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# Simulation of SAR and temperature distributions in 3D model of the human head exposed to mobile phone radiation at 900 MHz

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**Abstract:** In this study, using the finite element method via comsol multiphysics software package, specific absorption rate (SAR) distributions andtemperature increase are simulated in 3D human head model exposed to the field radiated from cellular phonewhich consists of square patch antenna. Both Maxwell and bioheat equations with suitable boundary conditions are solved to find SAR and temperature distributions. The maximum log scale of SAR calculated was of the 0.6 while the maximum temperature increase was 0.3 $^{o}$C for 900 MHz from the antenna**.**

## Introduction

As a result of the significant increase in portable phones use in recent years it has become the subject of research and studies.These studies indicated apotential health hazards owing to the absorption of radio frequency (RF) radiation emitted by portable telephones. RF waves emitted by these mobiles have been linked to brain cancer, salivary gland tumors, behavioral problems, and migraines. These risks have been shown to be higher in people who have used cell phones for at least ten years [1]. However, studies on brain cancer cast doubt on these results since it is difficult to accurately assess risk factors in humans [2].

It is broadly accepted that mobile phones cause heating of the human organ exposed to their radiation and specifically the human head. The current exposure limits are based on Specific Absorption Rate (SAR) of the exposure heat. The SAR parameter has been widely used to determine the possibility of health hazards Most previous studies of human exposure to electromagnetic field were limited with in the human head because of radio frequency (RF) radiation [3, 4]. A SAR limit of 2W/kg averaged over any contiguous 10 g head tissue was recommended by the Council of European Union [5] for the general public.Some significant thermal damage can occur in sensitive organs under conditions of partial body exposure to RF electromagnetic waves. Mobile phones are electromagnetic radiation devices, which may be harmful to human health from their radiation. Thus, it is interesting to analyze the heat transfer in the human head due to electromagnetic wave exposures.In accordance with the development of the computer and numerical analysis techniques, an anatomical human head model can be incorporated into simulated studies. Recently, the modeling of heat transport in human tissue has been investigated. Pennesbioheat equation, introduced by Pennes [6] based on the heat diffusion equation, is frequently used for analysis of heat transfer in human tissues.
respect to the electric field and SAR distribution. Nevertheless, they have not

been considering heat transfer in their model during exposure to electromagnetic fields. That leads to an incomplete analysis. Therefore, to approach reality, modeling of this work, it prefers a real link between the heat transfer and electromagnetic radiation. Therefore, in order to provide information on levels of exposure and health effects from mobile phone radiation, it is important to simulate both electromagnetic field and heat transfer within an anatomically based humanhead model to represent actual processes of heat transfer within the human head. In this study, a three-dimensional human head model was used to simulate the SAR distribution and the temperature distribution over the human head. The 900 MHz frequency was chosen for the simulations in this study, as it is used frequently in the areas of cell phone usage.

The human head geometry is the same geometry (SAM Phantom) provided by IEEE, IEC, and CENELEC from their standard specification of SAR value measurements. Geometrical data file was created from a magnetic-resonance image (MRI) of a human head; these images contain 109 slices, each with 256-by-256 voxels (7). The model comprises four types of tissue including skin, fat, skull, and brain. These tissues have different dielectric and thermal properties (8, 9). Finite element method (FEM) via COMSOL$^{TM}$ MULTIPHYSICS version 5.1 carries out this study.In this study, a square patch antenna is considered as a source of electromagnetic radiations and is placed at the left side of the head model at a distance of one cm. Figure 1 shows a three-dimensional finite element mesh of the human head model exposed to radiations from a mobile phone which consists of square patch antenna.

## Methods and models

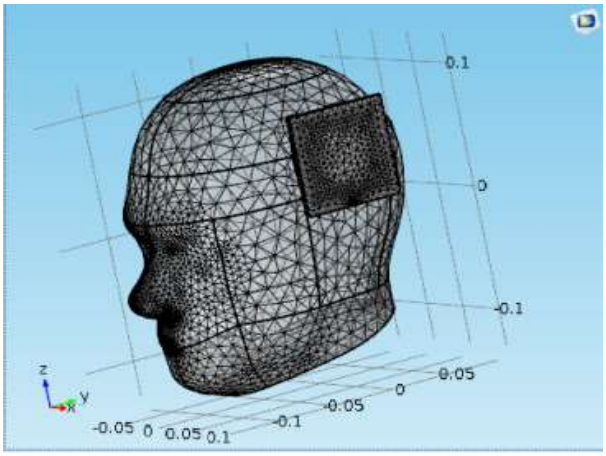


**Fig. 1:** A three-dimensional finite element mesh of human head model with square patch antenna

### *Mathematical modeling*

*Governing equation of electromagnetic wave propagation:* Mathematical models are developed to predict the electric field and SAR with relation to temperature gradients within the human head. The electromagnetic wave propagation in a human head is calculated using Maxwell's equations [10, 11]. The general form of Maxwell's equations is simplified to illustrate the electromagnetic field penetrated in human head as the following equation:

$$\nabla \times \frac{1}{\mu_r} \nabla \times E - k_o^2 \varepsilon_r E = 0 \quad (1)$$

where E is electric field intensity (V/m), $\mu_r$ is relative magnetic permeability, $\varepsilon_r$ is relative dielectric constant, and $k_0$ is the free space wave number ($m^{-1}$).

*Boundary condition of wave propagation:*
As the electromagnetic energy is emitted from the patch antenna and interact with the human head with a particular radiated power. The lumped port is used to define a voltage drop in microstrip patch antenna. Therefore, the boundary condition for solving electromagnetic wave propagation, is described as shown in Figure 2.

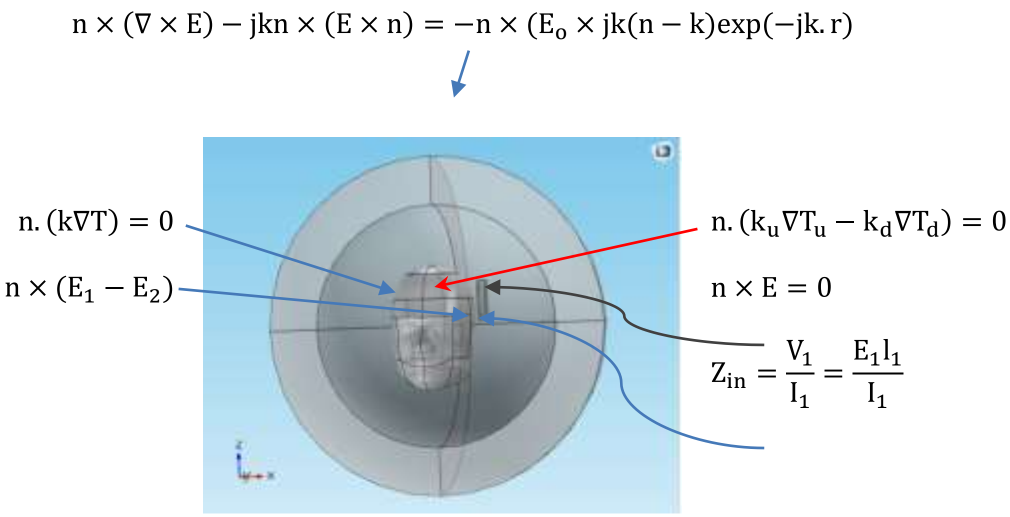


**Fig. 2:** Boundary condition for electromagnetic wave propagation and heat transfer at the bottom of the patch antenna, an electromagnetic simulator employs lumped port boundary condition with specified radiated power

$$Z_{in} = \frac{V_1}{I_1} = \frac{E_1 l_1}{I_1} \quad (2)$$

Where $Z_{in}$ is the input impedance (Ω), $V_1$ is the voltage along the edges (V), $I_1$ is the electric current magnitude (A), $E_1$ is the electric field along the source edge (V/m), and $l_1$ is the edge length (m). The perfect-electric-conductor boundary condition along the patches on the antenna is considered

$$n \times E = 0 \quad (3)$$

Boundary conditions along the interfaces between different mediums, for example, between air and tissue or tissue and tissue, are considered as continuity boundary conditions

$$n \times (E_1 - E_2) \quad (4)$$

The outer sides of the calculated domain, i.e., free space, are considered as scattering boundary conditions [10]

$$n \times (\nabla \times E) - jkn \times (E \times n) = -n \times (E_o \times jk(n-k)\exp(-jk.r) \; ..... (5)$$

where k is the wave number ($m^{-1}$), σ is the electric conductivity (S/m), n is the normal vector, j = $\sqrt{-1}$ and $E_o$ is the incident plane wave (V/m).

*Equation of heat transfer:* The temperature distribution within the human head is obtained by solving Pennes' bioheat equation [10,12], the equation can be written as

$$\rho C \frac{\partial T}{\partial t} = \nabla.(k\nabla T) + \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ext} \; ........................ (6)$$

where ρ is the tissue density ($kg/m^3$), C is the heat capacity of tissue (J/kg K), k is the thermal conductivity of tissue (W/m K), T isthe tissue temperature (°C), Tb is the temperature of blood (° C),$\rho_b$ is the density of blood (kg/m ), $C_b$ is the heat capacity of blood(3960 J/kg K), $\omega_b$ is the blood perfusion rate (1/s), $Q_{met}$ is the metabolism heat source ($W/m^3$), and $Q_{ext}$ is the external heat source(electromagnetic heat-source density) (W/m ). The heat conduction between tissue and blood flow is approximated by the blood perfusion term, $\rho_b C_b \omega_b (T_b\text{-}T)$. The external heat source term is equal to the resistive heat generated by the electromagnetic field (electromagnetic power absorbed), which is defined as [10].

$$Q_{ext} = \frac{1}{2}\sigma_{tissue}|E|^2 = \frac{\rho}{2}.SAR \; ...................................................... (7)$$

Where σtissue = $2\pi f \varepsilon_r' \varepsilon o$. Where SAR is the energy of electromagnetic wave propagation absorbed by the tissue. The specific absorption rate is defined as power dissipation rate normalized by material density [10, 13]. The specific absorption rate is given by

$$SAR = \frac{\sigma}{\rho}|E|^2 \; ......................................................................... (8)$$

*Boundary condition of heat transfer*: Heat transfer is considered only in the human head, which does not include parts of the surrounding space. As shown in Fig. 2, the outer surface of the human head corresponding to assumption (3) is considered to be a thermally insulated boundary condition

$$n.(k\nabla T) = 0 \; ......................................................................... (9)$$

It is assumed that no contact resistant occurs between the internal organs of the human head. Therefore, the internal boundaries are assumed to be a continuous

$$n.(k_u \nabla T_u - k_d \nabla T_d) = 0 \; ......................................................... (10)$$

## Results and discussion

In this study, the mathematical model of bio heat transfer and electromagnetic wave propagation performed for a mobile phone consisting of a patch antenna radiating maximum 1W power at 900 MHz.. For the simulation, the dielectric and thermal properties are directly taken from [8, 9], respectively. The exposed radiated power used in this study refers to ICNIRPstandard for safety level at the maximum SAR value of 2 W/kg [20].

*SAR Distribution*: The results of the simulations performed with COMSOL$^{TM}$ MULTIPHYSICS are shown in Figs. 3-5. It has been shown in Fig. 3, the maximum amount of SAR locates on the ear region and also it has the value of (0.603-0.654) W/kg. It is obvious that the regions near the antenna have the largest SAR values and by keeping away from these regions the SAR values diminish.Figure (4) show the distributions of the local SAR, at the y=0 plane; in xz plane in (W/kg), on the human head. It is evident from these results that the dielectric properties, [8, 9], become significant to SAR distributions in human tissue when electromagnetic energy is exposed in these tissues. The magnitude of dielectric properties in each tissue will directly affect the amount of SAR within the human head. Comparing these results to the ICNIRP limit of SAR value (2W/kg), one sees that the resulting SAR from this study does not exceed the limit value.

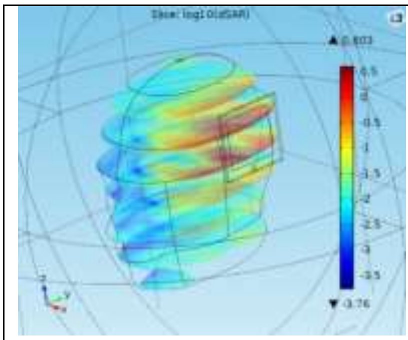
Fig.3 Log scale of the SAR distribution in brain region of human head model at 900 MHz.

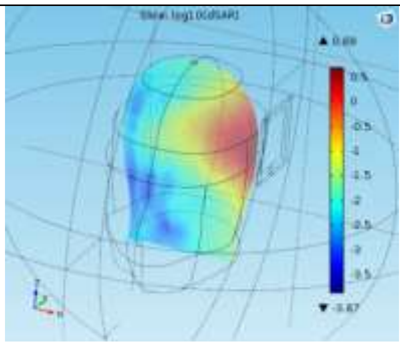
Fig.4 Log scale of the SAR distribution in brain region of human head model at xz plane for 900 MHz

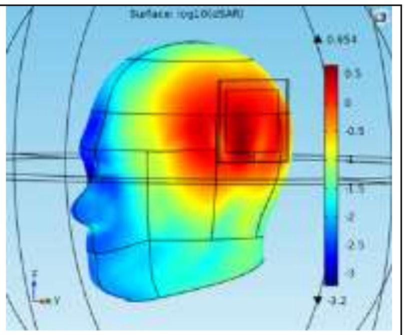
Fig.5 Log scale of the SAR distribution over surface of human head model at xz plane for 900 MHz.

*Temperature distribution:* Electromagnetic wave propagation and unsteady bioheat transfer are coupled together to study the heat transfer within the human head. Due to these coupled effects, the electric field distribution in the headisconverted into heat by absorption of the tissues. Simulations to obtain the temperature distributions using 900 MHz aredepicted in Figures 6-8.

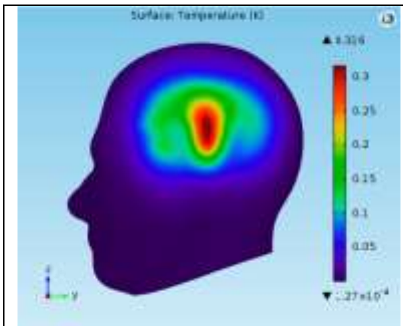
Fig. 6 The local temperature distribution in brain region of human head model at 900MHz.

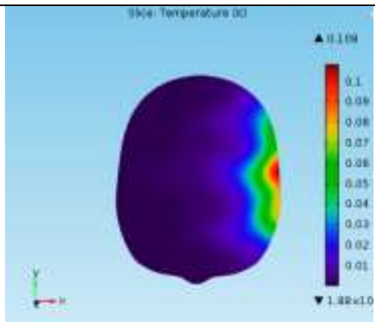
Fig.7Top view of the local temperature distribution in brain region of human head model at 900 MHz.

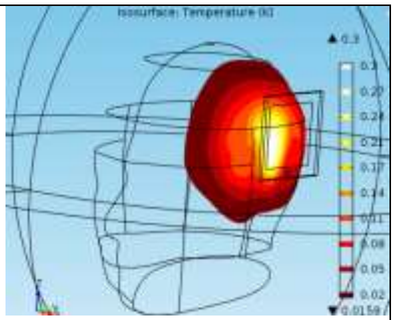
Fig.8 Isothermal contours of the temperature profile of the whole head at 900 MHz.

The temperature is highest closest to the antenna. The maximum temperature increase from 37 °C is approximately 0.3 °C, and drops rapidly inside the head. The obtained results confirm the importance of performing a thermal analysis together with the dosimetric one. SAR levels in the tissues are less than the safety limit recommendations [3 ,5, 15]. However, it is found that the induced temperature elevation in the brain, in all the examined conditions, never exceeds 0.4 °C. The obtained results were very close to those presented in the literature using more sophisticated models [10, 12].

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