NUMERICAL DOSIMETRY ON THE SCALES OF BIOLOGICAL BODY, TISSUE AND CELL

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Abstract
This paper gives a brief overview of numerical dosimetry on the scales of animal body, tissue and cell conducted by the authors. The paper presents some interesting results obtained in these studies, but also highlights some general engineering challenges.

INTRODUCTION
Numerical dosimetry is an important part of bioelectromagnetics research and has progressed greatly over last two decades with the dramatic increase of computing power and the further advances of computational electromagnetics [1]. The FDTD (Finite Difference Time Domain) technique has become one of the most favourable methods of dosimetry in view of its strengths in solving complex heterogeneous problems with reasonable computational requirements. Computations are now being made with millions of mathematical cells and anatomically realistic models are generated from MRI scans of typical human or animal bodies. Local internal field or SAR (specific absorption rate) distributions can now be computed in models of millimetre or even sub-millimetre resolution for almost any kind of exposure fields. Lately, considerable efforts have already been put into the numerical dosimetry on the cellular scale, i.e. the so-called microdosimetry, which is regarded as a prerequisite to quantification of direct field effects.

As a group of RF engineers, we have conducted a number of dosimetry studies on the scales of animal body, tissue and cell in cooperation with our biophysical colleagues over last few years. Both Finite Difference (FD) and Finite Element (FE) techniques in either time or frequency domain have been utilised in our studies. Generally speaking, for studies on the animal body scale, local electric field strengths are influenced by the shape and frequency dependent dielectric properties of the exposed object, and many other effects such as induction, coupling and resonance. Moreover, fields propagating through heterogeneous biological tissues suffer attenuation, reflections, or diffractions in different proportions depending on the boundaries and differences in properties of the tissues. Modelling of the EM fields on the tissue slice scale (small object represented by given dielectric properties) is also not straightforward due to the requirement of including the exposure apparatus in the model. Certain measures have to be taken to accommodate both large and small objects in the model to avoid the excessive generation of voxel and time step numbers leading to exhaustion of the current computing resource. On the cellular scale, the dimension of various cellular compartments is several (6~7) orders smaller in comparison to the wavelength, which renders that the conventional time domain techniques, such as FDTD, are no longer viable in this case. This introduces quasi-static situation where the frequency domain techniques or other equivalents have to be used.

In this paper, we would like to present some of the interesting results obtained in these studies and highlight some general engineering challenges.

ON ANIMAL BODY SCALE
In this study, numerical dosimetry has been performed using a research software package [2] on the digital anatomical model of the Sprague-Dawley rat (MRI space cell dimensions 71×42×134) under the plane wave exposure [3]. Aging implications on SAR profiles are assessed for exposure to fields in the three typical orientations with a range of frequencies on models of 10, 30, and 70 days old rats (Fig. 1). Dielectric properties of the modelled muscle, heart, liver, spleen, cortical bone, skin, grey matter, lung, and kidney tissues for each corresponding age are based on the data measured by MCL Ltd, UK.

It is noticed that for each of the 10, 30, and 70 days old models, the whole-body averaged SAR values depend heavily on the frequency and orientation of exposure. Resonances are detected at different frequencies depending on the rat age and exposure conditions (Fig. 2). It is interesting to find that the whole-body averaged SAR values are not notably affected by changing the dielectric properties of localised tissues, however, it can result in significant variations of the body SAR distributions (locations of localised tissue...
maximum SAR values). These variations are due to the changes of the localised electric field strengths caused by boundary differences between neighbouring tissue types.

Even with our best efforts, the validation can only be done indirectly on a homogenous model in the study. The direct validation of a heterogeneous tissue model remains as a general difficult problem. Solid or semi-solid phantom technique combined with thermal imaging seems to be an only feasible approach to address this problem.

ON TISSUE SCALE

On the tissue scale, the numerical dosimetry has been performed on a rat brain-slice exposed to electromagnetic fields inside an RF exposure system described in [4]. The tiny tissue slice of 8 mm length by 8mm width and 0.4 mm thick is treated as a lossy medium exposed to a continuous waves of different frequencies, injected into the system from a coaxial cable (Fig 3). Modelling of the thin brain slice in the much larger complete system is also a challenging task since it requires an enormous number of the small mesh cells. In order to make the simulation feasible, various techniques were used to facilitate the computations. The computed SAR values are summarised in Table 1. It is interesting to notice that the SAR distribution inside a tiny brain tissue slice, as shown in Fig. 4, is not uniform.

The validation of the numerical model has been 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 [5] for the frequency range 500-3000MHz. Furthermore, further assessment of the accuracy will be carried out by using thermal imaging technique on a dummy tissue slice.

ON CELLULAR SCALE

Microdosimetry is the most challenging task, the ‘holy-grail’ in the bioelectromagnetics research, due to the microscopic structure and dimension of cells. In this study, similar to others’ studies [6], the cell is modelled primitively as a double layer lossy sphere inside the cell culture medium exposure to a plane wave; the thin outer layer representing the cell membrane while inner layer representing the cell content (Fig. 5). The problem is treated as a quasi-static one and is solved by using both FD and FE Methods (Frequency Domain). Electric field distributions are obtained and also compared. This study is only the first step towards a more realistic microdosimetry in which cell membrane voltage should be taken into account.

CONCLUSIONS

We have demonstrated that numerical dosimetry on the scales of biological body, tissue and cell is quite challenging due to a variety of reasons, including complexity of heterogeneous tissue body, size of the tissue sample, microscopic structure and dimension of cells and limitation of computing resources. We can see that microdosimetry has a long way to go. Also, even at macrosdosimetry level, direct validation of the numerical model against the measurement turned out to be very difficult, if not at all impossible. We have tried to inject a certain degree of engineering rigorousness into our studies and felt that a great deal can still be done.

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REFERENCES


<table>
<thead>
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<th>Frequency (MHz)</th>
<th>Specific Absorption Rate (W/kg)</th>
<th>Tissue averaged</th>
<th>Peak values</th>
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<tr>
<td>400 MHz</td>
<td>0.016</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
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<td>0.090</td>
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<tr>
<td>2450 MHz</td>
<td>0.169</td>
<td>0.180</td>
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</tbody>
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Table 1: SAR values inside the brain tissue slice at different frequencies with peak input power = 1Watts