolution of 2 mm. Care was taken to minimize the effects of boundary conditions and to place both models at an identical distance to the excitation coil. Figure 1 depicts the calculated current densities in an axial slice of both brain models. The position of the coil is also drafted. In the segmented model, the highest current densities occur in the CSF. This is as expected, since the CSF exhibits the highest conductivity value in the segmented model (@1000 Hz - white: 0.062 S/m, gray: 0.098 S/m, CSF: 2 S/m). The highest conductivity in the presented slice of the measured model amounts to 0.52 S/m. Thus, the current densities in the segmented model are much higher than in the measured model. The maximal value in the presented slices amounts to 50 A/m² in the segmented model vs. 9 A/m² in the measured model. The step-wise assignment of the conductivities in the segmented model leads to a concentration of the current flow, in the good conducting CSF regions, hindering the current to spread into brain tissue. This clearly shows the limitation of segmented models. In the measured model, the calculated current densities exhibit a more smooth profile due to a better current spread, although the spatial resolution of the measurements was limited to 3.4 mm.

**Conclusions.** We have calculated the induced current densities inside the brain during a TMS treatment using a measured and a segmented model of the conductivity distribution inside the brain. The current density distributions exhibit some substantial differences that can be directly attributed to the applied modeling detail. In the full paper, also the effects of the conduction anisotropy will be presented.

**Acknowledgements.** References

*P-133* SIMULATIONS OF A MAPPING STUDY OF THE MOTOR CORTEX
Andreas Barchanski, Stefan Suwelack, Michael Landgrebe, Berthold Langguth, Peter Eichhammer, Erjon Gjonaj, Thomas Weiland
1Technische Universität Darmstadt, Darmstadt, Germany 2University of Regensburg, Regensburg, Germany

**Objectives.** The Transcranial Magnetic Stimulation (TMS) is the non-invasive application of a short, Localized magnetic field pulse of high intensity to the surface of the head. This magnetic pulse induces currents of a magnitude large enough to cause a depolarization of neurons, predominantly in the cerebral cortex. We have performed a mapping study of the motor cortex by varying the position of the stimulation coil on the head surface in a 5x5 array, and measuring the induced potential in the appropriate hand muscle. The results of this measurements are compared to induced currents densities inside the motor cortex, calculated using an individual, high resolution brain model segmented from a MRI dataset.

**Methods.** The mapping study was performed on a healthy male volunteer. Using an electrode on the skin surface, the potential in the nerve of the index finger of the right hand was measured (Muskulus Interosseus 1). By varying the position of the coil on the head surface, the stimulation point eliciting the maximal potential was estimated. Then, the potential in the finger nerve was recorded for an array of 5x5 points, around the hot spot. Using a conventional 3 T MRI scanner (Siemens Allegra) a 3D representation of the volunteer’s head, with a spatial resolution of 1 mm, was obtained. The position of the motor cortex was estimated from functional MRI recordings during which the subject was performing finger tapping movements. For the calculation of the induced currents, the MRI data was segmented into 5 tissue types: white matter, gray matter, cerebro-spinal fluid (CSF), dura, and skull bone. The segmentation was performed semi-automatically using...
the SPM (Statistical Parametric Mapping) and FSL (FMRIB Software Library) software and processed for use in our electromagnetic field software. The conductivity value of each tissue type was estimated using the parametric Cole-Cole equation, as proposed by Gabriel et al..

The induced currents are calculated using the Ex-SPFD approach [1], that is an extension of the classical SPFD method originally proposed by Stuchly and Dawson. The Ex-SPFD approach is a two step algorithm. In the first step, an approximative vector potential is calculated using the curl-curl equation, or alternatively a vector Poisson system when the shielding effect of the induced currents can be neglected. In the second step, a scalar correction potential is calculated from the SPFD equation, using the approximative vector potential on the right-hand-side. The induced currents can then be obtained from the ohmic law applied to the corrected potential.

**Results.** The computational domain was discretized using an equidistant mesh with a resolution of 1 mm. Care was taken to minimize the effects of boundary conditions. A X-ray picture of the figure-of-eight excitation coil (Magstim MCF-B65) was used to determine the geometry of the coil windings. In the simulations the windings are modeled as current paths mapped to the computational grid. The left part of Figure 1 depicts the positions of the excitation coil on the heads surface. In the middle part, the calculated magnetic field in a coronal cross section, for the central coil position is shown. The tissue distribution of the segmented model is overlaid, and the location of the motor cortex is highlighted. In the right part, the induced current densities in the brain tissue are shown. The same cross section as in the middle part of the figure was used. For presentation purposes, the induced currents in the CSF, dura and skull bone were set to zero, since these are of less interest.

**Conclusions.** The calculation of induced current densities in high-resolution brain models promises to predict the spot of neural stimulation in TMS. To analyze the modeling accuracy of these calculations, we have performed a mapping study of the motor cortex by varying the coil position on the head surface. Results of the mapping study are compared to simulations results. Preliminary simulations have already showed a good agreement of the calculated current densities and the measured potential in the finger muscle.

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**Figure 1.** Left: Array of coil positions, Middle: Magnetic field and position of the motor cortex, Right: Induced current densities in brain tissue.
P-134 DYNAMICAL MODELLING OF EXPOSURE TO MILITARY HAWK RADAR RADIATED FIELDS

Benoit Stockbroeckx\textsuperscript{1}, Thierry Colette\textsuperscript{1}, Etienne Degraeve\textsuperscript{2}

\textsuperscript{1}University of Louvain, Louvain-la-Neuve, Belgium \textsuperscript{2}ACOS WB, Brussels, Belgium

\textbf{Objectives.} The ACOS-WB Epidemiology and Biostatistics Division of the Belgian Defence is achieving a wide epidemiological study about the possible link between electromagnetic exposure and health problems by the operators of anti-aircraft Hawk radars. These persons were working and living during the Cold War period in the close neighbourhood of high power radars dedicated to the air surveillance. As these radars have been dismantled, on-site field measurements cannot be achieved and the exposure level is assessed with simulations.

\textbf{Methods.} Five radar types have been considered: CWAR, IFF, PAR, HIPIR and ROR. The working frequencies are around 1, 10 and 15 GHz. As the antennas are large and the wavelength short, most of the exposure situations are located in the radiated near field of the radar antennas. Hence radiation is modelled with the sub-antenna technique: the antenna apertures are discretized into sufficiently small elementary antennas which radiation contributions are combined at the assessment point. This general method is particularized by using the technical characteristics of the radars: the aperture distributions have been calculated in order to match the specified antenna 3 dB beamwidths in the far field. Nine sites located in Germany and Belgium have been investigated: Oesdorf, Tietelsen, Bosseborn, Flechtdorf, Haasheide, Freienhagen, Willebadessen, Rhoden, and Lombardsijde. Each site has been modelled. The topography is described by a digital elevation model (DEM). The radar hillocks are described in a secondary finer DEM. The building locations and shapes and the radar locations have been encoded. Some sites have been visited in order to compare the information provided by the maps with the observations made on-site. The building materials, structures and height have been observed and measured. The propagation modelling is based on the uniform theory of diffraction (UTD). The reflection on the building faces, diffraction on the building edges, reflection on the ground, masking by the buildings and the ground are all considered. The propagation paths are obtained by a ray tracing method. The penetration inside buildings is computed from measurement results, which have been obtained on-site. The radiation and propagation models are validated by measurement results. The radiation modelling method is validated with measurement on Dutch radars obtained from TNO for the CWAR and HIPIR radars. The propagation modelling method is validated with measurements achieved on-site. The error is far below 2 dB for the two highest frequency ranges (10 and 15 GHz) and around 4 dB for the lowest frequency range (1 GHz).

Time averaging of the exposure level is an important issue when dealing with high power rotating radars. The static analysis yields the exposure level on one observation point when the radars are directed towards this point. This is called the worst-case situation. The peak and average values due to the pulse amplitude modulated signals are obtained. Beyond this static analysis, a dynamical one has been achieved. Some radars are rotating permanently or only during some particular activity states of the site (status) and some other radars are moving when a target has been detected and must be identified and followed. Hence the
exposure level is averaged at 4 levels: signal, usage, status, and year. Each level corresponds to a particular duration for the time averaging. The signal level yields an averaging over the duty cycle of the radiated signal. This is the shortest averaging time: some microseconds. The usage level yields an averaging based on the movement of the radar when it is in service (some seconds averaging). The status level yields an averaging based on the percentage of the time the radar is in service during one status (some hours averaging). And the year level yields an averaging based on the sequence of the different status along the year (one year averaging time).

A volume averaging method is implemented in order to assess the average whole body exposure level, which is in general more relevant than localized values.

Results. The software implementing all the models and algorithms together with a user interface has been delivered to the Belgian Defence. It is referenced HawkCarto 3.1.7. It allows to produce assessment results and to control all the simulation parameters. The results are computed over surface areas matching the topography of the site at a user-defined height above ground. These results are formatted in a CSV file and used to build electromagnetic maps of the sites. Some typical calculated electromagnetic maps are provided.

Conclusions. The radar antenna radiation has been modelled in order to deal with near field exposure. The modelling based on the sub-antenna technique has proved its efficiency. It avoids the large computation times required by the full numerical techniques. The field propagation has been modelled by using a ray tracing method and the UTD in order to deal with the site topography and the presence of the buildings. The radiation and propagation models have been validated with the available measurement results and measurements achieved on-site. Four dynamics levels have been defined in order to produce peak E-field values as well as values averaged over different time periods. The averaged results are conditioned by some parameters, which have to be set in accordance with the site occupation habits.
P-135 THERMAL MODELING OF A FREE SPACE EXPOSURE SYSTEM FOR ON-LINE MONITORING OF CATECHOLAMINE RELEASE FROM CHROMAFFIN CELLS EXPOSED TO MICROWAVE FIELDS

Ranjan Misra³, Indira Chatterjee¹, Jihwan Yoon¹, Dana McPherson¹, Gale L. Craviso²
¹University of Nevada, Reno, Reno, NV, USA ²University of Nevada, Reno, Reno, NV, USA ³University of California, Los Angeles, Los Angeles, CA, USA

Objectives. In the exposure system we designed for on-line monitoring of catecholamine release from chromaffin cells exposed to microwave fields in the frequency range 1 - 6 GHz (Yoon, et al., 2006), average SAR values computed using the Finite-Difference Time-Domain method ranged from 0.05 to 67.25 W/kg over the region where the cells would be located during the exposures. Moreover, the SAR distribution over this region had a certain degree of inhomogeneity. The goal of this work was to compute the resulting temperature distribution over this region by solving the heat conduction equation and accounting for the flow of the balanced salt solution (BSS) across the surface of and through the glass fiber filter in which the cells are immobilized.

Methods. The exposure system consists of a cell perfusion apparatus (CPA) inside which chromaffin cells are immobilized on a glass fiber filter (GFF) of diameter 24 mm. The cells are continuously superfused with temperature-controlled BSS at a rate of 0.4 ml/min. The temperature of the BSS entering and exiting the CPA is continuously monitored in the inlet and outlet tubing respectively with non-perturbing fluoroptic temperature probes.
placed as close as physically possible to the GFF where the cells are immobilized. The CPA
is mounted vertically within a mini anechoic chamber and the cells exposed to continuous
wave microwave fields in the frequency range 1 - 6 GHz by positioning the CPA in the far
field of a high power broadband horn antenna.
As described in Yoon, et al. (2006), a commercially available Finite-Difference Time-Domain
(FDTD) software package XFDTD (Remcom, Inc.) was used to compute the detailed SAR
distribution over the GFF where the cells are immobilized. Over the frequency range 1 - 6
GHz, the average SAR varies from 0.05 to 67.25 W/kg, with the maximum SAR obtained
at around 3.5 GHz. This latter result is expected since at approximately 3.5 GHz, the
diameter of the GFF is approximately half a wavelength in the GFF soaked with BSS
and thus, coupling of the electric field would be maximal. The homogeneity of the SAR
expressed as the percentage of area of the GFF over which the SAR is homogeneous to
within 30% varies from 47% at 1 GHz to 18.7 % at 6 GHz.
Since the goal of the on-line experiments is to study non-thermal effects on catecholamine
release, it is important to ensure that the temperature of the cells immobilized on the
GFF is maintained to within an acceptable limit, i.e. 36 ± 0.2 deg.C. Hence a detailed
thermal model of the entire CPA was created and analyzed using the commercially available
software package COSMOSFloWorks (SolidWorks Corp.). This model takes into account
heat transfer by conduction and losses by radiation, inlet flow rate of the BSS (measured
using a flow meter), and pressure at the outlet of the GFF (measured using a pressure
transducer). The temperature of the solid at the boundaries of the model was set to room
temperature (default of 20°C). Both inlet and outlet temperature (measured) were given
as inputs to the model. The SAR distribution computed using XFDTD was input into the
model as a heat source. The total analysis time was 3600 s with a time step of 60s.

Results. The results of the thermal modeling indicated that without any SAR input, there
was a large temperature gradient between the center and edge of the GFF. The temperature
at the center was 36.1 deg.C and that at the edge of the GFF was 20 deg.C (i.e. room
temperature). This alerted us to the possibility that perhaps the BSS was not diffusing fast
enough across and through the porous GFF to maintain a uniform temperature distribution
on the GFF, although the actual computed temperature difference appeared too high. After
directly measuring the temperature at these locations on the GFF in the experimental set-
up, a temperature gradient was indeed observed, but it was not as severe as that computed.
At the center of the GFF the measured temperature was 36 deg.C and at the edge of the
GFF the measured temperature was 30.2 deg.C. Hence, we are in the process of not only
modifying our CPA design to decrease this temperature gradient (Yoon, et al., 2007), but we
are also incorporating a better representation of the GFF into the thermal model so that it
will predict more accurately the temperature distribution over the GFF. In addition, when
the SAR distribution computed using XFDTD at 3.5 GHz, for an input power of 250W to
the horn antenna, was supplied as a heat source to the thermal model, the temperature
distribution obtained over the GFF was almost identical to that obtained without the SAR.
This finding indicates that the SAR levels being used in the experiments are non-thermal.

Conclusions. In order to justify the claim that chromaffin cells that are exposed to mi-
crowave fields in our perfusion system are being maintained at a temperature that is within
physiologically acceptable limits, it is not sufficient to only report SAR values at the location of the cells. Thus, based on a thermal model, we have confirmed that the power levels we are using are indeed non-thermal. Also, based on the results of the thermal modeling some important design modifications have been incorporated into the CPA and the exposure system.

References

Acknowledgements. This work was supported by the Air Force Office of Scientific Research grants F49620-03-1-0262, FA9550-04-1-0194 and FA9550-05-1-0308.

P-136 COMPLEX PERMITTIVITIES MEASUREMENTS OF OCULAR TISSUES IN QUASI-MILLIMETER AND MILLIMETER WAVE BANDS

Hiroki Wakatsuchi1,2, Masahiro Hanazawa2, Taiji Sakai2, Soichi Watanabe2, Masami Kojima3,4, Yoko Yamashiro4, Kazuyuki Sasaki4, Osamu Hashimoto1

1Aoyama Gakuin University, Sagamihara, Kanagawa, Japan 2NICT, Koganei, Tokyo, Japan 3Kanazawa Medical University, Kahoku-gun, Ishikawa, Japan 4Kanazawa Medical University, Kahoku-gun, Ishikawa, Japan

Objectives. The applications of quasi-millimeter waves or millimeter waves are expected to increase in near future. This will require detailed evaluation of human-body exposure to those waves. In order to evaluate the power absorption in the human body, electrical properties of biological tissues and organs are necessary. Therefore, we have measured complex permittivities of blood samples as one of the most fundamental biological tissues. In this study, we report measurement results of complex permittivities of ocular tissues (cornea, aqueous humor, crystalline lens, and vitreous) which are the most sensitive tissues and organs for quasi-millimeter and millimeter wave bands because the power absorption in these bands is limited to the surface area of the exposed body.

Methods. Our measurement system is composed of a vector network analyzer (Agilent Technologies: PNA series E8316A) and an open-ended coaxial probe (Agilent Technologies: 85070E). This system is calibrated by open (air), short, and de-ionized water. After coaxial probe is contacted on or inserted into samples, complex permittivities are derived from
measured complex reflection coefficients at the probe edge. Frequency range was set from 5 to 50 GHz.

Pig eyes within 12 hours after butcher were used as measurement samples. The complex permittivities of cornea, aqueous humor, lens, and vitreous were measured. To prevent the samples from evaporation of moisture, pig eyes were with moisture chamber at 3 degrees Celsius.

Because our measurement system needs sample size of greater than 1 cm³, corneas (thickness: 0.5 mm/cornea) were layered vertically up to required size. Aqueous humor (volume: 0.3 ml/eye) was collected with a syringe up to the required amount and was measured. Lens was extracted from eyeball. Then the probe was touched to the center of the crystalline lens and its complex permittivities were measured. On the other hand, because the vitreous is gel and its volume of the eye is enough for the measurement, coaxial probe was inserted into the vitreous cavity after cornea, aqueous humor, and crystalline lens were removed. Table 1 lists the temperatures of each ocular tissue at the measurement.

**Results.** Figs.1 and 2 show the measurement results of the complex permittivities. In addition these measurement results, theoretical values of de-ionized water (22 degrees Celsius) are also shown in the same figures.

It is shown that the complex permittivities of aqueous humor and vitreous are corresponding each other as well as those of de-ionized water in both parts throughout measured frequency band. On the other hand, we can also confirm that there are clear differences between them and the measurement results of cornea and lens. These differences may be caused by the degree of the water content in those tissues.

**Conclusions.** We measured the complex permittivities of cornea, aqueous humor, crystalline lens, and vitreous using the coaxial probe from 5 to 50 GHz. Measured complex permittivities of the high-water-content tissues, i.e., aqueous humor and vitreous, are similar to those of water while those of the low-water-content tissues, i.e., cornea and crystalline lens, are clearly different from those of the high-water-content tissues.

We are now undertaking further measurement in order to clarify the temperature dependence of the complex permittivities of the ocular tissues as well as comparison with measured results by other measurement techniques. These investigations will contribute to dosimetric studies in quasi-millimeter and millimeter wave bands.

**Acknowledgements.** This work was supported by the 21st COE Program from MEXT of the Japanese Government.
**Figure 1.** Measurement results of the complex permittivities of each ocular tissue (real part)

**Figure 2.** Measurement results of the complex permittivities of each ocular tissue (imaginary part)
OBJECTIVES. Finite difference time-domain method is the most widely-used method when simulating the human exposure to radio frequency electromagnetic fields. One of the most important factors affecting the accuracy of the results is the implementation of absorbing boundary conditions (ABCs) in FDTD.

It was reported in [1] that uniaxial PML-ABCs (UPML) may cause significant error in whole-body SAR values in a homogenous muscle sphere. It was concluded that a thick free space region between the numerical phantom and the UPML-boundaries is required for accurate whole-body SAR results.

In [2], NORMAN-voxel phantom and split-field PMLs were studied. There was little variation in whole-body averaged SAR values, when the distance between the voxel phantom and PML-ABCs was varied. Also, the width of the PML-layer was shown to have little effect on the SAR values.

In this study, convolutional PML (CPML) absorbing boundary conditions are employed for SAR calculation. The objective of this study is to verify the performance of CPML and also find good CPML-parameters for SAR calculation.

METHODS. CPML absorbing boundary conditions are implemented in an FDTD code. To study their performance, muscle spheres and Norman-voxel phantom are exposed to a plane wave source. The distance from the sphere/phantom to CPML is varied, and SAR is calculated for each distance. If the ABCs were ideal, changing the distance would not affect the results. Thus the smaller the variation the better the ABCs.

CPML-parameters are chosen as follows (for notation, see [3]):

- Polynomial grading of CPML-parameters is used. Grading orders are 3 and 1 for \( \kappa \) (and \( \sigma \)) and \( a \), respectively.
- Parameter \( \sigma_{max} = \sigma_{opt} \) as in [3].

RESULTS. The studied situation consists of a homogenous 2/3-muscle (\( \sigma = 0.65 \) S/m, \( \epsilon_r = 36.5 \) at 1 GHz; \( \sigma = 1.00 \) S/m, \( \epsilon_r = 37.3 \) at 2 GHz) sphere with a radius of 2.5 cm in free space, exposed to a plane wave with an amplitude 1 V/m. The mesh resolution is 2mm, and the investigated frequencies are 1 GHz and 2 GHz.

Figure 1 and Figure 2 show the relative error of whole-body averaged SAR as a function of the distance from the CPML for four different parameter sets, at the investigated frequencies. The error is calculated relative to the situation in which the CPML is thick and is located far (> 100 cells) from the sphere. When the CFS-functionality is disabled (\( a = 0, \kappa = 1 \)), the error increases as the sphere to CPML distance decreases. This does not happen when the CFS is enabled (\( a > 0, \kappa > 1 \)). Also, as can be seen in the figure, increasing the width of the CPML by just one layer reduces the error significantly.

Some tests were also carried out with NORMAN-voxel phantom at 900 MHz. With 6 cell thick CPMLs, the variation of SAR with the phantom to boundary distance seemed to be very small, even with CFS disabled. These results are in line with [2].
The width of the CPML was relatively small in the above calculations, and it could be easily increased. That would make the error even smaller.

**Conclusions.** It is quite obvious from the results that, when the CPML-parameters are chosen correctly, the error caused by the ABCs is small. In many practical calculations, 4 or 5 cell thick CPMLs are sufficient.

**Acknowledgements.** This study was supported by Tekes and Nokia Corporation.

![Figure 1. Relative error of whole-body averaged SAR at 1 GHz](image)
A NUMERICAL ESTIMATION FOR HUMAN BODY MITIGATION EFFECTS ON IMPLANTABLE CARDIAC PACEMAKER EMI FROM CELLULAR RADIOS USED IN ELEVATORS

Takashi Hikage¹, Harris Louis-Ray¹, Yusuke Abiko¹, Toshio Nojima¹, Ally Y. Simba², Soichi Watanabe², Takashi Shinozuka²

¹Hokkaido University, Sapporo, Japan ²National Institute of Information and Communications Technology, Koganei, Japan

Objectives. This study is to estimate the Electromagnetic field (EMF) distributions emitted by cellular radios in environments surrounded by conductive surfaces, e.g., train carriages or elevators. In this paper, we estimate the EMI risk to pacemakers by cellular radio transmission considering the effect of EMF absorption and shielding due to a human’s body inside the elevator.

Methods. We used a numerical estimation method based on the FDTD technique to examine the EMF in actual elevators. Also an electric field histogram estimation method for electric field strength was developed to deal with the complicated EMF distributions [1]. An elevator having a PEC body was used and an example of the FDTD model [2] is shown in Figure 1. There are 2 phantom models with only one mobile radio operation. This is a case...
in which one cellular radio user and one non-user are present in the elevator. The homogeneous human phantom models are applied in the analysis. They have realistic shapes and homogeneous electric parameters. We use a half-wavelength dipole antenna to represent a cellular radio operating in the 800 MHz band. The antenna is set 20 mm from the human phantom’s head and 158 cm from the floor. We consider the case in the varying locations and numbers of the phantoms. Field histograms are used to estimate the percentage of areas having the same field strength in the inside plane of the elevator. We can determine whether or not a pacemaker malfunction is likely to occur by identifying those areas where the EMF exceeds that reference value in the elevators. The relative field strength normalized to a certain reference level determined from the experimentally obtained maximum interference distance of implantable cardiac pacemakers was used [3].

**Results.** Examples of the three dimensional electric field distributions are shown in figure 2. The gray spots depicted in the figures show areas that have same high magnitude of electric field components. These results suggest that the effects of losses or shielding due to the human body are not small, and the spots which have high magnitude of the electric field would become smaller or disappear due to the location of the human body. Additionally, there are no results in which the maximum EMF strength exceeded the threshold limit which can adversely affect pacemaker operation.

**Conclusions.** In the actual environment, we stated that the effects of losses due to the human body cannot be disregarded. The results of our study show that the EM field inside the elevator is entirely within threshold safety levels for pacemaker operation.


[3]”Results of investigation into the effect of electromagnetic waves on medical equipment,” Association of Radio Industries and Businesses (ARIB), Mar. 2002.

**Acknowledgements.** This study was partially supported by the Electromagnetic Environment Committee of ARIB.
**Figure 1.** FDTD model for Elevator.

**Figure 2.** Example of three dimensional electric field distributions inside elevator.
**P-139 BEHAVIOR OF A BRAIN MODEL IN RESPONSE TO SIMPLE AND COMPLEX STIMULI**

Robert Z. Stodilka\textsuperscript{1,2}, Frank S. Prato\textsuperscript{1,2}, John A. Robertson\textsuperscript{1,2}, Benoit Lewden\textsuperscript{1}, Alex W. Thomas\textsuperscript{1,2}  
\textsuperscript{1}Lawson Health Research Institute, London, ON, Canada \textsuperscript{2}University of Western Ontario, London, ON, Canada

**Objectives.** We previously demonstrated perturbation of human behavior and electroencephalography (EEG) by a complex neural pulse (CNP (R)), and that such perturbations are both acute (observed during exposure) and residual (after exposure termination) [Cook et al 2004 Bioelectromagnetics 25 196-203]. Others and we also demonstrated perturbations by simpler waveforms (sinusoids). To better predict perturbations and optimize complex waveforms to achieve desired endpoints, we developed a computer simulation of neurotransmission in a large-scale brain model (BM) possessing many features observed experimentally.

**Methods.** The fundamental element of the BM is a neuron, prototyped as an approximation to the Hodgkin-Huxley equations, incorporated into a multi-neuron model with axonal conduction delays (from 1 to 20ms) and synaptic connections having spike-timing-dependent plasticity [Izhikevich 2006 Neural Comput 18 245-282]. Our BM consisted of 800 excitatory and 200 inhibitory neurons, with interconnectedness approximating a cortical mini-column. In the BM resting state, individual neurons are stimulated randomly to mimic background thalamic influence. The BM also accepts external stimuli, assuming a capacitive coupling mechanism. At any time, the state of BM can be interrogated by summing voltages from all sub- and super-threshold (ie. firing) neurons, interpreted as an instantaneous EEG measurement.

The response of the BM to stimuli was evaluated as follows:

1. **SIMPLE STIMULI:** 50 of 1000 total neurons were selected randomly and exposed to pure tone sinusoid stimuli for 500s (simulation time). The peak amplitude of the sinusoid was 66% of the threshold required for an action potential. EEG was recorded throughout exposure to characterize both transient and steady states. Sinusoids from 2 to 200Hz were applied individually, thus characterizing fully the response of BM in that frequency band.

2. **COMPLEX STIMULI:** 50 of 1000 total neurons were randomly selected and exposed to CNP (R) for 10s and 2400s. The peak amplitude of CNP (R) was 66% of the threshold required for an action potential. EEG was recorded throughout exposure in order to characterize transient and steady states. After exposure termination, EEG recording was continued until 4400s had elapsed to capture transient and steady state residual behavior.

**Results.** During resting state, the BM exhibited delta (2-4Hz) and gamma (30-100Hz) rhythms (not shown).

1. **SIMPLE STIMULI:** For all frequencies, the BM reached a steady state following approximately 100s of exposure. EEG frequency-domain analysis showed that exposure to frequencies between 2 and 15 Hz elicited a complex response with a discrete frequency spectrum, visually discernable to 200Hz (Figure 1, Label ”A”). For all exposure frequencies
(2-200Hz), the BM passed the exposure fundamental frequency (Label "B"), the first harmonic (up to 100Hz) and even the second harmonic (up to 60Hz) (Label "C"). Between 55 and 60Hz, the BM responded with a compact continuous spectrum centered at $\sim$62Hz (Label "D").

2. COMPLEX STIMULI: Frequency-domain analysis revealed that CNP (R) exposure had an immediate impact on EEG in the 30-50Hz band. Steady state response was reached after $\sim$100s of CNP (R) exposure: this response included a broad-spectrum suppression of EEG above 30Hz. The BM also demonstrated residual effects following CNP (R) exposure termination. Compared with the BM resting state, a 10s CNP (R) exposure left a residual effect 10s after exposure termination, attenuating EEG in the 30-50Hz band. A 2400s CNP (R) exposure left a transient broad-spectrum suppression, visible 10s after exposure termination, that subsided to a narrow-band (30-50Hz) effect at 2000s post-exposure.

**Conclusions.** For SIMPLE STIMULI presented at low (2-15Hz) frequencies, the BM had a discrete wide-band frequency response. The high frequency content of this response (>100Hz) refutes whole-brain simultaneous depolarization (since neurons are modeled with refractory periods), and instead implies sequential firing of small groups of neurons, where the groups are temporally separated by conduction delays. The observed pattern in Figure 1 (Label A) suggests the BM established frequency-dependent self-organized structures. Future work could analyze how groups form and which groups potentiate firing sequences. COMPLEX STIMULI: We demonstrated previously "calming" effects in humans during and following exposure to CNP (R). Our BM demonstrates that during CNP exposure, EEG amplitude is reduced for frequencies above 30Hz – which was visualized in the time domain as EEG entrainment to CNP. This may be interpreted as long-term suppression of gamma rhythms (visualized even at 2000s post-exposure), with evidence of gradual recovery. Regarding transient behaviors observed, future work could determine if transients vary during repeat presentations of CNP, which might suggest "adaptation". Within the limitations of our BM, these findings begin to explain our experimental observations of CNP exposure, and even suggest brain sensitivity near 60Hz. Additional EEG experiments are required to corroborate our findings; however, our BM may be useful to narrow search parameters when planning experiments.

**Acknowledgements.** CNP (R) is a Registered Trademark of Fralex Therapeutics Inc. Funded by CIHR and ORDCF.
Objectives. Within recent years, numerical simulation and in particular the FDTD method has become an effective means to support RF engineers in the analysis and design of wireless devices. In addition, numerical optimization has gained increasing interest as a means to support design processes. However, previous limitations in handling high complexity have restricted its application mostly to simple structures. This paper presents a novel approach which allows the effective optimization of entire CAD derived devices embedded in complex environments. On the basis of a commercial mobile phone, the applied methods are outlined and demonstrated; the device antenna is optimized with respect to return loss, radiation performance and in particular SAR, while placed in different in-use positions. In addition, production tolerances such as electrical connections are analyzed and their effects on SAR are highlighted.

Methods. For the study, the simulation platform SEMCAD X (<http://www.semcad.com>) was applied. SEMCAD X is based
on 3-D FDTD, furthermore consisting of an ACIS (R) based GUI, CAD importer, modeling interface, a novel 3-D OpenGL rendering engine and automated non-homogeneous grid generation. A set of multiple electromagnetic solvers (FDTD, FIT, ADI-FDTD, C-ADI-FDTD, hardware accelerated, etc.) provides problem-specific simulation effectiveness.

B) CAD/Parametrization:
For the purpose of this project, a novel 3-D parametrization engine has been developed. It allows the full parametrization of arbitrarily complex CAD data such as, e.g., an antenna embedded in the 3-D electro-mechanical CAD dataset of an industrial mobile phone.

C) Genetic Algorithm Based Optimization:
We consider the use of a bayesian network in order to build up a decision tree as a good means to learn dependencies among traits (genes). The algorithm implemented into SEMCAD X codifies the vector parameters to be optimized into a binary string (chromosome), and generation after generation approximates the best chromosome bit distribution, progressively neglecting those chromosome distributions that have not given good fitness results. The optimization engine subsequently allows the handling of multi-goal (weighted) complexity (e.g., return loss, far-field, SAR) based on 20 parameters or more. The considered method also tracks the probability of each bit, which is used to build a vector probability associated to each parameter binary codification and finally contributes to the performance of a sensitivity analysis.

D) Simulation:
In order to allow GA optimization of real-world scenarios, the simulation time for each iteration must be short. The problem which is considered in this paper consists of more than 10 - 15 million FDTD cells and spatial resolutions down to 100 microns. The use of hardware accelerated FDTD allows simulation times of less than 10 minutes, enabling the run of 200 iterations or more within about 1 day.

E) Procedure:
In the study, a commercial mobile phone was used. Its CAD dataset (IGES) consisted of more than 300 distinguished parts. The integrated antenna was subsequently converted into a parametrized form, leading to a total of 12 different parameters. The work presented in this paper performs the optimization within three steps:
1. optimization of the return loss;
2. optimized SAR for a chosen frequency (at SAM head, including hand models);
3. connection failure and parameter sensitivity analysis.

Results. A) Setup:
In the study, the frequency bands for GSM-900, DCS and UMTS were optimized with the goal of having a return loss better than -10dB. SAR and far-field optimizations were performed at 902 MHz, tracking the minimization of the SAR as well as back radiation of the antenna towards the user’s head. For connection failure optimization, the user specifies the metallic connections at selected locations of the mobile phone. The optimizer will subsequently switch these electrical connection points between short and open. For validation purposes, significant performance parameters have also been assessed experimentally using the DASY5 scanners.

B) Outcome:
The return losses obtained from the optimization cover all the three bands with a level
better than -8dB. SAR optimization was performed at 902 MHz with a reduction of -20% with respect to the original value. The far-field back radiation reached a level better than -9dB with respect to the maximum. The failure connection study revealed a degradation of the return losses of 14%, while a 28% degradation was obtained in the higher bands. SAR was significantly reduced, depending on certain crucial connections.

C) Computation:
The optimizations were run using SEMCAD X and hardware acceleration, achieving simulation speeds of more than 450 MCells/second, thus allowing 20 MCell problems to be solved in less than 10 minutes - and a full optimization with 335 iterations in less than 2 days.

Conclusions. Within this study, GAs were applied to optimize the performance of a CAD derived commercial mobile phone. The applied methods lead to excellent results in both convergence time and the quality of the solution, whereby the performance parameters of interest included the return loss, radiation performance and in particular SAR. The efficiency of this optimization method combined with enhanced parametrization and hardware accelerated FDTD enabled the optimization of the entire mobile phone, including shieldings, PCB, etc. The subsequently applied failure analysis outlined the robustness of the process, showing the capability of assessing sensitivity, SAR dependence and possible failure of the device. Moreover, the straightforward application of the presented novel approach demonstrates its robust integration into industrial R&D processes - ranging from device optimization to virtual prototyping and failure mode analysis.

Acknowledgements. This work has been generously supported by the Swiss Commission for Technology and Innovation (CTI).

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**P-141 HIGHLY ACCURATE HEAD MODEL FOR BIOELECTRIC AND RADIOFREQUENCY FIELD CALCULATIONS**

Markus Hannula\(^1\), Nathaniel G. Narra\(^1\), Tuukka Arola\(^1\), Jafar Keshvari\(^2\), Jari Hyttinen\(^1\)

\(^1\)Tampere University of Technology, Tampere, Finland  \(^2\)Nokia Research Center, Helsinki, Finland

Objectives. The aim of this study was to develop a very accurate 3D model of the human head. This kind of model allows us to obtain more precise results for the purposes of physiological modeling. In particular, our interest lies in Specific Absorption Rate (SAR)-calculations in tissues as well as bioelectric forward and inverse problems. SAR is a measure of the amount of radio frequency energy absorbed by the body when using a mobile phone. Keeping this goal in mind, during the segmentation process, we wanted to create detailed models of certain peripheral tissues beyond their distinct visibility in the source images.
Methods. The volume data of the head used was of the Visible Human Female project consisting of anatomical cryosection images and CT slices. The initial segmentation of major tissues was performed employing 3D methods with flexible propagation restraints e.g., 3D active contour and level set methods. The resulting raw segmentations were further fine tuned where necessary using 3D morphological and 2D methods. 2D segmentation methods may create stepped results due to the absence of curvature restraints in the third dimension, which show up as rough surfaces during reconstruction. In order to avoid this, we took advantage of the available volume dataset by using 3D methods where possible and restricted the use of 2D methods to only obtain very detailed small structures. During the segmentation procedure we used mainly thresholding and Level sets. In addition, morphological methods such as dilation and erosion were used in three dimensions. In some cases when there were very complex structures or almost invisible tissue borders, manual segmentation was the only option. For tissues within the skin and the eyes, synthetic tissue layers were produced using morphological methods due to their low visibility resulting from poor image contrast.

Results. We have segmented Visible Human Female head from 855 cryosection images along with data from the CT images (Figure 1). The model comprises of 23 different tissue types consisting of all together over 290 million voxels (Table 1). Voxel resolution is 0.33 mm in all dimensions. Standard segmentation of major tissues such as white matter, gray matter, skull and muscles is included. In addition, we have focused on the eyes and skin by creating more detailed synthetic segmentations based on anatomical data from literature (Figure 2).

Conclusions. A new accurate model is now available for SAR-calculations and other modeling purposes such as bioelectric field problems. It has high spatial accuracy and number of inhomogeneities providing good platform for various simulations. For bioelectric simulation with FEM or FDM methods the number of elements in the resulting model exceeds the standard computer resources. For SAR calculation the model and its spatial accuracy provides possibilities to further increase the simulation accuracy. In future, we will also define new anatomical layers and structures in the area of the brain and skull such as the hard and soft bone area in the skull and cortical layers. These will be devised by synthetic segmentation basing on general knowledge of the depths of these anatomical details.

Acknowledgements. EMSOFT-project; Tekes (Finnish Funding Agency for Technology and Innovation) and Nokia
**Figure 1.** Segmented head
FIGURE 2. : Segmented eye of 7 tissues
**P-142 MICRODOSIMETRY OF A MULTILAYERED CELL MODEL WITH NON-CONCENTRIC NUCLEOLI**

Zhao Wang, Yasir Alfadhl, Xiaodong Chen
Queen Mary, University of London, London, United Kingdom

**Objectives.** Background
Microdosimetry, i.e. the numerical study of EM fields interacting with the biological systems at the cellular scale has received considerable interest. However, microdosimetry is confronted with a major computational difficulty, that is, the treatment of the thin membrane structures, which often leads to extremely large memory usage and long running time by using the EM based numerical techniques. In this paper, a finite element method (FEM) with quasi-static approximation has been utilized to solve the complex structured cell model in RF band.

**Methods.** Methodology
In our study of biological cells, the largest dimensions of the objects are no more than 100µm; while the frequencies of interest are RF frequencies (< 10GHz), whose wavelength are much larger than the objects’ dimensions, so the quasi-static approximation can be applied in this study. Therefore, the FEM with quasi-static assumption is justified. The primary cell model in this study is a four layer sphere, representing a cell with membrane and nucleolus, immersed in a dielectric medium with relative permittivity of 75.3 and conductivity of 2.04 S/m. The relative permittivities of the cytoplasm and membranes are 55.6 and 11.3, and their conductivities are 1.43 and 3x10-6 S/m, respectively. It is subjected to a uniform, linearly polarized plane wave with the electric field of 1V/m at RF frequency. The concentric four layer cell model (as shown in figure 1) was calculated analytically and numerically, whose results were compared to testify the validity of the FEM with quasi-static approximation. Moreover, the nucleolus with nucleolus membrane was shifted away from the centre to investigate its position effects. The electric field distributions and transmembrane potential for both the cell membrane and nucleolus membrane were examined in RF band.

**Results.** After verified our numerical method with quasi-static approximation, we can draw the following conclusions through our simulation. First, the induced electric field strength and the transmembrane potential on the inner membrane were at the same order as the one on the outer membrane (as shown in figure 2). When the nucleolus was positioned at the centre, the transmembrane potential on the nucleolus membrane was 8.7% lower than the one on the outer cell membrane. Secondly, the position of the nucleolus has limited influence on the induced field and potential distribution on the outer membrane. When the nucleolus was shifted to the right, the peak magnitude of the electric field and transmembrane potential doesn’t show significant change. While the nucleolus was moved up, the transmembrane potential presents at most 10% reduction on the outer cell membrane.
and the transmembrane potential across the inner nucleolus membrane remains almost the same as the concentric scenario.

**Figure 1.** 4-layer cell model with concentric nucleolus (cell radius 10µm, nucleolus radius 2µm, membrane thickness 10nm)
**Figure 2.** calculated transmembrane potential on outer (diamond) and inner (dot) membrane of the 4-layer cell model (red curves for nucleolus moving up and blue curves for nucleolus moving right)

*P-143 A SOFTWARE INTERFACE FOR SIMULATED EMF STIMULATION OF A THALAMIC BRAIN MODEL*

Benoit Lewden\(^1\), Robert Z. Stodilka\(^1,2\), Frank S. Prato\(^1,2\), John A. Robertson\(^1,2\), Alex W. Thomas\(^1,2\)

\(^1\)Lawson Health Research Institute, London, ON, Canada  \(^2\)University of Western Ontario, London, ON, Canada

**Objectives.** In the past few years the complexity and completeness of human neuronal brain models has significantly improved as part of a global effort at reverse engineering. At the same time there is increasing evidence that an electromagnetic waveform applied to the brain can have various effects/outcomes dependent on the characteristics/parameters of the exposure [Stodilka et al BEMS 2007 Behavior of a brain model in response to simple and complex stimuli]. Here, we demonstrate optimization techniques for a model that allows for extreme scaling, code portability, and a user-friendly graphical interface. We decided to implement the brain model of [Izhikevich 2006 Neural Comput 18 245-282] as it can accommodate a large number of neurons both excitatory and inhibitory. In this model each neuron’s behavior follows the Hodgkin-Huxley equations which approximate the synaptic connections and axonal conduction delays.
**Methods.** We maximized portability of the software to different operating systems without limiting the performance with respect to the data size and the appropriate computations. As such, we developed the graphic interface using QT [QT-Trolltech: http://www.trolltech.com/products/qt] for its cross-platform properties and C++ as the coding language. C++ offers great performance and allows better flexibility for further development of the software. The original model was developed in Matlab, and used hard-coded parameters. Adding an interface around this algorithm allowed easier interaction with users and better feedback in terms of results. We have also made our software compatible for command line access or batch file, which allows multiple sets of simulations. To increase flexibility of the software we converted the algorithm to handle dynamic allocation of relevant parameters such as neuron number/type and length of electromagnetic stimulation.

There are three classes of input: (1) Brain model: the user can define the number and relative mix of neurons (excitatory or inhibitory) and the maximum number of synaptic connections; (2) Simulation: the user can define the duration of the simulation in seconds (precision within the simulation being to the order of a millisecond); (3) Stimulus: the user can define the stimulus to apply to the network (simulating thalamic input) with two parameter files, one being stimulus on/off pattern as it changes with time and the other being the waveform shape of stimulus. Note that the user can also define a target group of neurons for a more precise stimulus (i.e. which subset of neurons are directly stimulated). The program then randomly generates neural connections according to the model and its input, and this information can be saved for comparison of repetitive simulations which used different input parameters.

There are two classes of output: (1) Firing: a list of the neural activation for each neuron binned per second; (2) Vmat: voltage values of every neuron, broken down by millisecond.

**Results.** Converting the original algorithm from Matlab to C++ greatly improved the performance of the program. Benchmark testing was performed on an Intel Core2 2.13GHz processor with 4GB DDR2 memory. We compared the processing time needed for a simulation of a group of 1000 neurons (80% excitatory, 20% inhibitory, with 10% of the group as the maximum number of synapses) over various durations (Figure 1a). We also compared the processing time for different sized neural groups (i.e. neuron number) with a 60 second simulation under the same conditions (Figure 1b). Memory requirements were reduced by a factor of 30 compared with Matlab implementation and the speed was improved by a factor of 15-30.

Our software (not shown) makes the simulation configuration and feedback more user-friendly than adjusting hard coded values in Matlab or C/C++ code.

**Conclusions.** We have successfully developed a user-friendly neuronal/brain model to evaluate the effects of electromagnetic stimulation on ensembles of inhibitory and excitatory neurons. The processing speed has been increased by more than 30 compared with Matlab, and the model is no longer limited to a small number of neurons.
Our input stimulus function can be used to model induced current waveforms, making it of potential use to the scientific community. The program is currently fully operational, and can be made available upon request. Future work will feature a data analysis toolkit. We are also investigating ways to significantly increase the number of neurons (i.e. from $10^3$ to $10^7$ neurons) using multi-processing and/or graphic processor unit usage.

As suggested by J.C. Weaver [IN SILICO BIOELECTROMAGNETICS. Joint Bio electromagnetics and EBEA Dublin, Ireland Meeting June 2005] the opportunities to perform bioelectromagnetics experiments in silico will, we predict, be a valuable tool in bioelectromagnetics.

**Acknowledgements.** This research was supported in part by grants from CIHR and OR-DCF.

**Figure 1.** Processor time required for the original Matlab code and our stand-alone software versus (a) the simulation duration and (b) the number of neurons simulated.

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**P-144** COMPUTATION OF COMPLIANCE REGION NEAR THE PASSIVE RFID READER ANTENNA OPERATING IN THE FREQUENCY 900MHZ

Juderk Park$^1$, Naesoo Kim$^1$, Nam Kim$^2$

$^1$ETRI, Daejeon, South Korea $^2$Chungbuk National Univ., Cheongju, South Korea

**Objectives.** Full wave analysis (FDTD method, e.g.) of Electromagnetic field including near and far field is a very rigorous work[2][3]. It takes much time and computer resources. Objective of this study is to achieving field distribution and compliance boundary in the RFID reading zone with simple and fast method.
**Methods.** As shown in figure 1, an applied antenna is a RFID reader antenna. Its operating frequency range is from 860MHz to 960MHz, gain is about 6dB, input power is 1W(4W EIRP). It’s typical performance of RFID antennas [4]. Antenna performance including radiation patterns of antenna is calculated with FDTD method. And then, in order to achieve distribution of E field, this results are applied to GBM equation (eq. 1) [5][6].

\[ E(R, \theta, \phi) \approx \sum_{i=1}^{N} \frac{\sqrt{30P_i G_i(\theta_i, \phi_i)}}{R} e^{j(kR_i + \psi_i)} \hat{u}(\theta_i, \phi_i) \]

**Results.** Figure 2 shows the distribution of E field near the RFID reader antennas. Compliance boundary with various orientations(positions and directions of antenna array) are calculated according to limits* for each occupational and non-occupational persons. As a result, it is shown that compliance boundary near the RFID reader antenna is smaller than that near the base station antenna [4][5].

**Conclusions.** The result is mainly caused that input power of the passive RFID readers, on the whole, is less than that of base station antennas.
P-145 ESTIMATING THE TISSUE WATER CONTENT FROM MAGNETIC RESONANCE IMAGES, PHANTOM DESIGN

Tanja Voutilainen\textsuperscript{1}, Tuukka Arola\textsuperscript{1}, Jafar Keshvari\textsuperscript{2}, Jari Hyttinen\textsuperscript{1}
\textsuperscript{1}Tampere University of Technology, Tampere, Finland \textsuperscript{2}Nokia, Helsinki, Finland

**Objectives.** The electric properties of tissues are related to the water content. Thus the knowledge of in vivo tissue water content has many applications ranging from clinical applications to bioelectromagnetic field modelling studies. In this paper, the first part of a new approach to obtain relative, accurate tissue water content values utilizing Magentic
Resonance (MR) Imaging is presented. For modelling purposes, the accurate water content can be utilized further in determining the tissue conductivity and permittivity values. We have constructed a phantom for MR imaging to help us in determining the water to conductivity ratio for various tissues. Changes in brain tissue water content (or in the percentage of water content or in the relative water content) can indicate oedema, tumour or other trauma. A simple and accurate, clinically applicable method to determine the tissue water content would allow easy follow-up of the status of the patients. Also, the tissue water content determines many of the physical properties of the tissue e.g. permittivity and electrical conductivity. Nowadays computer models are being used e.g. for simulating bioelectromagnetic phenomena and for evaluating the Specific Absorption Rate (SAR) of radio frequency-fields in the human body. Thus a new method to determine the tissue conductivity and permittivity in vivo is well warranted. We have studied methods to obtain the tissue parameters accurately by non-invasive methods in vivo. The motivation for this study was to develop a simple method to determine the tissue water content accurately by using Magnetic Resonance Imaging (MRI). There has been previous reports on the tissue water content analysis. The methods presented previously are mostly complicated and we have been seeking after for a more straightforward method.

**Methods.** We have decided to use MRI and phantoms with deuterium oxide in our measurements. The gyromagnetic ratios of deuterium (D=2H) and proton differ notably, and thus deuterium is not detected by an MRI scanner but mixes perfectly with ordinary water. Mixtures of H2O and D2O can be used as very accurate references in water content determinations done by MRI. The phantom will tested by many imaging sequences (proton density, T1 and T2 maps, T1 and T2 weighted images) and see, by which of these we get the most accurate relationship between the pixel data and the known water content. We will also utilize Independent Component Analysis (ICA) to try to find a combination of imaging sequences to obtain the best MR-water correlation possible. The studied method can be implemented in clinical imaging with a reference tube (100% H20) placed also in the FOV. As reliable water content values are available, the tissue water content can be converted into tissue conductivity and permittivity parameters on per voxel basis. This enables us to perform modelling of the human body with unprecedented accuracy.

**Results.** For our studies a cylindrical phantom was constructed from PMMA (cylinder) and polycarbonate (ends and two plates inside). The outer dimensions of the phantom are 12.5cm for the diameter and 17.5cm for the height. Inside the phantom, there are two plastic plates (thickness 6 mm) with drillings for inserting 7 test tubes firmly into the phantom. The phantom can be seen in Image 1. The volume of liquid in a test tube is 16ml. The tubes are filled with different volume ratios of H2O and D2O [distilled water and deuterium oxide. The mixtures which can be used in imaging are presented in Table 1. The phantom itself is also filled with distilled water to avoid edge artefacts around the test tubes.

**Conclusions.** We have constructed a phantom to study how to obtain accurate water content values by clinical MRI scanners. We will continue the research to develop an imaging sequence combination that will produce the best possible correlation between the MR image and the tissue water content. The water content images will provide directly
the material properties for electromagnetic field calculations such as bioelectric and SAR problems and they can be utilized in clinical decision making.

**Figure 1.** Image 1. The phantom created for water content measurement in MRI

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P-146 NUMERICAL ASSESSMENT OF HUMAN EXPOSURE TO MF AND HF BROADCAST ANTENNAS

Agustin Martin, Raimundo Villar, Mercedes Martínez-B—*acuteu*—rdalo
Consejo Superior de Investigaciones Científicas (CSIC), 28006 - Madrid, Spain

Objectives. Due to the widespread use of radiofrequency technologies in the last years, great social concern has arisen about possible harmful effects on the health of people exposed to the electromagnetic radiations from those technologies. International guidelines have established limits for the protection of general public and workers against all known adverse health effects from the exposure to those fields [1]. Most of recent studies have focused on mobile telephony (at frequencies of 800-900 MHz and above), analyzing the exposure to both mobile terminals (very close to the user’s head) and base-stations (usually in the far-field, but also in the radiating near-field in the case of workers). The objective of this work is to study the human exposure to electromagnetic fields from communication systems operating at the broadcast frequency band below 30 MHz (sub-resonant), by calculating specific absorption rate (SAR) and induced current densities, when necessary, in order to verify guidelines compliance.

Methods. The finite-difference time-domain (FDTD) method is used to calculate SAR and induced current densities in a grounded high-resolution human body model located outside the reactive near-field region of a broadcast transmitting antenna (Fig 1). Several frequencies have been used, from 3 to 30 MHz, and a frequency scaling technique is used for the lower frequencies, when the computational requirements of FDTD are too high. The human body model, developed from nuclear magnetic resonance by REMCOM and the Hershey Medical Center, PA, consists in a 132 x 84 x 390 grid of 0.5 cm cubic cells, including 23 different biological tissues. We have assigned to each tissue its corresponding dielectric characteristics at each frequency, obtained from [2]. As the free-space wavelength of the field at those frequencies is much greater than the dimensions of the human body, a plane wave incidence is considered in the FDTD simulations.

Results. In order to compare with the exposure limit values from the guidelines [1], SAR averaged over the whole exposed body (SARwb), SAR averaged over 10 grams of contiguous tissue (SAR10g) and current density (J) (for frequencies below 10 MHz) have been calculated. Numerical results of SARwb, maximum SAR10g and maximum current density as a function of the frequency, for different polarizations, have been obtained. In order to validate our simulations, results for SARwb have been compared with results obtained by using a quasi-static approach for SAR calculation and a good agreement have been found.

Conclusions. The FDTD method has been used to analyze human exposure to electromagnetic fields from antennas operating at broadcast frequencies between 3 and 30 MHz. Induced current densities and/or SAR have been calculated in a high-resolution human body model. Results show that the used methodology can be useful to assess guidelines compliance in regions outside the reactive near-field of the antenna, even for the lower frequencies of the band.

REFERENCES:


Acknowledgements. This work has been supported by the Spanish Ministry of Science and Education, project TEC2006-01499.

**Figure 1.** - Schematic view of problem geometry

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**P-147 PHOTON CHEMISTRY: THE MASS OF THE PHOTON**

Tony Fleming  
Biophotonics Research Institute, Highett, VIC, Australia

**Objectives.** Self-field theory (SFT) was recently used to solve for the motions of the electron and the proton in the hydrogen atom [Fleming 2005, 2006]. Applying a similar form of solution for the photon, a theoretical spectroscopy of the photon was predicted [Fleming and Bauer 2004]. Unlike the matter-wave of quantum mathematics, SFT suggests that the photon has a simple internal structure consisting of two sub-photonic particles termed the ephlectron and the phroton having equal mass and opposite charge. This structure gives it hydrogenic-like transition frequencies at which the various radial and spin eigenstates
of the photons' internal structure change. Once the photon mass is known, the transition points can be obtained. This photon spectroscopy appears an important mechanism behind a range of biological phenomena including very low levels of photons observed to be emitted from strands of DNA [Popp 1999] and the emerging application of EM and acoustic frequencies for therapeutic medical uses [Bauer et al. 2005]. The crucial element then in this spectroscopy is to determine the mass of the photon.

**Methods.** The photon is the mediator of the EM field within the hydrogen atom. In contrast to the probability densities of quantum mathematics, SFT obtains the actual motions of the electron and the proton for the hydrogen atom in the form of eigensolutions to a system of partial differential equations based on the Maxwell-Lorentz equations. In the analysis Planck's constant $\hbar = q^2/(2\epsilon_0 v_e)$ appears as the energy per cycle of the electron and proton. The photon transits between proton and electron performing relativistic spiralling motions many times each cycle of the electron and proton that move coherently with one another. The phase length of the photon each time it transits $\pi/2$ (quarter cycle) maintains the overall coherency of the atom's internal energy providing a method to analytically determine the energy of the photon compared with the energy of the electron $m_\gamma c^2 = <i>\hbar v_e/(8\pi c) </i>$. Thus $m_\gamma = q^2/(16\pi\epsilon_0 c^3)$.

**Results.** Using the physical constants, the mass of the photon can be evaluated as $0.21410^{-53}$ kg. This value is commensurate with the experimental estimates on the upper limit of the mass listed by the Particle Data Group [Caso et al 1998] [Okun 2005].

**Conclusions.** Self-field theory is able to discern the tiny mass for the photon given in the results as $0.21410^{-53}$ kg. This mass is over 20 decades below the mass of the electron. The photon must make an integral number of transits per cycle of the hydrogen atom if the overall periodicity of the atom is to be maintained. The next step must be to determine the frequencies given by this analytic photon mass and then proceed to examine how these theoretical frequencies compare to a range of biophysical and physical experimental spectroscopic data.

**Acknowledgements.** REFERENCES:
FIGURE 1. Geometry to determine SFT fields at the sub-photonic level. The ephectron and the phroton have equal mass but opposite charge. There is an orbital and a cyclotron separation between the particles measured via their centres of motion. Each particle is shifted in phase $180^\circ$ from the other in both rotational directions.

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**P-148 SWEAT INCREASE IN TEENAGERS BY CDMA CELLULAR PHONES**

Deok Won Kim$^1$, Ki Chang Nam$^2$, Sung Woo Kim$^1$, Soo Chan Kim$^3$

$^1$Yonsei University College of Medicine, Seoul, South Korea  $^2$AIST, Tsukuba, Japan  $^3$Hankyong National University, Anseong, South Korea

**Objectives.** Very few provocation studies have been conducted regarding the physiological effects of CDMA phones on teenagers. Objective of this study is to see if there is any effect on physiological parameters such as systolic and diastolic blood pressures, heart rate, respiration rate, and skin resistance for teenager and adult groups.

**Methods.** During the sham and real exposures by CDMA cellular phones, heart rate, respiratory rate, skin resistance, and blood pressures were measured. Measurements of the heart rate and the digital blood flow waveform were collected by applying a photoplethysmography (PPG) sensor (DS-100, Nellcor, USA) to the index finger. Respiratory inductance plethysmography (RIP) was utilized to measure the respiration rate by applying a coiled band built for this study on the subject’s abdomen to measure the inductance changes resulting from cross-sectional change. The skin resistance was measured using mesh type electrodes (3M, USA) attached to the left middle and fourth fingers. A NIBP monitor (T4, OMRON, Japan) was used to measure systolic and diastolic blood pressures. The cuff was applied on the subject’s right upper arm at approximately the same height as the position of the subject’s heart. The blood pressures were measured three times every minute and averaged.

A CDMA phone with a SAR of 1.6 W/kg and a transmitting frequency range of 824.64 to 848.37 MHz was used (SCH-V3000, SAMSUNG Electronics, Korea). The carrier frequency used in this experiment was 835MHz. The phone was set to test mode which radiated continuous clipped sine waves with a maximal transmit power of 300 mW.
A conventional headphone was modified to install a folder-type cellular phone on the left
side of the head. The lower part of the cellular phone with buttons was wrapped up with
5 mm thick insulating material on order for the subject to be unaware of whether the phone
was working by feeling the generated heat. Twenty-one teenagers (12 males and 9 females;
15.9 ± 2.3 yr) and 21 adults (11 males and 10 females; 30.9 ± 5.6 yr) participated in this
study.

The experimental procedure was as follows: (1) The experiment was divided into real and
sham exposures. The duration of each exposure lasted for half an hour from start to finish.
(2) Data was collected at four different stages with the headset on the subject’s head:
after a 10 minute rest, after 15 and 30 minutes exposures to the RF field, and 10 minutes
after exposure termination; (3) At each stage, PPG, respiration, and skin resistance were
measured during the first minute. Blood pressure was measured three times on one minute
intervals; (4) In order to avoid interference with the previous real exposures, the sham
exposures were performed first. The exposure sequence was not randomized because the
preceding real exposures might produce effect longer than a day, resulting in the different
physiological conditions between the real and the sham exposures; (5) Between the sham
and real exposures, the subject took a 30 minute break.

Results. Results of the repeated two-way ANOVA test did not show any effects of the RF
exposure and exposure duration on all the physiological parameters measured for the adult
group.

The results of the teenager group indicated that there were no statistically significant differ-
ences between real and sham exposures in heart rate, respiration rate, systolic and diastolic
blood pressure. However, the changes in skin resistance were all significant, for the real
exposure (p<0.0001), exposure duration (p<0.0001), and interaction between exposure and
duration (p=0.0048), respectively. By applying Bonferroni multiple comparison test, the
skin resistances at rest and 15 minutes (p=0.0211) and 30 minutes exposures (p<0.0001)
were significantly different. The resistances for the real exposure at rest and 15 minutes
(p=0.0091) and 30 minutes (p<0.0001) were significantly different.

To analyze the relative change of skin resistance, the resting resistance values of real and
sham exposures were set at 100% as shown in Fig. 1. The resistance returned to the initial
resting resistance (p=0.0574) 10 minutes after the end of the real exposure.

Conclusions. In conclusion, this provocation study found a statistically significant asso-
ciation between mobile phone exposure and decreased skin resistances in teenagers, lending
support to the recommendation by the WHO Children’s EMF Research Agenda (2003)
that assessment of children’s sensitivity to RF should be a high priority agenda item. The
replication studies are warranted to confirm the results of this study that skin resistance is
sensitive to RF radiation by cellular phone, and teenagers are sensitive to it.
Figure 1. Relative skin resistance changes (mean+SD) of the four exposure stages for teenagers by sham and real exposure (*P<0.01, **p<0.001).
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ACKNOWLEDGMENTS

The Bioelectromagnetics Society gratefully acknowledges the following confirmed organizations for their generous financial support for the 29th Annual Meeting (as of March 20, 2007). Any additional support received will be acknowledged at the meeting.

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Mobile Manufacturers Forum (MMF) is an international association of radio equipment manufacturers whose members include: Alcatel, Ericsson, Mitsubishi Electric, Motorola, Nokia, Panasonic, Philips, Sagem, Samsung, Siemens, Sony Ericsson and TCL & Alcatel Mobile Phones.

The MMF's role is to support research, standards development and improved communications concerning wireless communications and health.

Michael Milligan is the Secretary General of the MMF and their website is available at: www.mmfai.org.
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The Electric Power Research Institute (EPRI) was established in 1973 as an independent, non-profit center for electricity and environmental research. EPRI’s collaborative science and technology portfolio now spans every aspect of power generation, delivery and end-use, drawing upon a world-class network of scientific, engineering and technical talent. EPRI’s clients represent over 90% of the electricity generated in the US. International client participation represents over 10% of EPRI’s program investment. Through the power of collaboration, EPRI is able to leverage the collective resources of its members to address the industry's toughest and most critical challenges related to generation, delivery and end-use, with a special focus on safe, reliable, cost-effective electricity and environmental stewardship. Robert Kavet, ScD, is the EMF Business Area Manager responsible for programs in EMF Health Assessment and Radiofrequency Safety.

The National Center for Complementary and Alternative Medicine (NCCAM) is the Federal Government's lead agency for scientific research on complementary and alternative medicine (CAM). We are 1 of the 27 institutes and centers that make up the National Institutes of Health (NIH) within the U.S. Department of Health and Human Services. NCCAM sponsors and conducts research using scientific methods and advanced technologies to study CAM. CAM is a group of diverse medical and health care systems, practices, and products that are not presently considered to be part of conventional medicine.
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SILVER SPONSORS

NIKKEN® Discover it. Live it.  Nikken is a company with operations in more than 30 countries, recognized as the world leader in wellness technology ever since it pioneered the concept in 1975. Nikken introduced its first product, a magnetic insole, in Japan, and the company launched its North American operations in 1989. With its world headquarters located in Irvine, California, today Nikken offers wellness products in nutrition, skin care, fitness, rest and relaxation, and home environmental control. The company specializes in innovative technologies and Nikken products include unique, patented features, such as EQL Magnetic Technology, a design that provides consistent magnetic coverage; Magnetic Biaxial Rotation, which produces a dynamic magnetic field with constantly changing polarity; Far-Infrared Technology, using specially made ceramic-reflective fibers that absorb energy and reflect it as far-infrared to produce warmth; Kenzen Wellness Technology, whole-foods nutrition; PiMag Water Technology, which recreates the environmental conditions that produce natural pi water; and Air Wellness Technology, an air system that features multistage, advanced filtration and negative-ion generation without the production of ozone.

TASER International's products save lives every day, providing devices for use in law enforcement, corrections, private security and personal defense market. Since its founding in 1993, TASER International has remained committed to providing solutions to violent confrontation by developing products that enable people to protect themselves. The Company is driven to do all that is possible to ensure that society, as well as our customers, can benefit from our products, while upholding the highest level of personal and professional ethics in the execution of business. TASER International, Inc. develops, assembles and markets conducted energy weapons that enable people to protect themselves while minimizing the risk of serious injury or death. TASER International's corporate headquarters with its manufacturing facility is located in Scottsdale, Arizona.
ACKNOWLEDGMENTS

The Bioelectromagnetics Society gratefully acknowledges the following confirmed organizations for their generous financial support for the 29th Annual Meeting (as of March 20, 2007). Any additional support received will be acknowledged at the meeting.

BRONZE SPONSORS

Dairyland Power Cooperative, La Crosse, Wisconsin, provides the wholesale electrical requirements and other services for 25 electric distribution cooperatives and 20 municipal utilities. These cooperatives and municipals, in turn, supply the energy needs of more than half a million people. Dairyland Power Cooperative’s mission is, as a cooperative organization, to provide competitively priced energy and services to our customers and maximum value to our owners, consistent with the wise use of resources. Chuck Thompson, Project Manager, has been a member of BEMS since 1990.

EBI is a pioneering global leader in electro and biomechanical medicine and one of six strategic business units of Biomet, the fifth largest producer of orthopaedic products worldwide. EBI designs, develops, manufactures and markets products used primarily by orthopaedic medical specialists in both surgical and non-surgical therapy. We feature an unparalleled line of innovative electrical stimulation and external fixation devices, in addition to a comprehensive line of spinal and orthopaedic support products. EBI is continually enhancing product development technologies through state-of-the-art research and development initiatives. Our extensive network of field representatives work in concert with headquarters support personnel to respond promptly to every physician and patient inquiry.

Fralex Therapeutics, Inc. is commercializing a breakthrough neuromodulation therapy, F-NMT. This proprietary technology utilizes a non-invasive device to deliver specifically designed, low-power pulseforms that moderate activity within targeted regions of the brain. It will have its first applications in the treatment of chronic pain, depression and anxiety.

The GSM Association (GSMA) is the global trade association that represents the interests of more than 679 GSM mobile phone operators across 210 countries. In addition, more than 150 manufacturers and suppliers support the Association’s initiatives as key partners. The primary goals of the GSMA are to ensure mobile phones and wireless services work globally and are easily accessible, enhancing their value to individual customers and national economies, while creating new business opportunities for operators and their suppliers. The Association's members serve more than 1.6 billion customers - 78% of the world's mobile phone users. Jack Rowley, Ph.D., is the Director Research & Sustainability.
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Ivivi Technologies, Inc., a subsidiary of ADM Tronics Unlimited, Inc. was founded to develop non-invasive electrotherapies for clinical applications. The company is focused on soft-tissue repair and regeneration, maintains a clinical Center of Excellence at a major medical school and conducts research with several academic programs. Visit us at www.ivivitechnologies.com.

The Lawson Health Research Institute (Lawson) in London, Ontario, Canada is the research arm of London Health Sciences Centre and St. Joseph's Health Care, London. Lawson is one of the largest hospital-based research institutes in Canada attracting $50 million each year in research funding. More than 500 investigators throughout London investigate disease and ways to detect, prevent, and treat illness. Dr. David Hill is Scientific Director and Dr. Joe Gilbert is its Chief Administrative Officer. For more information on Lawson, visit www.lhrionhealth.ca.

The National Institute of Environmental Health Sciences (NIEHS) is one of 27 Institutes and Centers of the National Institutes of Health (NIH), which is a component of the Department of Health and Human Services (DHHS). The Director of the NIEHS is Dr. David A. Schwartz. The mission of the NIEHS is to reduce the burden of human illness and disability by understanding how the environment influences the development and progression of human disease. To have the greatest impact on preventing disease and improving human health, the NIEHS focuses on basic science, disease-oriented research, global environmental health, and multidisciplinary training for researchers. The NIEHS achieves its mission through: Extramural research and training, funded by grants and contracts, to scientists, environmental health professionals, and other groups worldwide.

U.S. Air Force Research Laboratory, Radio Frequency Radiation Branch in Brooks Air Force Base began in 1968 under the leadership of John C. Mitchell. Today it is one of the largest centers for the study of the effects of RFR on humans and their environment. Original research is conducted in the science of RFR dosimetry and RFR bioeffects. Quality research is promoted through the publication of the USAF RFR Dosimetry Handbook and support of the International EMF Dosimetry Project. International RFR standards development and harmonization are promoted by working with the IEEE and the World Health Organization. Lt. Col. William Roach is the Chief of the Radio Frequency Radiation Branch.