NUMERICAL DOSIMETRY OF A THIN RAT HIPPOCAMPUS IN A CONTROLLED RF EXPOSURE SYSTEM

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ABSTRACT:

Electromagnetic dosimetry was performed on thin rat hippocampal slices in a controlled radio frequency (RF) exposure system that is used to investigate the effects of RF radiation on brain tissues (*in vitro*). A software program based on the finite integral method was employed to simulate the exposure systems and the brain slices. A two-stage approach was utilised to overcome challenges due to the existence of large and small physical objects within the system, as well as the memory and simulation duration limitations. The computer models were validated against the practical measurements of the physical structures. The field strengths and the Specific Absorption Rate (SAR) inside biological tissue cells were assessed at 700MHz.

INTRODUCTION:

Many studies have demonstrated the biological tissues thermal increase due to the absorption of the electromagnetic radiation energy. The Specific Absorption Rate (SAR) is currently used as a quantity for the measurement of RF power absorption in biological tissues. Some studies have suggested the existence of the "non-thermal" effect on the brain functions as a result of exposure to RF radiation [1]. A recent study was performed on the effects of low level RF exposure on rat hippocampal slices [2-3]. A 400µm thick slice of a rat hippocampus was exposed to a 700MHz RF signal in a stripline waveguide exposure system, as shown in Fig.1. The exposure system consists of two parallel metal plates forming a stripline waveguide. The vertical distance between the two plates is 3.4cm and the width of the top plate is 10cm, thus the characteristic impedance of the waveguide is about 70O. Two 50O coaxial ports are located at each ends of the ground plate. Each of the coaxial feeds is connected to a triangular shaped transformer that is connected in turn to the upper parallel plate. The exposure model also has an upper central window, which is used for inspection/access. The inspection window has two configurations, one with a rectangular shape crossed by bonded metal wires, and another with an open diamond shape. The brain slice is placed on Perspex® mount, directly under the inspection window.

EM dosimetry using conventional probe based measurements is difficult to perform in this thin brain slice. Numerical dosimetry is hence required to calculate the electromagnetic field strengths within the brain slice and evaluate the SAR distribution. The Finite Difference – Time Domain (FD-TD) method is a common numerical technique for this kind of EM problem. However, an enormous number of mesh cells would be required to model

the complete system, due to the distinction between the thickness of the brain slice and the physical dimension of the complete exposure system. This results in an unrealistic demand on the current computer resources, i.e. requiring huge memory and long simulation time. Therefore, we have applied a two-stage approach to perform numerical dosimetry on the brain slice in the exposure system.

METHODS:

The software program being used in the study, called Microwave Studio™ [5], is based on the Finite Integral method (FI), which is equivalent to FD-TD in the time domain. The waveguide was modelled in free space, so that extra space was allowed above the waveguide to enable proper formation of the EM fields around the structure. An RF signal of 700MHz was fed through one coaxial port and absorbed at the other port. The field strengths (rms) along the vertical axes of the waveguide are measured using 'virtual probes'. Variable mesh sizes were created to model the various objects within the structure. The Perfect Boundary Approximations (PBA) technique was also employed to treat partly filled mesh cubes for the cylindrical ports and the slopes of the tapered ends. The modelling of a thin brain slice in the much larger complete system required an enormous number of the small mesh cells. In order to make the simulation feasible, the problem had to be solved in two stages. The first stage involved modelling the complete waveguide and the various supporting objects, but excluding the thin tissue slice. The field strengths along the vertical axes at the middle of the waveguide were then measured and the output power assessed. A typical electric field distribution along the propagation direction is shown in Fig. 2. The validation of the numerical models was carried out by comparing output power and the electric field strength along the vertical central axes of the empty waveguide, with those measured on the actual physical structure [4] for the frequency range 500-3000MHz.

The second stage involved the simulation of exposure of the brain slice in a 'cut-down' version of the waveguide, as shown in Fig.1.f. The 'cut-down' version of the system consists of the middle section of the waveguide, where the brain slice is placed in the holder (Fig.1.g). Evaluation of the SAR values inside the brain slice, relative to 1W rms input power, was then achieved at the second stage.

RESULTS:

The electric fields and power output obtained from simulating the empty waveguide (rectangular window) have shown a good agreement with those measured on the actual physical structure, as shown in Figs. 3 and 4. At 700MHz, the hippocampal slice has a relative permittivity of 53.898, conductivity (s) of 0.8595 S/m, and a density (?) of 1000 kg/m^3. The peak SAR value of the brain slice in the diamond shaped window waveguide was 0.034W/kg, and 0.035W/kg for the rectangular window, as listed in Table 1. An error factor based on the difference between the measured output power and those modelled was assessed at about ±2.8%.

The average SAR values were confirmed using the formula:

$$SAR = \frac{s\,|E|^2}{r}$$

where the field strength (rms) inside the brain slice is obtained directly in the simulation. Table 1 also shows the comparison of SAR values obtained here with those obtained in our previous study using a different FD-TD program, called XFDTD [3]. It is apparent that a good agreement has been achieved between the two studies.

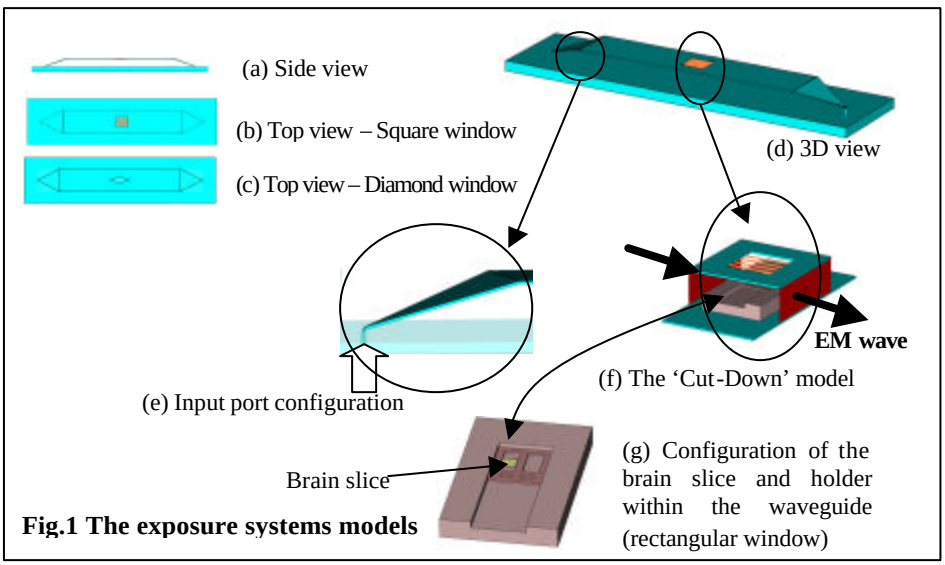

Fig.1 The exposure systems models

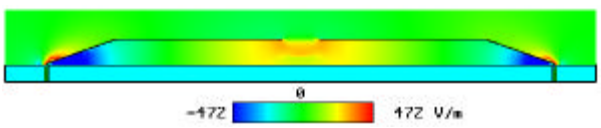

Fig.2, Electric field distribution along the waveguide (rectangular window)

Table 1, Peak SAR value of 1W rms input power at different frequencies

	Diamond shape window	**Rectangular window**
Frequency (MHz)	**700**	**700**
SAR (W/Kg) (CST-MWS)	0.034	0.033
SAR (W/Kg) (XFDTD [3])	0.030	0.035

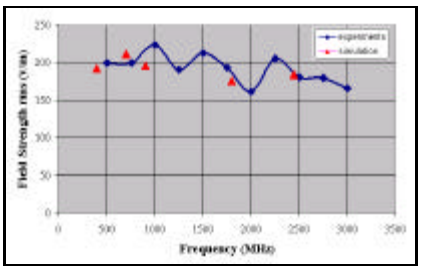

Fig.3, Comparison of Electric Field between the physical and simulation models.

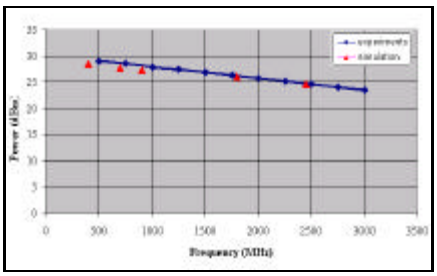

Fig.4, Comparison of output power between the physical and simulation models.

CONCLUSIONS:

EM dosimetry inside two controlled exposure systems was carried out at 700MHz, using the Finite Integral method. The empty exposure system model was validated against the actual physical measurements based on the electric field strengths and the output power. Even using the variable mesh size technique, it still requires considerable computer memory and simulation duration. An alternative approach was used to break down the modelling into two stages, one to simulate the large objects, and another to model the small objects (including the brain slice), under the identical EM field strength.

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