COMMISSION K: ELECTROMAGNETICS IN BIOLOGY AND MEDICINE

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Introduction

The research activities on the biological effects of electromagnetic fields in Japan from 2001-2004 are reviewed. In vitro, in vivo, dosimetrical studies on DC and ELF electric fields, DC, ELF and IF magnetic fields, RF and microwaves are discussed. Biomedical applications including magnetic stimulation, hyperthermia, thermal ablation, MEG, MCG, current distribution MRI, MRI, and radiometry are also introduced.

K1 Biological Effects of Electromagnetic Fields

K1.1 DC and ELF Electric Fields

On dosimetry, Shimizu *et al.* developed user-friendly software to visualize the ELF electric field exposed to a human body [Shimizu, 2003a]. It provides the distributions of the surface field and the current induced in the human body within a practical computation time using a regular personal computer. The GUI made the changes of body proportion and environmental conditions practically simple. On instrumentation, Yamashita *et al.* has developed a ring-type telemeter for the photoelectric pulse measurement [Yamashita, 2000a]. The variation in the autonomic nervous system could be measured and analyzed. They have also developed a telemetry technique to measure EEG and ECG at the subject exposed to strong ELF electric field. Since it makes unconstrained measurement possible, it is useful to evaluate the physiological change in field exposure [Yamashita, 2000b]

On cellular effects, Shimooka *et al*. has pursued the possibility of immuno-modulation caused by the electric stimulation of the current induced in the body on field exposure [Shimooka, 2004]. They have reported the suppression effects of macrophage phagocytosis [Fujii, 2002; Kagawa, 2004], histamine release [Morita, 2002] and the generation of the reactive oxygen species [Tatebe, 2004].

Biological effects were evaluated with plants. Nitta *et al.* has found that bean sprout has the better growth in the higher electric field in the range of 10-25kV/m [Kiatgamjorn, 2003]. Nitta *et al*. has found the growth rate of ice plants in the electric field of 28.5kV/m than that of no field condition [Rotcharoen, 2003].

In the experiments with human subjects, Yamashita *et al.* exposed ELF electric field on the skin surface of the human forearm, and measured the physiological changes such as the skin temperature, the surface blood flow and the blood volume in the arm. In the local field exposure, the increases in these parameters were observed. The results of these experiments suggested that this response was controlled by the central nervous system [Yamashita, 2004]. Shimizu *et al*. analyzed the body hair movement caused by ELF electric field exposure. Through theoretical and experimental study, the mechanism of field perception was explained in detail. In this study, the cause of the seasonal variation of the perception threshold was clarified [Shimizu, 2003b, 2004]. Ohsaki *et al.* has attempted to apply the strong field exposure to therapeutic use. Using the apparatus approved by a government, they performed various fundamental studies and clinical tests. In objective parameters, the alleviation of pain in various muscles was demonstrated [Ohsaki, 2004] (Shimizu).

K1.2 DC Magnetic Fields on genetic and cells

In several kinds of microbial species, example of reports of the positive effect of DC magnetic field has been confirmed. SoxR on *Escherichia coli* in which there are too many examples of reports until now. Variant sodAsodB [Zhang et al., 2003] which reports rising, since the mutagenesis frequency has it by 5 or high magnetic field of 9 T in the double mutant. *Saccharomyces cerevisiae* with the paper in which found the rise in expression strength of several kinds genes of by the high magnetic field of 14 T [Ikehata, 2003]. *Rhodobacter sphaeroides* [Utsunomiya, 2003], which the production of porphyrin reports the increase at 5.3 times in the high magnetic field of 0.3 T. There are some inhibitions of multiplication by 0.1mT magnetic field, example of reports of the effect by magnetic field to 0.51 mT conidium formation rate besides on 3 kinds of plant pathogenic fungi (Ikahata and Miyakoshi).

There are several studies to determine the mutagenicity by exposure to strong static magnetic fields. Takashima *et al*. reported dose response relationship between magnetic field density and its mutagenicity using DNA repair-proficient and -deficient strains of fruit fly *Drosophila melanogaster*.[Takashima *et al*., 2003]. It was found that exposure to 2, 5 or 14 T fields for 24 h caused a statistically significant enhancement in somatic recombination frequency in the post-replication repair deficient flies, whereas the frequency remained unchanged in the nucleotide excision repair deficient flies and in the DNA repair-proficient flies after exposure. An increase linearly dependent on the flux density was observed between 0.5 T and 2 T, while it was saturated at exposure levels over 2 T. These findings suggest that exposure to high density magnetic fields induce somatic recombination in Drosophila, and that the dose-response relationship is not linear.

Zhang *et al*. used an *Escherichia coli* mutation assay to assess the mutagenic effects of strong magnetic filed. The mutation frequency was significantly increased by the static magnetic field exposure in *soxR* and *sodAsodB* mutants, which are defective in defense mechanisms against oxidative stress. In addition, the expression of superoxide-inducible *socS:: lacZ* fusion gene was stimulated 1.4- and 1.8-fold in *E.coli* when exposed to 5 and 9 T, respectively. These results indicate that strong static magnetic field induces mutations through elevated production of intracellular superoxide radical in *E.col*. (Ikehata and Miyakoshi).

K1.3 Magnetic orientation- Microorganisms and agarose

Bull sperm and paramecium cilium are oriented in a strong static magnetic field. An anisotropic diamagnetic susceptibility of microtubules, which are one of their components contributes it (Higashi and Iwasaka).

Magnetic fields of 5-10 T were applied to agarose molecules to obtain the random, the planar and the axial gels. As a result, the electrophoretic velocity depended on the gel structure as well as the size and structure of DNAs. The magnetically ordered agarose gels can be used for a new separation method of DNAs at a high resolution (Yamaguchi and Iwasaka).

K1.4 DC and ELF Magnetic Field

K1.4.1 In vivo studies

It has been found that moderate-intensity DC magnetic field ranging 1 mT-0.35 T have significant circulatory system effects most notably on cutaneous microcirculation and arterial blood pressure. Ohkubo *et al*. studied the influence of 0.25T DC magnetic field and geomagnetic field activity, estimated b y K and A_k-indexes, on mean arterial blood pressure (MAP), heart rate, hemodynamic index, and cardiovascular variability in pentobarbital-anesthetized rabbits. DC magnetic field with application to baroreceptor region for 65-80 min decreased BP. There was positive correlation of geomagnetic field activity with MAP, and this result implied that magnetic storms could increase the incidence of severe cardiovascular events. They continued their research in three papers (Okano *et al*, 2003a, b, 2005). They investigated the effects of DC magnetic field, 3.0-10.0 mT and 8.0-25.0 mT, on development of hypertension in young male, rats (SHR). DC magnetic field suppressed and retarded the development of hypertension in both exposed groups in a non-dose dependent manner.

For ELF magnetic field effects, Kezuka *et al.* presented their experiments about the effects of 50Hz magnetic field on the pteridine levels in mice. Their results suggested that only circularly polarized magnetic field exposure may affect the pteridine level which provide an indirect estimate of the degree of stress emerging during immune response. There was no evidence for effects on cellular immune systems of exposure to linearly polarized magnetic fields (Kezuka *et al* 2004, 2005).

K1.4.2 In Vitro studies

No or very little effects of ELF electromagnetic field were found on basic cellular behaviors (proliferation, survival and cell cycle). Exposure to a high-density ELF electromagnetic field increased mutation and chromosomal aberration dose-dependently. Such a result was more significant under a combined exposure with external factors. Results of molecular biological analysis for its mechanism revealed that a response to an ELF electromagnetic field had an effect on the signal transduction system that was involved with intracellular calcium and protein kinase (Miyakoshi).

Exposure to a time-varying magnetic field (maximum flux density of 1.7T) inhibits K^+ influx via Ca^{2+}-dependent K^+ channel and an increase in intracellular Ca^{2+} concentration ($[Ca^{2+}]_i$) of HeLa cells incubated in high K^+ medium [Ikehara, 2002]. Addition of Ca^{2+} ionophore (ionomycin) to the high K^+ medium increase $[Ca^{2+}]_i$ to the level of control cells, regardless of exposure to the magnetic field. But the inhibition of K^+ uptake by exposure to the magnetic field is not restored by addition of the ionophore. This strong time-varying magnetic field (maximum of 1.51T) also inhibits a transient increase in $[Ca^{2+}]_i$ in bovine adrenal chromaffin cells induced by bradykinin (BK) in a Ca^{2+}-free medium [Ikehara, 2002]. The exposure does not affect BK induced production of inositol 1,4,5 trisphosphate (IP3). Inhibition of the BK-induced increase in $[Ca^{2+}]_i$ by exposure for 30 min is mostly recovered 1 hr after exposure ended. Our results reveal that the magnetic field exposure inhibits Ca^{2+} release from intracellular Ca^{2+} stores. Moreover, effects of exposure to a 50Hz magnetic field (maximum of 41.7 to 43.6mT) on the membrane structures of living HeLa cells were studied using attenuated total reflection infrared spectroscopy [Ikehara, 2003]. Exposure to the ELF magnetic field has reversible effects on the N-H inplane bending and C-N stretching vibrations of peptide linkages the secondary structure of α-helix and β sheet in cell membrane proteins.

On the other hand, in cultured osteoblast-like cells (MC3T3-E1), exposure to ELF magnetic field (60Hz, 3.0,T) for 3 days, both collagen and non-collagen protein content by multispectral imaging method, increased in the cells at peripheral; regions of culture dish than that at central regions of same dish. The treatment of IGF increased in collagen content at the peripheral cells for 17 days culture. But the additive effects of the exposure and IGF treatment were not observed [Yamaguchi, 2004].

ALP activity was increased significantly by the exposure alone or by combined with NGF treatment. These results indicate that the mechanisms of differentiation related to IGF and NGF in the osteoblasts were altered by the magnetic fields of extremely low frequency [Hosokawa, 2004]

K1.4.3 other studies

Takashima *et al*. reported that the effect of ELF magnetic fields on the DNA damage repair process, the gene conversion frequency and cell cycle kinetics in a DNA repair-proficient and nucleotide excision repair (NER)-deficient strain of diploid yeast *Saccharomyces cerevisiae*. DNA repair- or NER-deficient cells were irradiated with sub-lethal doses of ultraviolet light (UV) radiation followed by exposure to 50 Hz magnetic fields up to 30mT for 48 h. After exposure, gene conversion rate was increased by the combined exposure in DNA repair-proficient cells, whereas it remained unchanged between UV alone and the combined exposure in NER-deficient cells. The UV-induced G1 arrest was inhibited by exposure to 30mT ELF magnetic fields in both repair-proficient and -deficient cells. The results suggest that exposure to high-density

(30 mT) ELF magnetic field decreases the efficiency of NER by suppressing G1 arrest, which in turn led to enhancement of the UV-induced gene conversion [Ikehata]. Moreover, there are several fundamental research activities to clarify ELF or combined fields with static and ELFs (Ikahata).

K1.5 Intermediate frequency Magnetic field

WHO defines the intermediate frequency (IF) region of the EMF spectrum as being between 300Hz to 10MHz. Compared to ELF and RF fields, little research has been done of the effects of IF fields. There are two reports on the biological effects of IF magnetic fields. Haga *et al.* used a highly sensitive mutagenesis assay method (*umu* system) to evaluate the direct impact of exposure to 20kHz, 60 μT for DNA destruction gene mutation [Haga, 2004]. This exposure experiment induced bacterial *umu* DNA repair response in one experimental case. Tachi *et al*. also investigated whether IF magnetic field (20kHz, 0.5mT, 1mT) induce the DNA damage and physiological abnormality in bacterial cells containing bacteriophage λ [Tachi, 2005]. After about 4 and 8 hour's exposure, this result suggests IF magnetic fields induce physiological damage in bacterial cells. Further studies are needed (Yamazaki and Suzuki).

K1.6 RF and Microwaves

K1.6.1 In vivo studies

Effects of exposure to electromagnetic waves (EMW) used in cellular phones on learning and memory processes were examined in Sprague-Dawley rats using a carousel type exposure system [Tsurita, 2000] and T-maze [Yamaguchi, 2003]. This study suggests that the exposure to a TDMA field at levels about four times stronger than emitted by cellular phones does not affect the learning and memory processes when there are no thermal effects. Ocular effects of MW have also been investigated using rabbit with/without system anethesia [Kojima 2004].

K1.6.2 In vitro studies

Genotoxic effect of high frequency electromagnetic field (HF FMF) at 2.45GHz with a wide range of specific absorption rates (SARs) was examined in cultured cells. The micronucelus (MN) frequency of cells exposed to a HF EME at SAR of up to 50 W/kg was not different to that in sham-exposed cells, while those at SARs of 100 and 200 W/kg were significantly higher than in the sham-exposed controls. An increase in SAR causes a rise in temperature and this may be connected to the increase in MN formation generated by exposure to HF EMF. Effect of HF EMF on DNA damage was also examined using alkaline comet assay method. There was no significant difference in the tail moments between HF EMF- and sham-exposed groups. This finding suggests that exposure to HF EMF does not cause DNA strand breaks even at a SAR of 100 W/kg. For the gene expression, effect of HF EMF on the synthesis of heat shock protein 70 (Hsp70) was examined. Exposure to a HF EMF induced hsp70 expression at a high SAR of more than 20 W/kg but not at 5 W/kg in human glioma cells. In addition, there were no significant differences in Hsp27 and Hsp70 expressions between RF (1950 MHz)-exposed and sham-exposed cells at a SAR of lower than 10 W/kg. However, exposure to the RF field at 10 W/kg decreased the protein level of phosphorylated Hsp27 (^{78}Ser) significantly (Miyakoshi).

K2 Tissue Properties, Materials, and Phantoms

K2.1 Design Methods of the Electromagnetic Environment

In order to use the EM power effectively in dairy life without losing the safety in every respect, only the EM waves that are actually needed inside the living space should be transmitted into the space. A stratified construction material that is consisted of two low loss materials has been developed for satisfying such a demand. The new functional material can absorb more than 70 percent of the incident EM power at specific frequencies that are pre-designed according to the demand (Miyakawa).

K2.2 Tissue Properties- Bioelectromagnetics parameters

The radio frequency safety guideline compliance for mobile phones has been evaluated by measuring the specific absorption rate (SAR) in the phantom material. The electromagnetic properties of bio-tissues and phantom material need to be specified in order to achieve precise and accurate SAR measurements. Recently, there are many research activities focused on Liquid phantoms (Watanabe and Kamimura).

K2.3 Phantoms

Various phantoms for the SAR (Specific Absorption Rate) estimation have been studied. A real-shaped torso bust phantom is developed to achieve an accurate evaluation of the SAR in the head as well as the characteristics of an antenna for a mobile terminal placed close to the human body [Ito, 2004]. The shape and size of the torso bust phantom are based on the average Japanese youths in their twenties. Moreover, an abdomen phantom of pregnant women including the amniotic fluid and the fetus is developed to estimate the SAR in the fetus [Kawai, 2003, Ito, 2005]. The targeted frequency range of this phantom is the VHF band. The dielectric constants of the amniotic fluid and the fetus of rabbits were measured to determine the dielectric constants of the phantom. In addition, solid phantoms, whose targeted frequency range is up 3 to 6 GHz, are investigated [Ishido, 2004]. The phantoms can reproduce the electrical properties of human biological tissues in the range of 3 to 6 GHz without changing their compositions.

In IEICE Transactions, the special issue on phantom has been published, and a review concerning the tissue equivalent phantoms has been reported [Ito, 2002]. High-molecular gel phantom with high transparency and viscosity has been proposed to realize the evaluation of the three dimensional EM waves'exposure using a micro-capsulated thermo-chromic liquid crystal [Sunaga, 2003; Baba, 2004a, 2004b; Suzuki, 2004]. Moreover, the phantom test phantom for implantable medical device to estimate the impact from RF EMF has been presented [Ohshita, 2004].

Various liquids for compliance tests of cellular phones with safety guidelines have been also proposed in international standards, i.e., IEC and IEEE, and their characteristics have been investigated [Fukunaga, 2002a, 2002b, 2003a, 2004 and 2004a]. (Ito).

K3 Field Measurement, Dosimetry and exposure assessment

K3.1 DC and ELF fields

Several analyses have been conducted focusing on induced currents inside the human body. Chiba *et al.* conducted calculations of induced currents for grounded and ungrounded simple homogeneous human model when exposed to vertical uniform electric field, using finite element method (FEM) [Chiba, 2004]. Matsumoto *et al.* developed a method for the analysis of the induced current using two-step process achieved by combination of the surface charge method and the FEM [Matsumoto, 2004].

In the analysis of magnetically induced currents, non-uniformity of the fields has been an key issue especially when assessing compliance with existing guidelines. Kamimura *et al.* calculated the induced currents in human head using both analytical formulae and numerical computations when exposed to magnetic fields produced by AC driven electric shaver, that represents localized magnetic dipole sources [Kamimura, 2002, 2004]. Nishizawa *et al.* introduced equivalent magnetic source model which consists of multiple magnetic dipoles assumed to be distributed on a cylindrical surface to simulate magnetic fields around electric appliances, and calculated induced current in a simple homogeneous human model [Nishizawa, 2003, 2004a, 2004b]. Related to he characterization of the magnetic field sources, Yagitani *et al.* studied a method of MUSIC algorithm and applied it to identification of localized field sources [Yagitani, 2004]. Tarao *et al.* calculated the induced current due to usage of a hair dryer for a realistic human head model [Tarao, 2003]. Yamazaki *et al.* characterized the effects of the field uniformity on maximum induced current from homogeneous spherical human model for easy assessment of compliance with the guidelines [Yamazaki, 2005].

Yoshitomi *et al.* measured environmental ELF magnetic filed in an apartment I Japan and proposed reduction method for the fields [Yoshitomi, 2002; Moriyama, 2005a]. They also measured ELF magnetic fields originating from equipments used for medical diagnoses and treatments. Sakurazawa *et al.* measured personal exposure to ELF magnetic fields in working environments such as electric power substations, VDT operator, electric furnace operators, and arc welders [Sakurazawa, 2003].

Sasada reported a simple three-square-coil system to produce a uniform magnetic field in a fairly large volume inside the coil system, which is advantageous over the proposed systems [Sasada, 2003]. Nagai *et al*. reported exposure setups fro in vitro experiment for complex magnetic fields with static and time-varying components [Nagai, 2004] (Yamazaki).

K3.2 Intermediate frequency magnetic field

In recent years, electric appliances that utilize magnetic fields with frequency higher than the power frequency, defined as IF (intermediate frequency), for heating, detecting and switching, has raised new interest in health effects. An IH (induction heater) cooker is one of those appliances that utilize the IF magnetic field for heating ferromagnetic pans. The typical frequency of the IH cooker ranges from 20kHz to 100kHz. A similar frequency range is utilized in a metal detector usually installed at the security gates of airports, and electric article surveillance (EAS) system. Since higher frequency induces induced current inside the human body in proportion to the frequency, stricter magnetic field levels are set for the higher frequency range in some existing exposure guidelines.

Kamata *et al.* characterized the magnetic fields generated by induction cooking by a series of measurement [Kamata, 2004]. Yamazaki *et al*. proposed a simple method to characterize the magnetic field distribution around appliances in the IF range by identifying equivalent magnetic dipole moments [Yamazaki, 2004a, 2004b]. Suzuki *et al.* conducted numerical calculation of induced currents inside an anatomically correct human model when exposed to IF magnetic field [Suzuki, 2004a, 2004b, 2005] (Suzuki and Yamazaki).

K3.3 RF and MW

There has been increasing concern about adverse health effect in RF and microwave frequency range due to proliferation of mobile phones. In order to investigate this problem, computational and experimental works haven been conducted. Recent trends in Japan are summarized as follows:

1) Measurement techniques for electric constants of lossy dielectric

For reliable dosimetry, it is essential to measure electrical constants of human tissue and then to develop material for phantom [Fukunaga, 2004]. Additionally, uncertainties of an electric probe have been evaluated [Watanabe,2004b].

2) Development of experimental setups for small animals and in-vitro study

Some new techniques using ferrite material or high permittivity materials to realize a highly localized exposure in small animals has been developed [Wang, 2003b, 2004c], and detailed analysis for various uncertainties in exposure setups has been conducted [Wang, 2002b, 2004b]. A new antenna for localized exposure to rats has also been developed [Watanabe H., 2004].

3) Dosimetry for child

Based on the report by the NRPB, it is concerned that children might be more vulnerable to any adverse effects of RF radiation than adults. In order to give some insight on this problem, dosimetry has been conducted using a realistic child head model [Fujiwara, 2003, 2004]. A scaling technique for producing a realistic child model has been developed and adopted widely in the world [Wang, 2003a]. A parallel FDTD technique based on PCs has also been developed for large-scale dosimetry of mobile phones [Wang, 2004a].

4) Temperature rise due to RF exposures

Peak-spatial averaged SAR is used as a measure in the ICNIRP guideline to evaluate the safety of humans for RF electromagnetic field exposure, while temperature increase would be a direct cause of physical burning and physiological effect. In order to bridge this gap, a correlation between peak SAR and temperature increase has been investigated [Fujimoto, 2003a, 2003b, 2004a, 2004c; Hirata, 2002, 2003a, 2003b, 2004a, 2004b]

5) Improvement of numerical simulation techniques

In order to overcome limitations of FDTD method, which is the most powerful numerical method to evaluate SAR in the biological bodies, surface impedance and hybrid methods have been proposed [Watanabe 2002 and 2004c; Mochizuki 2004a, 2004b, and 2004c] (Fujiwara and Watanabe).

K4 Biomedical Applications

K4.1 Thermal Therapy

In recent years, various types of medical applications of microwaves have been investigated. Among them, minimally invasive microwave thermal therapies are of great interest. They are interstitial hyperthermia and microwave coagulation therapy for thermal treatment of cancer, cardiac catheter ablation for ventricular arrhythmia treatment, etc. Previously, a coaxial-slot antenna, which is one of the thin antennas for interstitial heating, has been studied. In this research, the heating characteristics of the antenna are investigated by numerical simulation based on FDTD calculations [Saito, 2003] and phantom experiments. Moreover, the results of hyperthermic treatments for neck tumor by use of the coaxial-slot antenna and the array applicator composed of several coaxial-slot antennas are reported [Saito, 2004a]. In addition, the improvement of the characteristics of the coaxial-slot antenna especially the input impedance of the antenna is considered [Saito, 2004b] and the feeding technique of the array applicator composed of several antennas is investigated [Saito, 2004c] (Ito).

K4.2 Microwave Imaging of the Human Body

Chirp Pulse Microwave Computed Tomography is a noninvasive imaging modality, which enables microwave imaging of a human body using a chirp pulse microwave signal and signal processing techniques. The prototype model using a microwave from 1 to 2 GHz showed that the spatial resolution is better than 10 mm and temperature variation less than 0.3 degree Celsius can be measurable. The higher resolution model, which works at 2 to 3 GHz has also been developed for diagnostic imaging of an early stage breast tumor. Feasibility of the practical application of CP-MCT has been investigated through a series of computational studies and basic studies using those two models. A new CP-MCT with fan beam geometry, which is able to collect projection data very quickly is now being developed for a high speed imaging of experimental animals (Miyakawa).

K4.3 Thermal therapy- Inductive heating

A novel implant with the function of a high efficient temperature raise is proposed to achieve a local high temperature hyperthermia or ablation therapy. The idea of the new implant with a heating function is based on not material component but on resonant circuit theory viewpoint .The new implant proposed here consists of a small coil and a microchip condenser to make a resonant circuit. By applying an RF magnetic field to the implant, large current flows in the coil based on the resonance and elevate the coil temperature efficiently. As a coil, a silver wire or a stainless is used. The temperature rise of more than 70 from the initial value is obtained at 15 cm depth of agar phantom in a case of implant with the diameter of 3 mm and the length of 4 mm, using a ferrite core applicator with output power of 500 W at the resonant frequency of 4 MHz. This idea of the implant can be applied to a stent with a heating function (Kotsuka).

K4.4 Radiometry

Multi-frequency microwave radiometer system for noninvasive temperature measurement of biological tissues has been at the final stage of its development as well as the temperature retrieval method from measured brightness temperatures of biological tissues. Chirp radar-type microwave computed tomography which can provide a cross sectional image of temperature change has been also under development (Sugiura).

K4.5 Soft heating

In hyperthermia, the soft-heating method has been proposed. This is an inductive heating method that uses as a hear element a thermosensitive magnetic material. The feature of this method is automatic temperature control using Curie-point of the magnetic material. When the element is implanted into the tumor tissue, however, authors have to adjust the size of element to that of each tumor tissue. Therefore, the purpose of this study is to clarify heat characteristics of heat elements with various volumes.

The heat element is composed of a thermosensitive magnetic material and a metal ring. The thermosensitive magnetic material used to experiment is Ni-Cu-Zn ferrite and Curie-point is 90℃. Moreover, the copper ring is wrapped around the ferrite. The aim of wrapping copper ring is increase of the heat quantity generated compared with that using only the magnetic material. When temperature of the thrmosensitive magnetic material is lower than the Curie-point, the magnetic flux is concentrated by the effect of high permeability of the magnetic material. Then, short-circuit current induced in the copper ring, raises the temperature of heat element. In experiments, this element is put in the heat insulator, then excited by solenoidal coil. The specification of this coil is 8mT at 100 kHz.

The results provided evidence that the temperature characteristics show a saturation tendency with an increase of the element volume. Based on this tendency, it seems reasonable to suggest that sufficient heating can be obtained, even on smaller element volumes. Therefore, when considering heating per unit volume, it is expected that a volume with the most effective heating temperature can be obtained. For further research, we will continue to analyze the temperature characteristics, aiming to achieve the high hyperthermia (Matsuki).

K4.6 current distribution MRI

Magnetic resonance imaging of electrical phenomena in living bodies is potentially useful for quantitative evaluations of biological effects of electromagnetic fields, and for direct detection of neuronal electrical activities in the brain. Magnetic field in an object causes a shift in the resonant frequency [Sekino, 2004a]. Stationary electric current causes an increase in the apparent diffusion coefficient [Yamaguchi, 2003]. Spatial distributions of externally applied magnetic field and electrical current can be estimated from these changes in magnetic resonance signals. These methods have potential medical applications such as imaging of current distributions in electrical defibrillation. Detection of electrical currents associated with neuronal or muscular electrical activities requires extremely high sensitivity. The sensitivity for detecting weak magnetic fields was estimated using numerical simulations [Hatada, 2005a, 2005b] and experiments [Hatada, 2005c]. The theoretical limit of sensitivity was approximately 10^{-8} T. These studies potentially lead to a new method for visualizing brain function with a spatial resolution of millimeters and a temporal resolution of milliseconds. The ADC reflects electrical conductivity of a tissue, which enables an estimation of anisotropic conductivity of the tissue [Sekino, 2003a, 2004b, 2004c]. This method was applied to imaging of electrical conductivity in the human brain. Several regions in the white matter such as the corpus callosum and the internal capsule exhibited high anisotropy in conductivity. Magnitude and phase of magnetic resonance signals are affected by permittivity [Sekino, 2005; Mihara, 2005]. A distinctive signal inhomogeneity arises in images of objects whose dimension is comparable to the wavelength of electromagnetic fields at the resonant frequency. This phenomenon, dielectric resonance, particularly appears in scanners with high static fields. Electric current in electrolyte solution give rise to fluid motion. Magnetic resonance imaging was applied to visualization of the flow velocity [Sekino, 2003b, 2003c, 2004d]. In strong static magnetic field, biological macromolecules such as fibrin and collagen are oriented in the direction parallel or perpendicular to the magnetic field. The magnetic orientation causes a change in the spin-spin relaxation time of gels, which contain these macromolecules [Takeuchi, 2003, 2004a, 2004b, 2005](Sekino and Ueno).

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