Calculation of the SAR and Temperature Rise in the Human Eye due to RF Sources

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This paper presents a thorough numerical analysis of the specific absorption rate (SAR) and temperature increase in a three dimensional (3D) anatomical human eye model exposed to electromagnetic fields (EM) at 1.9GHz, 2.4GHz and 5.1GHz, in particular devices such as tablets, smart phones, etc., situated at 30cm, 15cm and 2cm from the eye. A new 3D model of the human eye composed of nine different tissues with a resolution of 0.5mm is discussed, including a precise definition of the cornea and lens. The thermal problem is solved from the bioheat (Pennes') equation coupling the SAR as an input of the power dissipated by the EM field. Measured values of the irradiated power of the devices were considered for the source of the EM. In terms of maximum temperature, for the source distance of 30cm, the highest values encoutered are 0.01^{o}C in the cornea, aqueous humor and lens at 5.1GHz. For the source distance of 15cm, the worst case is 0.04^{o}C increase in the vitreous humor at 1.9GHz. For the source distance of 2cm, the worst case is 1,62^{o}C rise in the lens at 1.9GHz.

***Index Terms*—Electromagnetic fields, human eye, SAR calculation, temperature distribution.**

I. Introduction

In recent years, there has been increasing public concern on whether portable devices, which are based on wireless technology may cause any adverse health effect. Initially, the concern was with the human head due to the use of mobile phones [1], [2]. Subsequently, the attention turned to the human eye considering the popularity of tablets and smart phones and also the fact that the eye is very sensitive, specialy at high frequency EM fields [3], [4].

II. Models and Methods

A. Human Eye Model

The human eye model comprises nine different tissues: cornea, aqueous humor, iris, lens, muscle, vitreous humor, retina, choroid and sclera. A zoom in the frontal part of the eye ilustrating its tissues and dimensions is shown in Fig.1a, which can be compared to Fig.1b taken from a reference in hystology of the human eye. Particular emphasis was paid to the definition of the cornea and lens considering its sensitivity and possible adverse effect (cataracts) to the temperature increase due to the EM exposure.

B. EM and SAR Calculation

The SAR is calculated using the peak values of the electric field vector components in which σ and ρ are, respectively, the conductivity and mass density of the tissue [5]:

$$SAR = \frac{\sigma}{2\rho}|\hat{E}|^2 = \frac{\sigma}{2\rho}(|\hat{E}_x|^2 + |\hat{E}_y|^2 + |\hat{E}_z|^2) \qquad (1)$$

C. Temperature Calculation

The temperature increase in the human eye is calculated using a modified Pennes' bioheat equation [5], [6]:

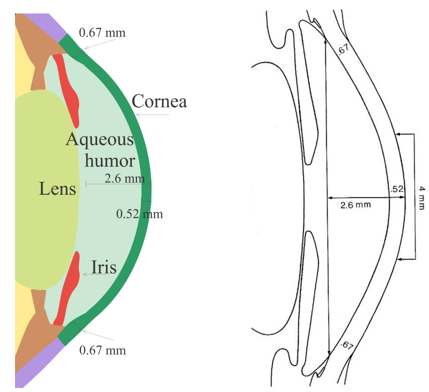

Fig. 1. Zoom in the eye model

$$\rho c\frac{\partial T}{\partial t} = \nabla \cdot (k\nabla T) - b(T - T_b) + Q_{MET} + Q_{EM} \qquad (2)$$

where ρ, c and k are the density, the specific heat, and the thermal conductivity, respectively; T and T_b are the tissue and blood temperature (K), $b = \rho_b c_b \rho\omega$ is proportional to blood perfusion. The term Q_{MET} is the metabolic heat generation rate and $Q_{EM} = \rho SAR$ is the power dissipated by the EM field, which is calculated by (1). The solution of (2) using the finite difference requires adequate boundary conditions on the body-air interface (skin and cornea) taking into account the radiative, convective and evaporative conditions which will be detailed in the full paper.

III. Results

The model used for the calculation comprises a cube (edge of 27.1mm) that contains the eye model as indicated in Fig.2. Next to the outer boundaries, convolutional perfect matching layer (CPML) and thermal boundary conditions are imposed for the EM and thermal problems respectively [7].

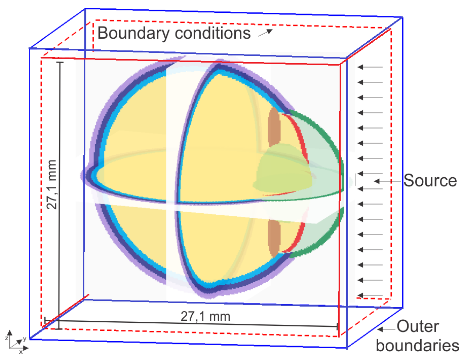

Fig. 2. 3D Numerical model.

The source of the electromagnetic field was defined as a plane wave placed at the distances of 30cm, 15cm and 2cm from the eye, in all cases at frequencies 1.9GHz, 2.4GHz and 5.1GHz. The distance of 30cm is considered as the average distance that most users keep their devices (tablets, smart phones, etc.) while in use. The other positions of the source were considered as intermediate (15cm) and extreme (2cm) situations. The values of irradiated power by the devices were obtained from measurements carried out by the Brazilian Agency of Telecommunications [8]. From the irradiated power, the power density was calculated for the specified frequencies and distances, as indicated in Table I.

TABLE I
SOURCE DEFINITON

Freq. (GHz)	Power (W)	Power Density (mW/m^2) Distance (cm)			Electric Field (V/m) Distance (cm)		
		30	15	2	30	15	2
1.9	0.207	183	732	41181	11.8	23.5	176.2
2.4	0.138	122	488	27454	9.6	19.2	143.9
5.1	0.143	126	506	28449	9.8	19.5	146.5

The results for maximum SAR in the eye model are given in Table II. In terms of maximum SAR, for the source distance of 30cm and 15cm, the highest values found for the lens are 0.28W/kg and 0.53W/kg at 5.1GHz; and the worst cases in the eye tissues are 0.43W/kg and 1.14W/kg in the vitreous humor at 5.1GHz. For those source distances all calculated values of maximum SAR are within the limit of 2W/kg defined by international standards. For the source distance of 2cm, the highest value for the lens is 29.96W/kg at 5.1GHz and the worst case in the eye model is 64.22W/kg in the vitreous humor at 5.1GHz. For this extreme situation, the limit value of 2W/kg is exceeded in all tissues of the eye for all power densities and frequencies studied.

The simulation with no EM source yielded the following final temperatures (^oC) in the eye: cornea = 36.80; aqueous humor = 36.80; iris = 36.72; lens = 36.75; muscle = 36.78; vitreous humor, retina, choroid, sclera = 37.00, which are considered as the reference values for comparison with the temperature results given in Table III. In terms of maximum temperature, for the source distance of 30cm, the highest values encoutered are 0.01^oC in the cornea, aqueous humor and lens at 5.1GHz. For the source distance of 15cm, the worst case is 0.04^oC increase in the vitreous humor and the lens experience a maximum increase of 0.03^oCat 1.9GHz. For the source distance of 2cm, the worst case is 1,62^oC rise in the lens at 1.9GHz.

From the cases studied, it can be concluded that a negligible increase is observed for a distance of 30cm and 15cm and that attention must be paid for distances smaller tham 5cm. The full paper will discuss the more realistic situation in which the user (and the eye) are in the presence of multiple sources.

TABLE II
MAXIMUM SAR [W/Kg]

Tissues	1.9 GHz Distance (cm)		2.4 GHz Distance (cm)		5.1 GHz Distance (cm)	
	30	2	30	2	30	2
Cornea	0.12	25.74	0.09	16.85	0.20	17.60
Aq. Hum.	0.13	28.97	0.10	18.45	0.40	47.43
Iris	0.06	11.17	0.08	8.33	0.25	18.96
Lens	0.06	13.80	0.10	17.29	0.28	29.96
Muscle	0.07	17.15	0.08	12.08	0.25	23.13
Vit. Hum.	0.28	60.19	0.24	49.23	0.43	64.22
Retina	0.21	46.05	0.11	18.12	0.25	23.34
Choroid	0.21	56.42	0.11	22.86	0.25	31.39
Sclera	0.20	45.65	0.10	17.21	0.27	26.89

TABLE III
MAXIMUM TEMPERATURE [^oC]

Tissues	1.9 GHz Distance (cm)		2.4 GHz Distance (cm)		5.1 GHz Distance (cm)	
	30	2	30	2	30	2
Cornea	36.80	37.78	36.80	37.36	36.81	37.49
Aq. Hum.	36.80	37.90	36.80	37.47	36.81	37.59
Iris	36.72	37.93	36.72	37.43	36.72	37.62
Lens	36.75	38.37	36.75	37.83	36.76	38.04
Muscle	36.78	38.11	36.78	37.58	36.78	37.80
Vit. Hum.	37.00	38.57	37.00	38.09	37.00	38.16
Retina	37.00	37.89	37.00	37.51	37.00	37.59
Choroid	37.00	37.84	37.00	37.46	37.00	37.54
Sclera	37.00	37.78	37.00	37.42	37.00	37.49

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