COMMISSION K: ELECTROMAGNETICS IN BIOLOGY AND MEDICINE
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INTRODUCTION

The research activities on the biological effects and medical applications of electromagnetic fields (EMFs) in Japan from 2013 to 2016 are reviewed. *In vivo*, *in vitro*, human volunteer, and dosimetric studies at frequencies up to THz region are discussed. For these topics, in order to compare with previous terms, similar items have been chosen. Biomedical applications including wireless capsule endoscope (WCE), wearable and implantable medical devices, magnetic stimulation, hyperthermia, thermal ablation, magnetic resonance imaging (MRI), wireless power transfer (WPT), and electromagnetic interference (EMI) are also introduced.

K1 BIOLOGICAL EFFECTS OF EMFS

K1.1 Static and Low Frequency (LF)

Research activities in this field were low in last three years. Instead of experimental research, measurements of static magnetic field were reported to clarify working environment during MRI diagnosis.

K1.1.1 *In vivo* studies

There is no relevant study in this term.

K1.1.2 *In vitro* studies

There is no relevant study in this term.

K1.1.3 Other studies

Occupational exposure to the high static magnetic fields (SMFs) during MRI examinations raises concerns of adverse health effects. Yamaguchi-Sekino *et. al.* [2014] reported personal exposure monitoring of the magnetic fields during routine examinations in two 3 T MRI systems. The maximum exposed field ranged from 0 to 1250 mT and the average peak magnetic field (B) was 428 ± 231 mT (mean ± standard deviation (SD): number of samples (N) = 103). Yamaguchi-Sekino, *et. al.* [2015] proposed a safe working procedure involving a restricted access area set at a distance of 30 cm from the end of a 3 T MRI system. The values for maximum field exposure (peak B) were reduced for all subjects using the safe working procedure. The average peak B also decreased by approximately 26%, compared with the results obtained without any restrictions (conventional protocol) with no significant differences in worker performance compared with conventional procedure. They concluded that this simple safe working procedure may be applied to MRI system operation in order to reduce occupational SMF exposure, without noticeable changes in worker performance.

K1.2 Extremely Low Frequency (ELF)

Research activity of this field was not high during last three years.

K1.2.1 *In vivo* studies

There is no relevant study in this term.

K1.2.2 *In vitro* studies

There is no relevant study in this term.

K1.2.4 Other studies

Shimizu *et. al.* [2014] reported that perception threshold of ELF electric field by body hair movement and its seasonal change. In addition, Shimizu *et. al.* [2016] gave a review of their research to investigate human perception of static and ELF electric fields. Kanemaki *et. al.* [2016] reported altar of peripheral blood flow in body surface by ELF electric field exposure and found enhancement of the blood aggregability.

Ikehata M. *et. al.* [2014a, 2016a] reviewed their research and trend of risk evaluation to build a process of communication with people who are concern health impact of ELF magnetic field and RF electromagnetic field. Ikehata M. *et. al.* [2016b] also propose a procedure to evaluate conformity with international guideline (e.g. International Commission on Non-Ionizing Radiation (ICNIRP) guideline and The Institute of Electrical and Electronic Engineers (IEEE) standard) including measurement and dosimetry applied for railway systems.

K1.3 Intermediate Frequency (IF)

Research activity in intermediate frequency range is still higher than ELF. Several research groups vigorously investigated about several biological indices both *in vivo* and *in vitro* to establish data for health risk assessment.

K1.3.1 *In vivo* studies

In National Institute of Public Health, several projects have been conducted. Ushiyama A., *et. al*. [2014] reported that exposure to 21-kHz sinusoidal IF-MF at 3.8 mT for 1 h/day for 14 days did not affect immune function in juvenile rats. Win-Shwe TT., *et. al.* [2015] reported that the expression levels of NR1 and NR2B as well as transcription factors (CaMKIV, CREB1), inflammatory mediators (COX2, IL-1 b, TNF-α), and the oxidative stress marker heme-oxygenase (HO)-1 were significantly increased in the IF-MF-exposed mice, compared with the control group, in the 7-week-old mice, but not in the 3-week-old mice. However, these changes are transient and recover after termination of exposure without histopathological changes.

K1.3.2 *In vitro* studies

Miyakoshi and his colleagues have been engaging on in vitro studies in IF frequency region. Mizuno K., *et. al*. [2015] investigated whether exposure to magnetic resonant coupling WPT (12.5 MHz) has genotoxic effects on WI38VA13 subcloned 2RA human fibroblast cells. They studied cell growth, cell cycle distribution, DNA strand breaks using the comet assay, micronucleus formation, and hypoxanthine-guanine phosphoribosyltransferase (HPRT) gene mutation, and did not detect any significant effects. Koyama S., *et. al.* [2015] investigated the effect of exposure to a 23-kHz IF magnetic field of 2 mT for 2, 3, or 4 h on neutrophil chemotaxis and phagocytosis using differentiated human HL-60 cells. They found no effect on neutrophil chemotaxis or phagocytosis. Mizuno K., *et. al.* [2014] investigated whether extremely low frequency (ELF) magnetic field exposure has modification effects on cell survival after ultraviolet B (UV-B) irradiation and on repair process of DNA damage induced by UV-B irradiation in WI38VA13 subcloned 2RA and XP2OS(SV) cells. They found neither significant change in cell survival between ELF magnetic field and sham exposures nor DNA damage induced by UV-B irradiation change significantly following ELF magnetic field exposure.

From a research group of the Railway Technical Research Institute, several reports of the biological effect of the intermediate frequency magnetic fields (IF-MFs) were published. Yoshie S., *et. al.* [2015, 2016] investigated developmental toxicity of intermediate frequency (IF) magnetic field (MF) using murine embryonic stem (ES) cells and fibroblast cells based on the embryonic stem cell test (EST). No significant difference was observed in the test of 21 kHz IF–MF up to 3.9 mT. In addition, the expressions of a cardiomyocytes-specific gene, Myl2, and an early developmental gene, Hba-x, in the exposed cell aggregate were not altered. Wada K., *et. al*. [2016] reported several exposure devices to expose strong

IF-MF for in vitro experimental study. Ikehata M., *et. al.* [2015] reviewed their activity to evaluate mutagenic effect of magnetic field from static strong MF up to 14T to IF-MF up to 21 kHz, 3.9 mT. Ikehata M., *et. al.* [2014b] reported that no significant effect by exposure to 21 kHz, 3.9 mT IF-MF. They suggested that IF-MF is unlikely to cause adverse biological effects with our previous results.

K1.3.3 Other studies

Several topics related to effect of transient electric field were reported. Ito R. and Masugi M. [2014a] investigated the effect of pulse electric field with charging voltages of 10 kV and 15 kV on growth of a plant, broccoli (Brassica oleracea var italica). They found the exposed plant which had been applied 10kV/3days and 15kV/3days, became greater than the others by around 30% with higher chlorophyll content. Ito R. and Masugi M. [2014b] reported an analysis of the effects of transient electromagnetic fields on bioelectric potential responses of plant leaves. A single transient electromagnetic field was periodically applied to aloe and pachira for 3 days. They found that bioelectric potential energy was increased by application of transient electromagnetic fields. Ito R. and Masugi M. [2014c] reported an analysis of biological effects of a transient electromagnetic field on a nerve cell using Hodgkin-Huxley model. In this paper, a single pulse waveform is set as an external electromagnetic field. The non-linear response of cell membrane potential was influenced by pulse width and amplitude of a transient electromagnetic field in their result. Ito T. and Masugi M. [2016] investigated effects of transient electromagnetic fields on bioelectric potentials of plants by a self-similarity-based-analysis. A single transient electromagnetic field was applied to aloe and pachira caused increase of the Hurst exponent of bioelectric potential.

K1.4 Radio Frequency (RF)

K1.4.1 *In vivo* studies

Masuda *et. al.* [2015a-c] reported many results of investigations to elucidate the effects of RF-EMF exposures on the brain. They focused on changes in several brain microcirculatory parameters, including the Blood-Brain Barrier (BBB) function. Experiments were performed with a figure-of eight applicator, which enabled highly localized exposure on the brain and real-time direct observation of brain circulation through a cranial window in the skull of the animal. Frequency and waveform were those of the 2G-TDMA system at 1439 MHz. Under the local exposure condition at an average SAR of 2.0 W/kg in the target brain tissue, no significant changes were found in hemodynamics, leukocyte behavior, and permeability of BBB in juvenile and adult rat brains using in vivo imaging and histological evaluation.

Shirai *et. al.* [2014] carried out with rats to evaluate the effects of whole body exposure to 2.14 GHz band code division multiple access (W-CDMA) signals for 20 h a day, over three generations. The average specific absorption rate (SAR, in unit of W/kg) for dams was designed at three levels: high (<0.24 W/kg), low (<0.08 W/kg), and 0 (sham exposure). Pregnant mothers (4 rats/group) were exposed from gestational day (GD) 7 to weaning and then their offspring (F1 generation, 4 males and 4 females/dam, respectively) were continuously exposed until 6 weeks of age. The F1 females were mated with F1 males at 11 weeks old, and then starting from GD 7, they were exposed continuously to the electromagnetic field (one half of the F1 offspring was used for mating, that is, two of each sex per dam and 8 males and 8 females/group, except for all offspring for the functional development tests). This protocol was repeated in the same manner on pregnant F2 females and F3 pups; the latter were killed at 10 weeks of age. No abnormalities were observed in the mother rats (F0, F1, and F2) and in the offspring (F1, F2, and F3) in any biological parameters, including neurobehavioral function. Thus, it was concluded that under the experimental conditions applied, multigenerational whole body exposure to 2.14 GHz W-CDMA signals for 20 h/day did not cause any adverse effects on the F1, F2, and F3 offspring.

Ohtani *et. al.* [2015] investigated the effects of RF-EMFs on T cell responses during development due to the lack of science-based evidence for RF-EMF effects on developmental immune systems. Sprague Dawley (SD) rats were exposed to 2.14-GHz W-CDMA RF signals at a whole-body specific absorption rate (SAR) of 0.2 W/kg. Exposures were performed for a total of 9 weeks spanning in utero development, lactation and the juvenile period. Rats were continuously exposed to RF-EMF for 20 h/day, 7 days/week. Comparisons of control and exposed rats using flow cytometry revealed no changes in the numbers of CD4/CD8 T cells, activated T cells or regulatory T cells among peripheral blood cells, splenocytes and thymocytes. Although only the Il5 gene was significantly regulated in spleen tissues, Il4, Il5 and Il23a genes were significantly upregulated in thymus tissues following exposure to RF-EMF. However, ELISAs showed no changes in serum IL-4 protein concentrations. These data indicate no adverse effects of long-term RF-EMF exposure on immune-like T cell populations, T cell activation, or Th1/Th2 balance in developing rats, although significant transcriptional effects were observed.

Ohtani *et. al.* [2016] investigated the thermal effects of RF-EMFs on the variation in core temperature and gene expression of some stress markers in rats. Sprague-Dawley rats were exposed to 2.14 GHz W-CDMA RF signals at a whole-body averaged SAR (WBA-SAR) of 4 W/kg. The results revealed that the core temperature increased by approximately 1.5°C compared with the baseline and reached a plateau till the end of RF-EMF exposure. At WBA-SAR of 4 W/kg, some Hsp and Hsf gene expression levels were significantly upregulated in the cerebral cortex and cerebellum following exposure for 6 hr/day but were not upregulated after exposure for 3 hr/day. On the other hand, there was no significant change in the core temperature and gene expression at WBA-SAR of 0.4 W/kg.

K1.4.2 *In vitro* studies

Koyama S. and Miyakoshi J. [2015a] reviewed recent studies on the cellular response and potential risks of exposure to RF radiation. Although most studies have reported no significant effects at the cellular or genetic level due to exposure to RF radiation, a consensus has yet to be reached. Therefore, the cellular response to RF radiation requires further investigation. Koyama S. *et. al.*, [2015b] examined the effect of 2.45-GHz RF fields at the SAR of 2 and 10 W/kg for 4 and 24 h on neutrophil chemotaxis and phagocytosis in differentiated human HL-60 cells. Neutrophil chemotaxis was not affected by RF-field exposure, and subsequent phagocytosis was not affected either compared with that under sham exposure conditions. These studies demonstrated an initial immune response in the human body exposed to 2.45-GHz RF fields at the SAR of 2 W/kg. The results of their experiments for RF-field exposure at an SAR under 10 W/kg showed very little or no effects on either chemotaxis or phagocytosis in neutrophil-like human HL-60 cells.

K1.4.3 Other studies

Nakatani-Enomoto *et. al.* [2013] investigated subjective and objective effects of mobile phones using a W-CDMA-like system on human sleep. Subjects were 19 volunteers. Real or sham EMF exposures for 3 h were performed before their usual sleep time on 3 consecutive days. They were exposed to real EMF on the second or third experimental day in a double-blind design. Sleepiness and sleep insufficiency were evaluated the next morning. Polysomnograms were recorded for analyses of the sleep variables and power spectra of electroencephalograms (EEG). No significant differences were observed between the two conditions in subjective feelings. Sleep parameters including sleep stage percentages and EEG power spectra did not differ significantly between real and sham exposures. We conclude that continuous wave EMF exposure for 3 h from a W-CDMA-like system has no detectable effects on human sleep. Kiyohara *et. al.* [2015] developed in Japan were modified from 3G (cdma2000) phones and were unique in their ability to record the laterality of use estimated from the information from a gravity sensor. A study was performed to examine the recall accuracy of laterality of use by using the new software modified phones (SMPs). A total of 198 subjects were instructed to use SMPs for 1 month. The results showed that recall was prone to small systematic and large random errors for both the number and duration of calls and that the laterality of use was misclassified by 19% of the subjects. The authors stated that the results should be interpreted cautiously in epidemiological studies of mobile phone use based on self-assessment considering the large random recall error for the amount of calls and misclassification of laterality.

K1.5 Millimeter and THz waves

K1.5.1 *In vivo* studies

Kojima *et. al.* [2015] investigated the effects of quasi-millimeter and millimeter wave exposures on the eye. Rabbits were exposed in the eye to 18, 22, 26.5, 35, and 40 GHz continuous waves at 200 mW/cm^2 for 3 min. The changes in temperature in various parts of the eye were measured. It was found that temperature elevations were dependent on various factors, including the penetration depth, convection of the aqueous humor, and so on. As a result, the temperature elevation characteristics were dependent on frequency.

K1.5.2 *In vitro* studies

Koyama S. *et. al.* [2016a] investigated human corneal epithelial (HCE-T) and human lens epithelial (SRA01/04) cells derived from the human eye exposed to 60 GHz millimeter-wavelength radiation for 24 h. There was no statistically significant increase in the micronucleus (MN) frequency in cells exposed to 60 GHz millimeter-wavelength radiation at 1 mW/cm^2 compared with sham-exposed controls and incubator controls. The MN frequency of cells treated with bleomycin for 1 h provided positive controls. The comet assay, used to detect DNA strand breaks, and heat shock protein (Hsp) expression also showed no statistically significant effects of exposure. These results indicate that exposure to millimeter-wavelength radiation has no effect on genotoxicity in human eye cells. Koyama S. *et. al.* [2016b] investigated the cellular effects of THz exposure, human corneal epithelial (HCE-T) cells derived from human eye were exposed to 0.12 THz radiation at 5 mW/cm^2 for 24 h, then the genotoxicity, morphological changes, and Hsp expression of the cells were examined. There was no statistically significant increase in the MN frequency of cells exposed to 0.12 THz radiation compared with sham-exposed controls and incubator controls, whereas the MN frequency of cells treated with bleomycin for 1 h (positive control) did increase significantly. Similarly, there were no significant morphological changes in cells exposed to 0.12 THz radiation compared to sham-exposed controls and incubator controls, and Hsp expression (Hsp27, Hsp70, and Hsp90α) was also not significantly different between the three treatments. These results indicate that exposure to 0.12 THz radiation using the present conditions appears to have no or very little effect on MN formation, morphological changes, and Hsp expression in cells derived from human eye. Yaekashiwa N. *et. al.* [2014a, b, c, 2015] tried to elucidate the Frorich hypothesis which tells that THz/MWW irradiation may cause non-thermal effect on the cell membrane or on the biological systems. The authors have measured the cell activity using two methods; Real-time and End-point analysis.

K2 DOSIMETRY

K2.1 Numerical dosimetry

K.2.1.1 LF

Yamazaki K. [2015] reported the review of dosimetry technique for magnetic field in Japan including an intercomparison study of six research group. This comparison suggests that the computational uncertainty of the in situ electric field/current density due to different methods and coding is smaller than that caused by different human phantoms and the conductivity of tissue, which was reported in a previous study.

Research group of Prof. Hirata vigorously investigated human models with electromagnetics and thermos physiology. To use their model, they proposed evaluation technique and research needs. De Santis V. *et. al.* [2013] reported the compliance assessment that is the most stable against both time- and frequency-domain biases. It does not create any filter phase artifact, which can lead to variations of ±25% in the obtained results. De Santis V. *et. al.* [2015] investigated LF magnetic field dosimetry of skin model. They report the relationship between the basic restrictions and the reference or maximum permissible exposure levels recommended by these safety standards is not always consistent by dosimetry evaluation using a multi-layer skin structure with conductivity of the stratum corneum or of a weighted average between several skin layers. Chan KH, *et. al.* [2015] investigates in situ electric field due to low-frequency contact current and specific absorption rate (SAR) due to high-frequency contact currents in a realistic child model and compared with those in the adult model. The in situ electric fields and SAR in the child model are found to exceed the corresponding values in the adult. At the finger tip, the electric field and SAR due to contact currents, both at the ICNIRP reference levels and IEEE Maximum Permissible Exposures, are well beyond the corresponding basic restrictions. Reilly JP and Hirata A. [2016] reported 25 issues needing attention as research agenda of the IEEE ICES. Their fitting 25 issues into three general categories: induction models; electrostimulation models; and human exposure limits.

K.2.1.2 IF

Activity in this area is high because research groups of National Institute of Information and Communications Technology (NICT), Nagoya Institute of Technology, and NTT DOCOMO INC. conducted various topics related to evaluate compliance with existent guideline and to evaluate basic philosophy of guideline itself.

Laakso I. and Hirata A. [2013] investigated an induced electric field in a human body is evaluated for the magnetic field leaked from a WPT system for charging an electrical vehicle. The induced electric field in a human standing around the vehicle is smaller than the allowable limit prescribed in international guidelines, although the magnetic field strength in the human body is locally higher than the allowable external field strength. Sunohara, *et. al.* [2014] investigated the SAR and the in situ electric field in human models for the magnetic field from an inductive WPT system using 140kHz developed on the basis of the specifications of the wireless power consortium. The results indicate that the peak value of the SAR averaged over a 10 g of tissue and that of the in situ electric field are 72 nW/ kg and 91 mV/ m for a transmitted power of 1 W. Consequently, they showed the maximum allowable transmitted powers satisfying the exposure limits of the SAR (2 W/ kg) and the in situ electric field (18.9 V /m) are found to be 28 MW and 43 kW. Shimamoto T., *et. al.* [2015a] investigated the in-situ electric field of an adult male model in different postures is evaluated for exposure to the magnetic field leaked from a wireless power transfer system (7 kW and 85 kHz) in an electrical vehicle. They evaluated four scenarios (i) crouching near the vehicle, (ii) lying on the ground with or without his arm stretched, (iii) sitting in the driver's seat, and (iv) standing on a transmitting coil without a receiving coil. In each scenario, the maximum in-situ electric fields are lower than the allowable limit prescribed by international guidelines, although the local magnetic field strength in regions of the human body is higher than the allowable external magnetic field strength. Laakso I., *et. al.* [2015a] reported an example of the assessment of human exposure to the non-uniform magnetic field of a realistic WPT system for wireless charging of an electric vehicle battery, and proposed a coupling factor for practical determination of compliance with the international exposure standards using the quasistatic approximation which reduces the computational requirements of the assessment of human exposure. Sunohara, *et. al.* [2015] proposed compliance procedure that is applied to and demonstrated for a prototype WPT system in 140 kHz band. The maximum allowable transmitting power is relaxed by a factor of 23 with the proposed procedure for the prototype system. The contribution of the harmonics decreased the allowable transmitting power by 39%, indicating their importance for safety compliance. Shimamoto T., *et. al.* [2015b] reported the internal electric field in the fetus and mother is investigated in anatomically based pregnant- and non-pregnant-woman models. The computational results show that the internal electric field strength is smaller in the fetus than in the mother, because the magnetic field there is weaker than around the feet, even though the abdomen of the pregnant woman may come closer to the vehicle than that of a non-pregnant adult female.

Chakarothai J. [2014a] investigated exposure assessment of the WPT system in 10 MHz band with a homogeneous cylinder in various operating situations possible was performed to characterize the dosimetry. As the result, the maximum allowable input power of the WPT system was restricted based on the whole-body average SAR rather than the peak 10g-average SAR for some exposure conditions. Chakarothai J. [2015a] investigated numerical exposures of adult and child models in proximity of a WPT system in 7 MHz bands. He found that the exposures of human models in vicinity of the WPT system is highly localized, where the peak 10g average SAR is higher than the whole-body average SAR in all exposure scenarios in the study. Park *et. al.* [2014] reported the difference between the two resonant modes of the WPT system for the SAR induced in the head model. Chakarothai *et. al.* [2015b] also reported numerical exposures of adult and child models in proximity of a WPT system in 7 MHz bands. They found that the exposures of human models in vicinity of the WPT system is highly localized, where the peak 10g average SAR is higher than the whole-body average SAR.

Ishii N. [2015] proposed an extension of reference antenna method, which is one of methods for calibrating the probe. As a reference antenna, they examined a circular folded loop antenna immersed in normal saline solution. If its perimeter is well selected, constant near-field gain can be realized in its near-field region. And, to reduce its size, the number of folding should be larger. Also, they showed the validity of estimated formula for electric field intensity radiated by the reference antenna with its near-field gain.

Aoki Y. [2016] reported calculation of the distance characteristics of an external magnetic field strength and internal electric field strength in human bodies when WPT system is put on the perfect electric conductor (PEC) ground plane. As a result, it was indicated that the external magnetic field strength and the internal electric field strength for the case of the PEC ground plane may be as large as 142 % and 130 % of those for the free space at the maximum, respectively. In addition, they reported that the coupling factor in free space was larger than that for the PEC ground-plane case when the compliance distance is equal to 0.4 m.

Ishihara S. [2014a] and Onishi T. [2014, 2016a] reported a measuring system of electric field distributions around a cuboid phantom. They found measured results with a coaxial cable were different from calculated results even though direction of the cable was changed. However, when measured results were well matched with calculated results by using an optical fiber. Ishihara S., Onishi T., and Hirata A. [2014b, 2015b] reported a measurement method of magnetic field ranged from 100 kHz and 6.78 MHz near a magnetic source. As a result, even if magnetic sensor is placed nearest to the source, change of current flowing through the source is marginal in this study. This paper describes about an exposure assessment for the WPT systems to ascertain the actual exposure level from commercial WPT systems when they are used close to the body.

K.2.1.3 RF

Study on the numerical dosimetry is very active in Japan, because various computational human models with fine-resolution are available from NICT. New models of pregnant females in the second and third trimesters of pregnancy recently developed by Nagaoka *et. al.* [2013, 2015] and SARs in these models for whole-body exposure were estimated. Tateno *et. al.* [2014, 2015a] reported SARs of pregnant females and their fetuses in the second and third trimesters of pregnancy due to wireless radio terminals in proximity to a fetus. Tateno *et. al.* [2015b] also reported the SAR in human body for various configurations of a commercial tablet computer using Japanese adult models.

Core temperature elevation and perspiration in younger and older adults for plane-wave exposure at WBSAR of 0.4 W/kg at 65 MHz and 2 GHz was reported by Nomura *et. al.* [2014]. The results indicated that the core temperature elevation in the older adult model was larger than that in the younger one at both frequencies.

Graphics processing unit (GPU) is a powerful tool for the numerical dosimetry using the computational human models because GPU calculations offer very effective acceleration for Finite-Difference Time-Domain (FDTD) algorithm. Large-scale FDTD computations on GPUs are reported [Nagaoka *et. al.*, 2014, Chakarothai and Watanabe, 2016]. In addition, Chakarothai *et. al.* [2016] propose a new approach for determining convergence in FDTD method for numerical dosimetry at a single frequency.

K2.2 Experimental dosimetry

K.2.2.1 IF

Chakarothai J. [2015c] reported construction of a near-field measurement system using magnetic field probe developed inhouse in order to measure both magnitude and phase of magnetic near-field radiated from WPT systems. They conducted measurements for WPT systems in 7 MHz bands and 100 kHz bands. Comparison with numerical results demonstrates validity and accuracy of their measurement systems. They concluded that the proposed system is able to provide a direct way to determine a limit for input power for WPT devices in compliance with the ICNRIP guideline.

K.2.2.2 RF

Wake *et. al*. [2014] experimentally evaluated the hand effects for SAR in child head phantom with several types of the phones. Form the results, hand effects on 10 g SAR were negligible for about half of the cases compared to experimental uncertainty. Among the cases the hand effect is not negligible, the cases whose SAR is reduced and increased by the hands are same order.

Ishii *et. al.* [2014] proposed a novel method for calibrating the probes used in standard measurement systems to evaluate SAR of the radio equipment operating at frequencies over 3GHz.

Higashiyama J. [2014] and Iyama T. [2015, 2016a, b] investigated exposure assessment methods regarding radiocommunication base-stations. Iyama T. [2016c] also reviewed IEC 62232 - Determination of Radio-Frequency (RF) Field Strength and Specific Absorption Rate (SAR) in the Vicinity of Radiocommunication Base Stations (RBS) for the Purpose of Evaluating Human Exposure.

K.2.2.3 Millimeter

Recently research and development as well as standardization on the 5th mobile communication system (5G) have been actively conducted all over the world. Frequency bands above 6 GHz for 5G are considered in addition to those used for current mobile systems. From exposure assessment point of view, the power density should be used above 6 GHz as a measurement index while the SAR has been used for near-field exposure up to 6 GHz. Satoh K. *et. al.* [2015] exhibited their preliminary measured electrical fields close to a standard horn antenna using both waveguide (WG) and electro-optical (EO) probes at 15 GHz. Onishi T. [2016b] and Satoh K. [2016a, b] also conducted measurement using a conventional probe such the WG probe, which has been used for near-field to far-field transformation.

K2.3 Development of exposure setups and dosimetry for medical and biological studies.

An in-vivo research project on local and whole-body exposure of rats to RF-EM fields above 6 GHz was started in Japan in 2013. Therefore, Shi *et. al.* [2015a, b] perform a dosimetric design for the whole-body-average SARs of unconstrained rats exposed to RF-EMFs in a reverberation chamber (RC).

On the other hand, Chakarothai *et. al.* [2014] proposed a hybrid approach combining the method of moment (MoM) and the FDTD method for evaluating SARs in a small rat inside a RC. The hybrid method is able to overcome the problem of poor convergence for a solution of the FDTD method in analyzing the RC.

K2.4 Mechanism between biological tissues and EMF.

Dielectric properties of biological tissues and organs are crucial parameters for the dosimetry. Although Gabriel’s Cole-Cole models have been widely used, further studies on expansion or improvement of the database have been conducted in Japan.

Sasaki *et. al.* [2014a] proposed optimal Cole-Cole parameters for the dielectric properties from 43 biological tissues and organs for frequencies between 1 MHz and 20 GHz. Sasaki *et. al.* [2014b] reported dielectric properties for the epidermis and dermis with in vitro measurement at frequencies ranging from 0.5 GHz to 110 GHz, and they [2015] also reported the dielectric properties for ocular tissues up to 110 GHz. In intermediate frequency band, Wake *et. al.* [2016] presented the data for the conductivities of the tissues composing the skin (epidermis, dermis and subcutaneous tissue).

In view of the thermal effects, the relationship between the SAR and the temperature elevation is the most important issue in RF dosimetry. Hirata *et. al.* [2014] proposed a thermal model for a pregnant woman, and then applies it to simulate the temperature variations due to ambient heat exposure and RF exposure. They found that the fetal temperature elevation for radio-frequency exposure is higher than that in the mother. Morimoto *et. al*. [2016] also reported the relationship between the peak temperature elevation and the peak SAR averaged over 10 g of tissue in human head models in the frequency range of 1–30 GHz.

For estimating the SAR enhancement due to metallic implants in the human body and Hikage *et. al.* [2014, 2015] assessed by experimental and numerical methods whether two parallel metal plates implanted in the head region could be expected to cause SAR enhancements under ultra high frequency (UHF) near-field exposure.

K2.5 Dosimetry for medical application (see also K3)

Anzai D. *et. al*. [2014] investigated the effect of spatial receive diversity on SAR reduction based on outage probability analysis for wireless capsule endoscope (WCE). Morimoto *et. al.* [2015] developed an ultra wide band (UWB) planar loop antenna for implant communication, and calculated the implant path loss and SAR using the finite difference time domain method together with an anatomical human body numerical model.

Liao *et. al.* [2015] reported the two-step approach to evaluate EMI with a wearable vital signal sensor and demonstrated its usefulness by wearable electrocardiogram (ECG).

There are several types of implantable medical devices and the implantable cardiac pace maker is the most popular device among them. It should be appreciated that the mobile radio terminals are used close to the implanted cardiac pace maker. Therefore, mechanism of EMI of the implanted pace maker due to the cellular phone is analyzed by Endo *et. al.* [2016a]. In the above situation, hot spots may appear around the implanted metallic objects due to concentration of the electric field. Saito *et. al.* [2014a] calculated the SAR around the implanted cardiac pace maker induced by the mobile radio terminal in VHF band. In order to evaluate some characteristics of the implantable devices, human phantoms are developed. Ito K. *et. al.* [2013] introduced the physical phantom for evaluation of antenna performances for implantable antenna. Moreover, Antenna for capsular endoscope is developed and its performances are measured with the abdominal phantom model by Ito K. *et. al.* [2016].

K2.6 EMI evaluation with medical devices

Ishihara S. *et. al.* [2014c] investigated EMI with medical devices from third generation mobile phone including LTE (Long Term Evolution). Thirty-two different medical devices, which are mainly used in the operating room or Intensive Care Unit, are used in this evaluation. The results show that 12 medical-device models (37.5%) incurred EMI. The results also clearly show that the EMI strongly depends on the transmission power and the distance between the mobile phone and medical device. In addition, Ishihara S. *et. al*. [2015a] evaluated electric field distributions around a half-wave dipole antenna, broadband antenna, and various mobile terminals and compared in the frequency bands of 800 MHz, 1.5 GHz, 1.7 GHz, and 2 GHz to confirm the difference among radiation sources when conducting EMI tests on medical devices. Comparison results show that the electric field strengths around dipole antennas is almost equal to or higher than those of all mobile terminals used in this study for all the considered frequency bands.

K3 BIOMEDICAL APPLICATIONS

K3.1 Hyperthermia

Thermal therapies which include hyperthermia is one of the important research fields employing the thermal effect of electromagnetic wave to the body. In the low frequency such as high frequency (HF) band, the electric field induces the current inside the patient body. Then the current heats up the target region by the Joule heating. Nowadays, many capacitive heating devices for hyperthermic treatment are used in Japan. However, only a few considerations have been studied in terms of the SAR and the current distributions. Therefore, Kumagae and Saito [2016] introduced some characteristics of RF capacitive heating device. The microwave energy is suitable for localized heating. Especially, the interstitial and the intracavitary schemes can be certainly heated the target tumor. Saito *et. al.* [2014b] and Yashima *et. al*. [2014] introduced intracavitary microwave heating for treatment of bile duct carcinoma by use of thin microwave antenna. In these techniques, they have studied the bile duct heating under the metallic stent placement. In addition, Debnath *et. al*. [2015, 2016] have studied the interstitial microwave heating combined with the interstitial radiation therapy. They have been considering not only the microwave heating but also the brachytherapy in view.

Saito *et. al.* have been studying the surgical devices using the microwave thermal effect. In recent surgical operations, many energy devices such as electrical scalpel using RF current and ultrasonically activated scalpel are often employed. However, there are some problems should be improved. On the other hand, the microwave surgical device (microwave antenna) may improve the problems. Therefore, several kinds of microwave surgical devices are developed Saito *et. al.* [2014c, 2015], Endo *et. al.* [2014, 2015a], Suzuki *et. al.* [2014]. In addition, devices combining the microwave antenna with the electrodes for RF current have also been studied Suzuki *et. al.* [2015]. Ogasawara *et. al.* [2015] have studied tissue coagulation detection mechanism by measurement of impedance of the treated tissue. The proposed system is installed the forceps type microwave device Saito *et. al.* [2016a, b]. In the using the microwave surgical devices, temperature of treated tissue will be increased dramatically. In order to simulate the performances of the device, temperature dependent tissue properties are included for the numerical computations Endo *et. al.* [2015b, 2016b].

K3.2 Other medical applications related topics

Up to now, biological tissue equivalent phantoms for microwave band are developed and utilized. However, the phantoms around HF band have not been considered, because the measurement of electrical properties of the materials in HF band have not been established. Suga *et. al.* [2013] have developed the phantom for HF band and measured its properties.

Tsuzaki *et. al.* [2014a, 2014b] and Takei *et. al.* [2014] have considered the WPT to a capsular endoscope. Recent capsular endoscope is operated by the battery and has some limitations of operation by battery capacity. Therefore, if the WPT can be realized in this field, it may be useful for diagnosis in the human body.

Some antennas for body centric wireless communication have been developed. Lin *et. al*. [2014a, 2014b] suggested the dual mode wearable antenna for the body centric wireless communication. It can realize the body centric wireless communication between some sensors installed on the body and can also communicate with outer base station located at a short distance from the body. If this kind of antenna system can be realized, it may be useful for the telemedicine.

K3.2 Therapeutic applications of electromagnetic fields

Transcranial magnetic stimulation (TMS) is a method to stimulate the brain using pulsed magnetic fields inducing eddy currents in the brain. Recent clinical studies showed that TMS is effective for the treatment of neurological and psychological diseases such as depression, Parkinson’s disease, and neuropathic pain. Daily TMS treatment at home has been desired for continuous effect by TMS. To improve efficiency of stimulation leads to a compact driving circuit suitable for home treatment. Sekino *et. al*. [2015] proposed eccentric figure-eight coils, which required a less driving current intensity than conventional one, and Yamamoto *et. al*. [2016a] showed the improvement of the eccentric coil with combination of iron core plates laminated in different directions in simulations. The coil-position system for home treatment has been proposed. However, it is challenging to stimulate the accurate target with the system by conventional figure-eight coils, which induces highly localized electric field. Sekino *et. al.* [2014] proposed a coil design which has a high robustness to positioning error and then, Yamamoto *et. al.* [2015] proposed a bowl-shaped coil for stimulating a wider area of the brain. Laakso *et. al.* [2014a, 2014b, 2015a, 2016] performed a study of multi-scale computer simulations whose techniques can predict about which or where neurons are activated and the effect of the electric field depend on the position and orientation of the coil. For obtaining inter-subject variations in the efficacy of transcranial direct current stimulation (tDCS), the electric fields among subjects and the strength and variability of group-level electric fields in the standard brain space were investigated. Yamamoto *et. al.* [2016] reported a development of numerical analyses software on individual brain model by using scalar-potential finite-difference (SPFD) method, which could be applied to the research of individual differences in the therapeutic effect. Lu *et. al.* [2015a, 2015b] proposed the Halo-circular assembly coil and Halo coil working with two circular coils, and Halo-Fo8 assembly coil for deep brain stimulations. Hirata *et. al.* [2013] simulated the electric field distribution induced by implanted and transcutaneous electrode for the treatment of bladder overactivity.

Electrical dosimetry in the skin layers due to different types of intra-epidermal electrical stimulation (IES) electrodes was conducted by Motogi *et. al.* [2016].

Ueno and Sekino [2015] published the book, which explains physical principles of biomagnetic stimulation and imaging, and introduces applications of these techniques in neuroscience, clinical medicine, and healthcare. The brief overview of the recent research trend in biomagnetics is also reported in this book.

K3.3 Magnetic resonance imaging

MRI serves as an important tool in medical inspection. Since MRI systems with higher static magnetic fields are able to provide images with higher signal-to-noise ratio, there is a tendency of expanded use of MRI system with 3T magnetic field in clinic, calling for concerns of exposure to the high magnetic field. Yamaguchi-Sekino *et. al.* [2014, 2015] performed experiments to evaluate exposure levels during routine MRI examinations in 3T MRI system by personal monitoring, providing valuable information for exposure levels for scanner operators. Then they proposed a save working procedure involving a restricted access area set at a distance of 30 cm from the end of a 3T MRI system to reduce occupational SMF exposure without notable changes in worker performance for the one with 3T of magnetic field. Another concern raised with the application of high field MRI is the SAR, especially for patients with m*et. al.* materials like implants or pacemaker inside their body. The SAR evaluations have been done for artificial knee joint by Suga *et. al.* [2014a] and carotid artery stent by Koizumi *et. al.* [2015].

On the other hand, researches for developing MRI system with higher magnetic field are continuing. Recently, Suga *et. al.* [2014b] designed a new birdcage coil with no lumped circuit elements for 4T systems, which matches the performance of the conventional birdcage coil that includes several capacitors.

Contrast agent also plays an important role in finding out useful interesting information in MRI. Ahmed *et. al.* [2016] applied the MRI to analysis the superparamagnetic iron oxide (SPIO) uptake to sentinel lymph nodes for researches of a new sentinel lymph node biopsy (SLNB) method based on magnetic tracer. The phase map cross-correlation detection and quantification are used to produce highlighted signal at tissues contains SPIO. However, underestimations of magnetic susceptibility changes may occur while facing high-concentrated iron accumulation. Zhu *et. al.* [2016] proposed a positive contrast imaging method based on least square analysis of phase gradient image and its corresponding template for measuring the high-concentrated SPIO labeling in MRI-monitored implantation or drug delivery.

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