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Microwave Applicators for EM Exposures of Small Animals

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Abstract

Research of interactions between EM Field and biological systems is of growing interests elsewhere. In the Czech Republic there are several groups working in this field, mostly in international co-operations. We will describe here mainly basic technical equipment developed for 3 different research projects in the discussed area.

1 Introduction

Three medical and biological research institutions (1 in Germany and 2 in the Czech Republic) run research on studies of interactions between EM field and biological systems. They are technically supported by 2 teams from the Czech Technical University in Prague. In this paper we would like to give more details about that projects and obtained technical results (i.e. description of developed exposition systems). First two projects are oriented on research of thermal effects of EM Field (using either waveguide or array applicators), the third one then on research of non-thermal effects (using small animal whole-body exposure chamber). The whole-body exposure system for unrestrained mice was designed in order to analyze the influence of electromagnetic field. The setup operating at 900 MHz was designed with respect to induced uniform field, external radiation elimination, absorbed power determination, sufficient space for mice movement together with even mice exposure and costs. The main aim of this paper is to assure that the dosimetry results reached by computer simulations can be used for determination of absorbed power in the unrestrained mouse. The whole-body exposure chamber with anatomical mouse model was simulated by two different numerical methods e.g. finite-difference-time-domain method (FDTD) and Finite Integration Technique (FIT) and its dosimetry results were compared by computed SAR values.

2 Waveguide Applicator

Very good results of EM field expositions in biological experiments can be obtained by simple but efficient waveguide applicators, see example in Fig. 1.

Figure 1. Waveguide applicator for biological experiments.

Waveguide offer a very big advantage – in approximately of 50% of its aperture area the irradiated electromagnetic field configuration is very near to a plane wave, which is basic assumption for good homogeneity of the heating and optimal treatment penetration. Here described system is used at Institute of Microbiology of the Czech Academy of Sciences. Aperture of this waveguide is 4.8 x 2.4 cm and it is excited at frequency 2.45 GHz. Effective heating is in the center of the real aperture – its size is approximately 2.4 x 2.4 cm. Waveguide is filled by teflon to reduce its cut-off frequency. Power from generator is possible to control from 10 to 180 W, in these experiments we work between 10 and 20 W mostly.

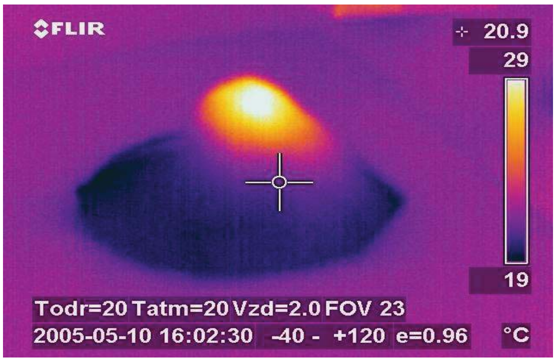

Figure 2. Temperature distribution obtained on surface of a model of mouse.

To evaluate this applicator from technical point of view we made a series of experiments, see e.g. Fig. 2, where you can see example of measurement of temperature distribution by IR camera.

Here you can see temperature distribution obtained on surface of a model of mouse made from agar – with a simulated tumour on mouse back. Experiment has been done by heating phantom during 2 minutes delivering a power of 10 W. Maximum of temperature increase has been found approximately 10 °C. Similar results with different increase in temperature we have got also in other technical experiments on phantom or live mouse when power or heating time was changed.

3 Array Applicator

The main goal of the planned biological experiment is a hyperthermia treatment of the experimentally induced pedicle tumours of the rat to verify the feasibility of ultrasound diagnostics and magnetic resonance imaging respectively to map the temperature distribution in the target area of the treatment. That means to heat effective volume of approximately cylindrical shape (diameter approx. 2 cm, height approx. 3 cm). Temperature to be reached is 41 °C or more (i.e. temperature increase of at least 4°C from starting point 37 °C), time period of heating is 45 minutes.

Therefore the applicator itself (see Fig.3) is created by two inductive loops tuned to resonance by capacitive elements. Dimensions of these resonant loops were designed by our software, developed for this purpose. Coupling between coaxial feeder and resonant loops (not shown in Fig.3) as well as a mutual coupling between resonating loops could be adjusted to optimum by microwave network analyzer. The position of the loops is fixed by Perspex holder. There is a special cylindrical space for experimental animal in lower part of this holder. As the heated tissue has high dielectric losses, both loops are very well separated and so no significant resonance in heated area can occur. From this follows, that either the position of the loops with respect to heated area or the distance between the loops is not very critical. Evaluation of the discussed applicator: First measurements to evaluate the basic properties of the discussed applicator were done on agar phantom of muscle tissue:

- evaluation of basic microwave properties (transfer of EM energy to the tissue, reflections),
- evaluation of compatibility with US and MR,
- calculation and measurement of SAR and temperature distribution and its homogeneity.

Exact tuning of the resonant loops to frequency 915 MHz has been easy and we could optimize the coupling between the coaxial feeder and resonant loops as well, reflection coefficient less than 0.1. We have tested the power to be delivered to the applicator to obtain sufficient temperature increase (approximately 4 °C in less than 5 minutes is required). With power 10 W delivered to each loop for period of 2 minutes we succeeded to obtain the temperature increase of approximately 7 °C.

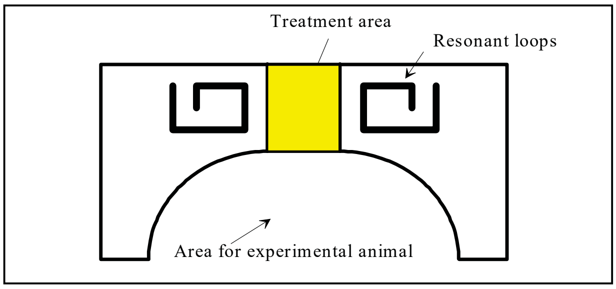

Figure 3. Arrangement of discussed microwave hyperthermia applicator

To keep the increased temperature for a long time, 2 W in each loops were sufficient. Similar values were obtained during first experiments on rats also. Even with higher level of delivered microwave power we did not observe the change of resonant frequency (caused e.g. by increased temperature of the loops).

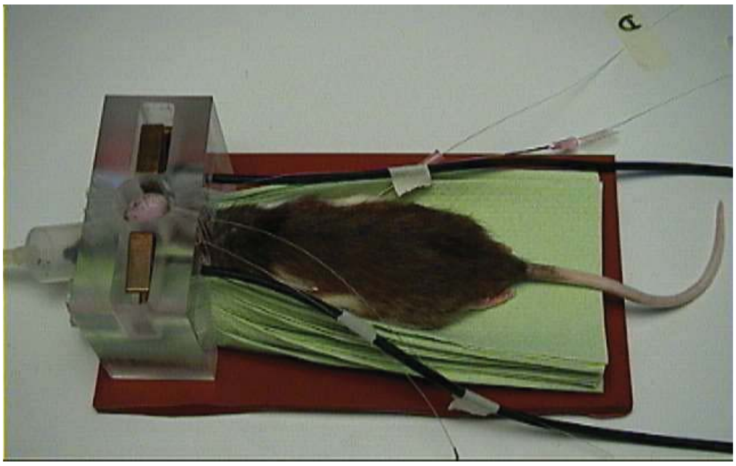

Figure 4. Photograph of the discussed applicator.

4 Exposure chambre

The whole-body exposure system for unrestrained mice was designed in order to analyze the influence of electromagnetic field. The major advantage of the system is the capability of direct measurement the whole-body averaged SAR which is performed by analysis of measured scattering parameters.

As the basic structure of the exposure chamber a waveguide was chosen. The advantage of the waveguide structure is a shielding of electromagnetic field generated inside in order to protect the operators and also generated outside the system in order to eliminate outer radiation. Dimensions of the exposure chamber were calculated in order to use desired frequency of operation and the volume needed to exposed mice. The exposure chamber is made of copper plate with dimensions of 1650mm length and 240mm diameter. The chamber is terminated by matched loads at both ends. In order to avoid reflection and assure an attenuation of power the loads must be made of lossy dielectric material and must have a suitable shape. The electrical resistance of the shape should grow linearly in a direction of the wave propagation. The designed matched loads are conical, 500mm long and are made of RF absorber. The reflection loss of the matched load is more than -20 dB at 900 MHz. The circular polarized wave TE_{11} is excited in the waveguide. This wave is comprised by two monopoles which have mutually orthogonal orientation and the distance between them is equal to one-fourth of wavelength. Circular polarized wave provides relatively constant coupling of the field to each mouse regardless of its position, posture or movement. The exposed mice are kept in a box which is made of Styrofoam. Styrofoam has a dielectric constant of 1.03, i.e. very close to that of air, and thus the disturbance of exposure and measurements is negligible. The box provides space for two separated mice. Punctured slit-like holes are set on the cover and side of the box for air ventilation. In the study the mice are hold in the chamber only during RF exposures and therefore, no food or drinking water is necessary.

Efficient ventilation is necessary to maintain constant temperature and good air quality in the chamber. The air exchange is realized by a ventilation system which consisted of a fan installed outside the chamber and a tube attached to the ventilation hole. The exchange air come towards mice through the ventilation hole placed below the styrofoam box and flow towards the second opposite ventilation hole placed above the box.

Basic properties such as electromagnetic field distribution and impedance matching of the designed chamber were optimized and verified by a 3D electromagnetic field simulator SEMCAD X.

Important area of our activities is the research of exposure chambers for studies of biological effects of EM field in microwave part of frequency spectrum. The exposure chamber (Fig. 5) is designed to investigate the non-thermal biological effects of the EM field in the microwave part of frequency band.

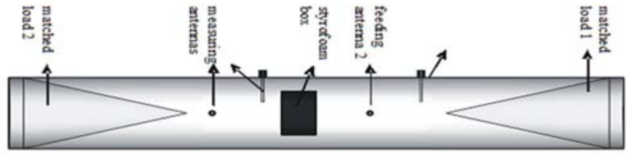

Figure 5. Schematics of the exposure chamber for animal experiments.

Dosimetry is an inherent task for exposure setups. Dosimetry is the quantification of the magnitude and distribution of absorbed electromagnetic energy within biological objects that are exposed to electromagnetic fields. At RF, the dosimetric quantity, which is called the specific absorption rate, is defined as the rate at which energy is absorbed per unit mass. The SAR is determined not only by the incident electromagnetic waves but also by the electrical and geometric characteristics of the irradiated subject and nearby objects. It is related to the internal electric field strength as well as to the electric conductivity and the density of tissues. Therefore, it is a suitable dosimetric parameter, even when a mechanism is determined to be “athermal.” SAR distributions are usually determined from measurements in animal tissues or from calculations. It generally is difficult to measure the SAR directly in a living biological body, and therefore dosimetry efforts are forced to rely on computer simulations.

An anatomically based biological model is essential for numerical dosimetry. Such a numerical model is developed commonly from MRI or CT scans. In order to develop a model for numerical dosimetry original gray-scale data must be interpreted into tissue types which is known as a process of segmentation. Segmentation is the task of partitioning the data into contiguous regions representing individual anatomical objects. Segmentation is a difficult task because in most cases it is very hard to separate the object from the image background. This is due to the characteristics of the imaging process as well as the grey-value mappings of the objects themselves. The most common medical image acquisition modalities include computer tomography (CT) and magnetic resonance imaging images (MRI).

MRI or CT provides gray-scale image data as many transverse slices, at a designated spacing, from the head to the feet of the biological body. The resolution in each slice is on the order of several millimeters. CT scans for mouse model development were obtained from the web site: http://neuroimage.usc.edu/Digimouse_download.html.

The mouse model (Fig. 6.) has the resolution 0,1mm, meaning voxel size 0,1 x 0,1 x 0,1 mm. Each voxel was assigned to one of 14 different tissue types, such as bone, muscle, brain, etc.

For dosimetry with the numerical voxel models, proper permittivity and conductivity values must be assigned to each tissue. The data from 10 MHz to 6 GHz, which were derived from 4-Cole-Cole extrapolation based on measurements for small animals [7], constitutes the most widely accepted database for this information. The data are recommended by various international standardization organizations and can be accessed from the web site http://www.fcc.gov/fcc-bin/dielec.sh.

5 Results

In order to verify and rely on numerical dosimetry results, the simulations of exposure chamber is desired to be performed in different electromagnetic field simulators using different numerical methods. As 3D simulators using different numerical methods were chosen SEMCAD X [5] which uses Finite Difference Time Domain (FDTD) method and CST Microwave Studio [6] which uses Finite Integration Technique (FIT) method. For the purpose of results comparison the model of the mouse was chosen homogenous phantom with anatomical shape of the mouse. The model dielectric parameters were set the same like muscle tissue. The simulations were performed for three positions of mouse in order to verify an even exposure which should be assured by circular polarized wave. The first and the second position of the mouse was chosen perpendicularly to one of the feeding antenna and the third position was chosen generally (Fig.7.).

Figure 6. The numerical mouse model based on CT scans

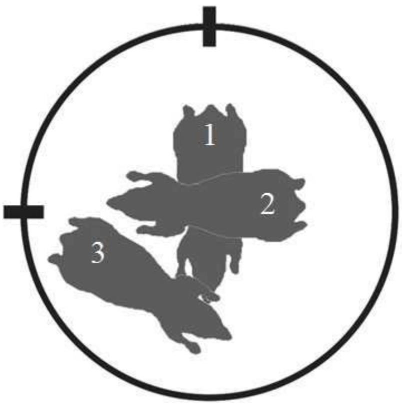

Figure 7. Positions of mouse inside the box

From the Fig.8. it is obvious that the reached simulation results for both numerical methods are in a good agreement. Further, it was verified that the circular polarization provides constant coupling of the field to each mouse regardless of its position or movement.

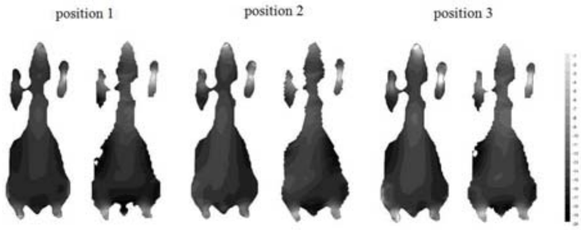

Figure 8. SAR distribution in middle cutting plane (top view) for three positions of mouse

Biological experiments were done by researchers from Medical Faculty in Pilsen, Charles University. A series of EM exposures of small animals (mice) was done by this exposure chamber. SAR level was on the level of 0.8 W/kg in case of these experiments. Evaluation of preliminary results is displayed in Fig. 9. New experiments to verify these results are being prepared.

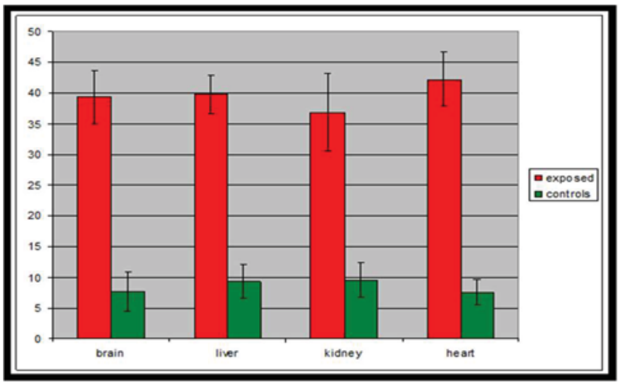

Figure 9. Results of animal experiment – in all 4 studied organ specimen (brain, heart, kidney and liver) significantly increased content of free radicals was found.

6 Acknowledgements

Acknowledgements go in here.

7 References

1. N. Kuster and F. Shonborn, “Recommended Minimal Requirements and Development Guidelines for Exposure Setups of Bio-Experiments Addressing the Health Risk Concern of Wireless Communications”, *Bioelectromagnetics,* Vol. 21, p. 508-514, Vol. 40, pp. 16-19, Jan. 2000.

2. O. Fujiwara, J. Wang, *Electromagnetics in Biology*, Springer Japan, 2006.

3. B. Dogdas, D. Stout, A. Chatziionnou and R.M. Leathy, “Digimouse: A 3D Whole Body Mouse Atlas from CT and Cryosection Data”, *Phys Med Biol,* vol. 52, no. 3, p. 577 – 587, 2007 .

4. D. Stout, P. Chow, R. Silverman, R.M. Leathy, X. Lewis, S. Gambhir and A. Chatziionnou, “Creating a Whole Body Digital

Mouse Atlas with PET, CT and Cryosection Images”, *Molecular Imaging and Biology*, vol. 4, no. 4, p. S27, 2002.

5. *Schmid & Partner Engineering AG*, [Online], URL:<http://www.semcad.com/>, 2010.

6. *Computer Simulation Technology*, [Online], URL:<http://www.cst.com/>, 2010.

7. C. Gabriel “*Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies*”*,* Brooks Air Force Technical Report, AL/OE-TR-1996-0037

8. Franconi, C., Vrba, J., et al.: "27MHz Hybrid Evanescent-Mode Applicators”. *Int. Journal of Hyperthermia,* 1993, Vol. 9., No. 5., pp. 655 – 674

9. Vrba, J., Franconi, C. et al. :"Evanescent-Mode Applicators for Hyperthermia”. *IEEE Trans. on Biomedical Engineering*, Vol.40, No5, May 1993, pp.397-407