THERMAL EFFECT OF 1.8 GHz MOBILE PHONE RADIATION ON DURA TISSUE

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Abstract. Several recent studies investigated the impact of mobile phone radiation on cells of the human body. Thermal effects have been investigated, *via* experimentation or simulation in many types of research. This paper deals with thermal effects of electromagnetic radiation, produced from a mobile phone with a frequency of 1.8 GHz, in human dura tissue, using the finite-difference-time-domain method (FDTD). This study focuses on the thermal effect response of a semi-infinite biological tissue. Maxwell's equations and transient bioheat transfer equation were numerically calculated, to predict the effects on the transient temperature of dura tissue. Electric and magnetic field simulation is also done. The prediction of the temperature evolution in biological bodies can be used effectively for thermal diagnostics in medical practices. Modeling the electromagnetic field distribution in the human body allows providing a good answer to the worried persons. This analysis and results can be used during the design process for the newest mobile phones, and also help in determining the biological effects due to exposure to electromagnetic waves irradiated from the mobile phone.

Key words: Finite-difference-time-domain method, mobile phone radiation, thermal effect, dura tissue.

INTRODUCTION

In recent time, spread using of mobile phones has led some scientists and researchers to study the effects of electromagnetic waves produced from mobile phone base station and phone on human tissue. Most studies focus on the variation of the specific absorption rate (SAR), and power density which is considered to be a relevant parameter for quantifying the degree of absorption of the electromagnetic waves in living tissues. Several models have been proposed. Most of these models use the coupling of an electromagnetic model with a bioheat model. Our study focuses on electromagnetic-biothermal coupling model applied to the human head, taking into account the presence of cerebrospinal fluid (CSF), because its physical

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characteristics (either thermal or electromagnetic) are very different compared to other tissues within the head. The temperature within the human head subjected to electromagnetic waves of very high frequency has been evaluated [5, 10–12]. Also, the radiation characteristics of an ingestible wireless device in human intestine in different positions were investigated by Max [6] at operating frequencies ranging from 430 MHz to 2.4 GHz and applied input power of 25 mW. Reproductive function, and fetal development in animal systems have also been studied [4], where the reproductive parameters reported to be altered by electromagnetic radiation exposure include male germ cell death, the estrous cycle, reproductive endocrine hormones, reproductive organ weights, sperm motility, early embryonic development, pregnancy success protein misfolding, and DNA breaks. The effect of electromagnetic field (EMF) exposure on reproductive function differs according to frequency (energy), and duration of exposure. Wessapan *et al*. [13] realized a numerical analysis of specific absorption rate and heat transfer in the human body exposed to leakage electromagnetic field at 915 MHz and 2450 MHz.

Another study has evaluated the radio frequency radiation modeled as boundary value problem control by partial differential equations subject to initial boundary values. The spatial domain of the boundary value problem may be complicated in general, and the direct analytical solution has been estimated [8]. The study of a heterogeneous model for human tissue is a difficult theoretical task. Maxwell's equations are the basic equations to simulate human liver tissue by FDTD method [9]. Elwasife *et al*. [1] studied a model of nerve tissue as a layered system time-domain method. The electric field, the magnetic field, and the specific absorption rate have been also evaluated. The electric properties as conductivity, relative permittivity of nerve tissue are plotted with different frequencies. Human eye was modeled by studying the temperature distribution of three different laser radiations, using the finite element method [7]. In this work, the thermal effect of 1.8 GHz mobile phone radiation on dura tissue has been studied, using the finite-difference-time-domain method. Also, in this work, the electric and magnetic field are simulated.

THEORY AND MODEL

Many research studied the effect of electromagnetic radiation from a global system mobile on human body tissue. A simple model of an one dimensional one layer tissue is supposed in this work. The problem is to find the electric field E, the magnetic field H in the whole domain and the temperature T in the human dura tissue. Suppose that electromagnetic radiation a with frequency of 1.8 GHz is incident vertically upon the interface dura tissue with properties shown in Table 1 [15]. The heat sources arising from the electromagnetic wave are proportional to the square of the modulus of the electric field intensity, hence Maxwell's equations coupled with bioheat equation can be written as in previous work of Elwasife [2].

Table 1

Some properties of blood and dura tissue at 1.8 GHz

ρ (kg/m³)	**ρ$_b$ (kg/m³)**	***c*$_p$ (J/kg·K)**	***c*$_b$ (J/K)**	**σ (S/m)**	**μ$_b$ (N·s/m²)**	**ε**	***k* (W/m·K)**	**ω$_b$ (m³/s)**
1030	1060	1300	3960	1.3198	0.003	42.894	0.436	4.36×10^{-4}

where ρ is the density of the tissue, ρ_b is the density of blood, c_p is the specific heat of blood at constant pressure, c_b is the heat capacity of blood, σ is the electric conductivity of tissue, ε is the relative permittivity of tissue, μ_b is the dynamic viscosity of blood, k is the thermal conductivity of tissue, and ω_b is the mass flow rate of blood flow per unit volume.

A one dimensional finite-difference-time-domain method is used to solve Maxwell's equations and bioheat transient equation mathematically and by simulation in MATLAB program. A finite difference method was applied to the system of the partial differential equations to yield the following difference equations [8]:

$$\frac{\partial E}{\partial t} = -\frac{1}{\lambda_1}\frac{\partial H}{\partial z} - \frac{\lambda_2}{\lambda_1}E$$

$$\frac{E_x^{n+1/2}(k) - E_x^{n-1/2}(k)}{\Delta t} =$$

$$-\frac{1}{\lambda_1}\frac{H_y^n(k+1/2) - H_y^n(k-1/2)}{\Delta z} - \frac{\lambda_2}{\lambda_1}\frac{E_x^{n+1/2}(k) - E_x^{n-1/2}(k)}{2} \tag{1}$$

$$E_x^{n+1/2}(k) = \frac{1-\frac{\lambda_2\Delta t}{2\lambda_1}}{1+\frac{\lambda_2\Delta t}{2\lambda_1}}E_x^{n-1/2}(k) - \frac{\frac{\Delta t}{\Delta z\cdot\lambda_1}}{1+\frac{\lambda_2\Delta t}{2\lambda_1}}\left[H_y^n(k+1/2) - H_y^n(k-1/2)\right]$$

where E and H are electric and magnetic field strength, respectively, $\lambda_1 = \frac{v\varepsilon E_0}{LH_0}$, $\lambda_2 = \frac{L\sigma E_0}{H_0}$, $\lambda_3 = \frac{\mu_e H_0 v}{LE_0}$, E_0 is the electric field in the free space, H_0 is the magnetic field in free space, ν is the kinematic viscosity, μ_e is the magnetic permeability of free space and $n\Delta t$ reprezents the discretized time.

Similarly, the magnetic field becomes:

$$H_y^{n+1/2}(k) = H_y^{n-1/2}(k) + \frac{\Delta t}{\Delta z\cdot\lambda_3}\left[E_x^n(k-1/2) - E_x^n(k+1/2)\right] \tag{2}$$

And the bioheat equation was solved as:

$$T^{n+1/2}(k)=$$

$$\frac{\dfrac{-\Delta t}{p_{\mathrm{r}}\Delta z}}{1-\dfrac{\omega_1\rho_1 c_1}{2}+\dfrac{\lambda}{8}\left[E_x^{n+1/2}(k)-E_x^{n-1/2}(k)\right]}[T^n(k+1/2)-2T^n(k)+$$

$$+T^n(k-1/2)]-\omega_1\rho_1 c_1+\frac{\omega_1\rho_1 c_1}{2}-\frac{\lambda}{8}\left[E_x^{n+1/2}(k)-E_x^{n-1/2}(k)\right] \tag{3}$$

where T is the tissue temperature (°C), and p_{r} is the Prandtl number [14]. The parameters which we used in the software program to find the heat diffusion in dura tissue by simulation FDTD method are illustrated in the equations below:

$$\lambda=\frac{L^2 T_{\mathrm{b}}^{m-1}\left|E_0^2\right|}{v\rho c_{\mathrm{p}}},\ \lambda_3=\frac{v\mu_{\mathrm{e}}H_0}{LE_0},\ \rho_1=\frac{\rho_{\mathrm{b}}}{\rho},\ c_1=\frac{c_{\mathrm{b}}}{c_{\mathrm{p}}},\ \omega_1=\frac{\omega_{\mathrm{b}}L^2}{v},\ p_{\mathrm{r}}=\frac{c_{\mathrm{p}}\eta_{\mathrm{b}}}{k} \tag{4}$$

where T_{b} is the blood temperature (°C), and the tissue thickness is denoted by L.

RESULTS AND DISCUSSION

The dispersion relations in this model are denoted by equations (1, 2, and 3); they must be solved numerically to find the temperature as a function of time steps as appeared in figures below. A one-dimensional transient bioheat equation by finite difference model for predicting temperatures in living tissues such as dura tissue undergoing mobile phone radiation heating is presented. The electrical properties of human tissues vary at different temperatures due to the different water concentrations in tissues. Penne's perfusion term [16] is assumed to predict the effect of perfusion on heat transfer. Figure 1 shows the relation between the electric field in free space E_0 and the heat distribution in dura tissue. It is seen that the temperature distribution increases as E_0 increases. The thickness of the tissue differs from different people and different locations. In software program we considered time steps as 100,000 steps. In Figure 2, the curve is plotted to show the heat distribution at different magnetic field; the heat increased at decreasing magnetic field. The transient heat for different thickness is shown in Figure 3. For the electric and magnetic field, another MATLAB code program was used to calculate the dielectric properties of dura tissue at 1.8 GHz. The results are shown in Figures 5 and 6. According to the results evaluated in reference [3], the distribution of electric field in dura tissue is very small compared with another tissue, as a prostate tissue exposed to cellular phones radiation.

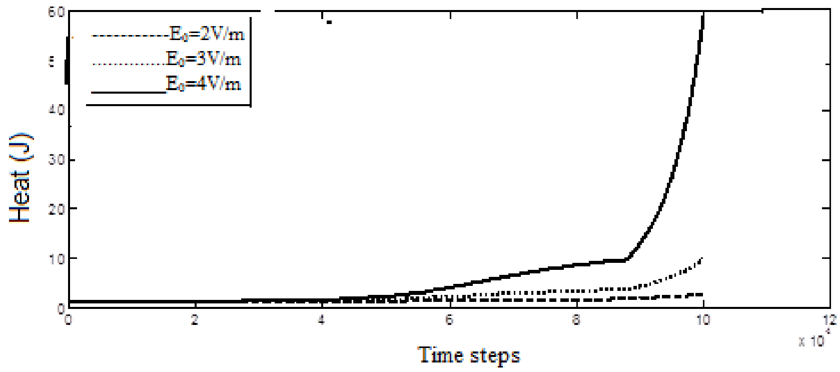

Fig. 1. The heat distribution plotted against time steps for different value of electric field; L = 0.002 m; the values of other parameters are those from Table 1.

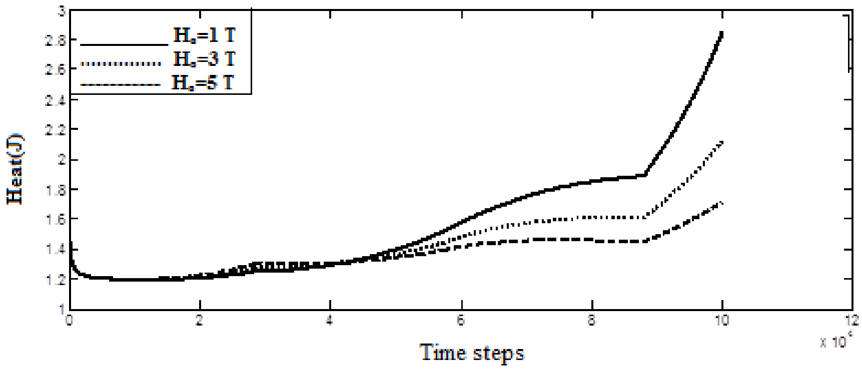

Fig. 2. The heat distribution plotted against time steps for different magnetic field; E_0 = 2 V/m; the values of other parameters are those from Table 1.

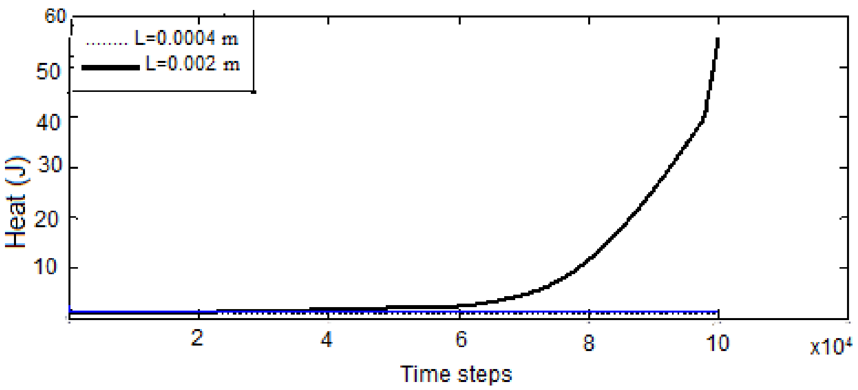

Fig. 3. The heat distribution plotted against time steps for different thickness; E_0 = 2 V/m; the values of other parameters are those from Table 1.

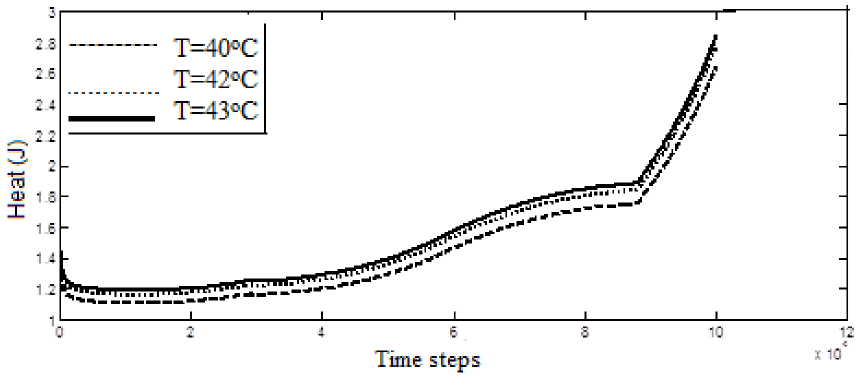

Fig. 4. The heat distribution plotted against against time steps for different values of temperature.

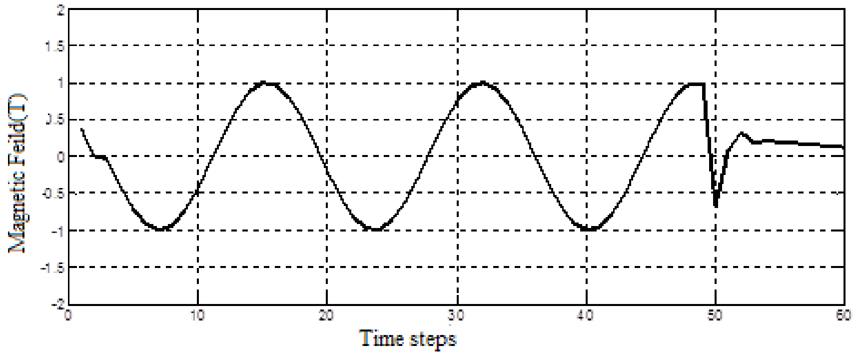

Fig. 5. Magnetic field simulation in human dura tissue; the values of ε, ω_b and σ are those indicated in Table 1.

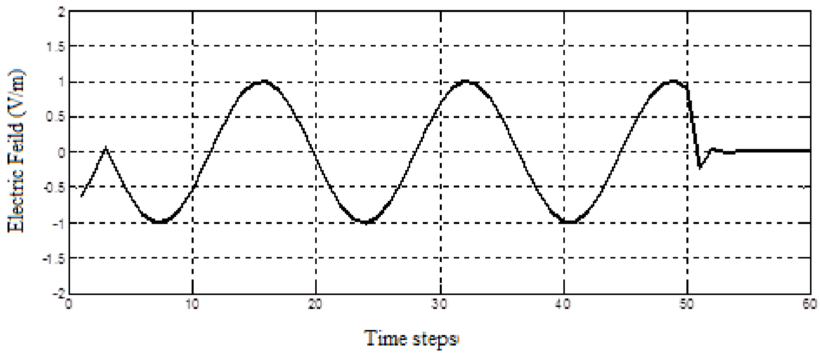

Fig. 6. Electric field simulation in human dura tissue; the values of ε, ω_b and σ are those indicated in Table 1.

CONCLUSION

According to varying radiation frequency, the dielectric properties of living tissue immediately change. The temperature distributions for different thermal properties of tissue have been illustrated using the numerical method as finite–time-domain method. Heat distribution, plotted against time steps for different value of magnetic and electric fields, shows that the temperature is incresead at high electric field and low magnetic field respectively. Also, this prediction of the temperature evolution in biological bodies can be used as an effective model by FDTD method. This prediction of the temperature evolution in biological bodies can be used as an effective tool for thermal diagnostics in medical practices, and its applications could have a great benefit in various branches, especially in cancer therapy using microwave devices. Also, the results and applications of this work are important in biological radiation effect on living tissue, and one of reason to cause health problems like cancer. From the curves we observe that when the radiation of the electromagnetic waves enters the living cells, their amplitude is reduced, indicating that the tissue absorbs the electromagnetic radiation. According to the proposed model, the effect of the mobile phone radiation is increased by exposure for a long time, depending on the resulting heat exposure as shown in the figures. Also, long-term exposure to an electromagnetic radiation, causes a high heat, which effects the functions of the tissue, as in line with the previous studies.

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