Parametric Dependence of Specific Absorption Rate (SAR) on Permittivity of Different Biological Tissues

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Abstact: *It is well known that specific absorption rate (SAR) values are dependent on permittivity values. However, variability in the published permittivity values for human and animal tissue and the development of sophisticated 3-dimensional digital anatomical models to predict SAR values have resulted in the need to understand how model parameters affect the predicted whole body and localized SAR values. In this report, we establish the partial derivative of whole body and localized SAR values with respect to permittivity values of all tissue types, as well as for only the tissues with the most variable permittivity values as reported by Hurt et al. [1].*

INTRODUCTION

In general, permittivity values are intrinsic parameters that determine the effects of electric fields on matter. Permittivity values (*relative dielectric ε' and effective conductivity σ*) have a dominant role in the overall consideration of interaction between electromagnetic fields (EMF) and matter and in related applications in numerous disciplines including electromagnetic dosimetry. Determining dielectric constant and specific conductivity of various biological tissues is the first step when calculating the SAR. There are differences in characteristics of the same tissues in various publications (the use of tissues from different species as well from different animals of the same species). Variability in the permittivity value of a single organ results from the heterogeneous nature of the biological tissues, age of the animal or sample, the temperature of the sample, the tissue preparation procedure, and whether the tissue is anisotropic [2].

METHODS

A FD-TD program based on code originally described by Kunz and Leubbers [3] was used to predict localized and whole-body normalized SAR values (W/kg/mW/cm^2). The use of this method is reported in numerous publications each year (www.fdtd.org) and has become one of the most frequently used methods to predict SAR values in organic and non-organic materials.

Digital anatomical model of Sprague-Dawley rat (voxel dimension 1.95x 1.95x 2.15 mm^3), based on magnetic resonance imaging (MRI) data was used in numerical calculations to predict EMF induced SAR values. MRI scan files of the Sprague-Dawley rat were converted into color-coded digital images representing permittivity values and tissue type. The resulting data were imported into a mathematical model to predict electrical fields and SAR values. Detailed procedure on constructing the digital anatomical databases of rat was presented by Mason et al. [4]. To determine the dependence of SAR on the permittivity values, a rat model was processed for three different conditions of permittivity. The three values of the permittivity used were either 0.5 times Gabriel's values, 2.0 times Gabriel's values, or the actual values published by Gabriel [2]. Practical reasons for choosing such ratios could be found in average differences between Gabriel's data and results reported by other authors for most of the tissue types [2].

The model was processed in the far field at the frequencies below resonance (200 MHz), resonance (500 MHz) and above resonance (2060 MHz) for EHK orientation. In present study, other orientations (KEH, KHE, HEK) of the model to the incident fields were used where no significant resonant frequency exists. Then, the permittivity value of only a single tissue type (e.g., muscle, skin, fat) was varied at any one time. The selected tissues were those with the most variable permittivity values as reported by Hurt et al. [1] and with the highest percentage of the contents in the body mass. The permittivity value assigned to a voxel was calculated from the 4-term Cole-Cole fits published by Gabriel [2].

RESULTS

The SAR values (SAR_{1x}) for resonance frequency (500 MHz) using the permittivity values as reported by Gabriel [2] are the highest for E orientation (0.94 W/kg/mW/cm^2), somewhat lower for K (0.06 W/kg/mW/cm^2), and the lowest for H orientation (0.04 W/kg/mW/cm^2). Normalized whole body SAR (W/kg/mW/cm^2) for a rat model for selected frequencies in relation to the different orientations

and permittivity values are presented in the Table 1. Ratios are between whole body SAR calculated by changing the permittivity value either 0.5 times Gabriel's values ($SAR_{0.5x}$), 2.0 times Gabriel's values (SAR_{2x}), and whole body SAR calculated using the actual values (SAR_{1x}) published by Gabriel. Permittivity values where changed for all tissue types or only muscle, skin, and fat .

Table 1: Normalized whole body SAR (W/kg/mW/cm^2) values for a rat model for selected frequencies in relation to the different orientations and permittivity values.

Orientation	f (MHz)	SAR_{1x} *	WB SAR ratio ** SAR_{2x}/SAR_{1x}				WB SAR ratio ** $SAR_{0.5x}/SAR_{1x}$			
			All	Muscle	Skin	Fat	All	Muscle	Skin	Fat
EHK	200	0.16	0.86	0.91	1.02	1.06	1.10	1.10	1.00	1.01
	500	0.95	1.42	1.32	1.03	1.04	0.60	0.80	1.01	1.02
	2060	0.32	0.90	0.90	0.94	1.08	1.10	1.10	1.11	1.05
HEK	200	0.02	0.93	0.90	1.01	1.03	1.11	1.12	1.01	1.00
	500	0.04	1.95	1.51	1.10	1.04	0.90	0.92	0.95	1.01
	2060	0.33	0.90	0.95	1.06	1.05	1.22	1.32	1.01	1.02
KHE	200	0.01	1.22	1.15	1.05	1.05	1.15	1.12	1.08	1.07
	500	0.06	3.23	2.37	1.12	1.08	0.52	0.61	0.95	0.96
	2060	0.26	0.85	0.87	0.93	1.00	1.10	1.11	1.03	1.01

* normalized whole body (WB) SAR (W/kg/mW/cm^2) when using actual permittivity data published by Gabriel [2].

** ratio between whole body SAR, when changing permittivity (2.0x and 0.5x) values for all tissue types or individually the muscle, skin, and fat, and whole body SAR values using actual values published by Gabriel [2]. To obtain the absolute value, normalized whole body SAR in a column (*) must be multiplied by a number from column (**).

CONCLUSIONS

In the rat model, variability in permittivity values significantly influence SAR values, but only under special combinations of orientations, frequencies, and tissue types.

Orientation seems to be one of the most important issues when studying the relationship between permittvity data and SAR values. Whole body SARs in the K orientation showed the most sensitivity to permittivity variations. It must be clarified that in the K orientation there is no significant resonance and absolute values of localized and whole body SAR are low. In the E orientation, the rat absorbs the most incident RF energy at 500 MHz and represents a good "antenna" (the absolute whole body SAR values are the highest) in comparison to the other orientations. Irrespective of permittivity variations, the whole body SAR values do not change much and its ratios are low.

Changes in permittivity values of muscle had the most substantial influence on whole body and localized SAR when changing only one tissue type. This is most likely because the muscle tissue spreads through the body and represents the main organ according to its body mass. Muscle (high water content tissues) is more lossy than drier materials (fat, skin, bone) and hence absorbs more energy from electromagnetic fields.

These results clearly show that in future EMF dosimetry studies, the recognition of SAR dependence on variability in permittivity will lead to increased confidence in the validity of the numerical calculations. Further investigations on other animal species and human are underway.

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