Analysis of specific absorption rate of electromagnetic field, generated by smartphone

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Abstract: *This article analyses the Specific Absorption Rate (SAR) and outlines the thermal effect in depth of the human head. SAR is the most important dosimetric value when the human body is irradiated with signals in the radio frequency range. For this purpose, a computer model is created using COMSOL Multiphysics software, taking into account the specific characteristics of the human head and the parameters of a working smartphone. This model is suitable for studying the effects of radio waves on humans.*

Keywords: *Specific Absorption Rate, computer model, thermal effect*

1. Introduction

Creating a model to study the process of absorbing electromagnetic energy, emitted by a mobile phone and the subsequent thermal effect in the human body, is crucial in analyzing the effects, caused by the use of wireless smart devices. The purpose of the model is to facilitate the research and understanding of the processes leading to an increase in the temperature of the human head as a result of the absorbed radiation, emitted by a mobile device [1].

Biophysical effects such as tissue heating and nervous stimulation of the body by strong electromagnetic fields are well-known to scientists, as radio frequency radiation is not ionizing and therefore cannot directly cause damage to human DNA [2], [3]. According to researchers, the most significant effect of radio waves is the heating of the tissues of the human head. Harmful thermal effects cause cataract, but there are also non-thermal effects that are controversial [4]. It should be noted that not all biological effects necessarily lead to negative consequences on human biophysical conditions.

In addition to the characteristics of the electromagnetic fields, the thermophysiological processes of the human body and the parameters of the environment such as the specific heat capacity of the tissues, the cooling of the blood circulation and the ambient temperature should be taken into account. The aim of the present study is to create a computer model of the Specific Absorption Rate of the electromagnetic field, generated by a working mobile phone. Its verification will be carried out through author's experimental research, done via thermal images from a thermal imaging camera and electroencephalogram – EEG.

2. Specific Absorption Rate

As already mentioned, SAR is a characteristic that describes the absorption of the power of the electromagnetic field that propagates in different types of tissues [5]. Local SAR is defined as the loss of power dP_1, absorbed in an infinitesimally small mass dm, and can be described by the following equation:

$$SAR = \frac{dP_1}{dm} = \frac{\sigma_{eff} E_{rms}^2}{\rho} = \frac{J_{rms}^2}{\rho \sigma_{eff}} \quad (1)$$

where E_{rms} and J_{rms} are the root mean square values of the electric field strength and the density of electricity, respectively σ_{eff} is the effective conductivity of human brain tissue and ρ is the tissue density. As it is known, the energy from the electromagnetic fields in the radio range is absorbed into the tissue of the human body and transformed into heat. This leads to another definition of SAR, namely:

$$SAR = c_p \frac{\Delta T}{\Delta t} \quad (2)$$

where c_p is the specific heat capacity of the tissue and ΔT is the change in temperature over a period of time Δt.

A distinction between the instantaneous SAR and the permissible SAR should be made, where an average value is measured for a given mass of tissue and a specified period of time.

The increase of the temperature can be estimated by the equation [5]:

$$\Delta T = \frac{SAR\tau}{c_p}\left(1 - e^{-t/\tau}\right) \quad (3)$$

where τ is the thermal time constant. The created computer model examines the interaction of heat transfer between tissues due to the presence of two heat sources. It does not take into account the influence of vascular geometry on heat transfer.

3. Computer model of SAR

The created model is a combination of a model of a human head and a model of an antenna built into a mobile phone. The human head pattern includes layers of varying thickness, skin, skull, and brain tissue patterns. This model allows to simulate the processes of penetration and absorption of electromagnetic energy from the tissues of the head, as well as to observe the thermal processes, caused by high-frequency fields. The characteristics of the human head and the parameters of the biological tissues, used in the model, are as close as possible to the real ones.

The design and geometry of the human head are provided by the IEEE, and the model was imported into the COMSOL Multiphysics software from a file named sar_in_human_head.mphbin (Fig. 1).

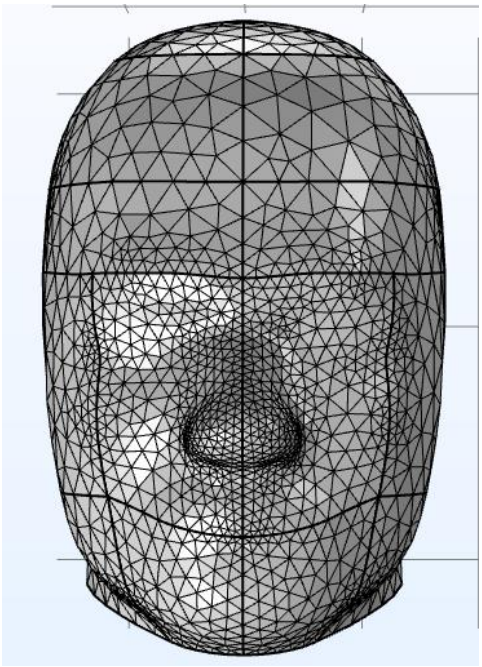

Fig. 1. *Human head model*

The source of electromagnetic radiation is a model of a mobile phone that was added manually (Fig. 2). The electromagnetic parameters of the biological tissues of the human head are modelled

using an interpolation function that applies the characteristics of a particular tissue inside the human head.

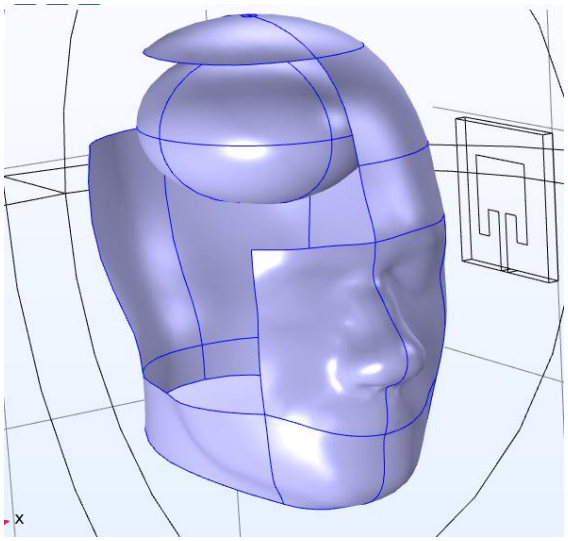

Fig. 2. *Human head model and GSM*

The output data for this function is directly taken from a system file that is created using multiple magnetic resonance images of human head sections. The model is obtained from 109 images, each with a size of 256 by 256 pixels. The sar_in_human_head_interp.txt system file can also be used to visualize the dielectric permittivity and perfusion inside the head.

The pattern of propagation of the electromagnetic field is simulated by a mobile phone, located one centimeter on the left side of the human head (Fig. 2). The distribution of the strength of the electric field E is obtained by solving the equation [6]:

$$\nabla \times \frac{1}{\mu_r} \nabla \times E - k_0^2 \varepsilon_r E = 0 \qquad (4)$$

where μ_r is the relative permeability, k_0 is a wave vector and ε_r is the permittivity of the tissues.

The depth of penetration of the electric field into the biological tissue of the human head depends on the frequency of electromagnetic waves and is determined by the formula:

$$\delta = \frac{1}{\omega} \left(\frac{\varepsilon_r \mu_r}{2} \left(\sqrt{1 + \frac{\sigma_{eff}^2}{\omega^2 \sigma_r^2}} - 1 \right) \right)^{-1/2} \qquad (5)$$

At the frequency of the electromagnetic field at $f = 900\,MHz$ the depth of penetration for different tissues of the human body is shown in Table 1.

Table 1. Depth of penetration of the electromagnetic field

Tissue	Skin	Fat	Muscle	Skull	Brain
$\delta[mm]$	40.2	164.5	42.3	131.8	47.5

4. Results

The simulation of the created computer model in the environment of COMSOL Multiphysics allows to estimate SAR on any shape and tissue of the human body. The local SAR value in a human head at an electromagnetic field frequency of 900 MHz is demonstrated in Fig. 3. When a human head is irradiated with an electromagnetic wave, it penetrates the tissue and gives part of its energy to the head or the wave is absorbed into the head tissue. Electromagnetic energy affects the particles in the tissue due to the electrical and magnetic components of the electromagnetic field. SAR values are higher in the surface layers of the human head.

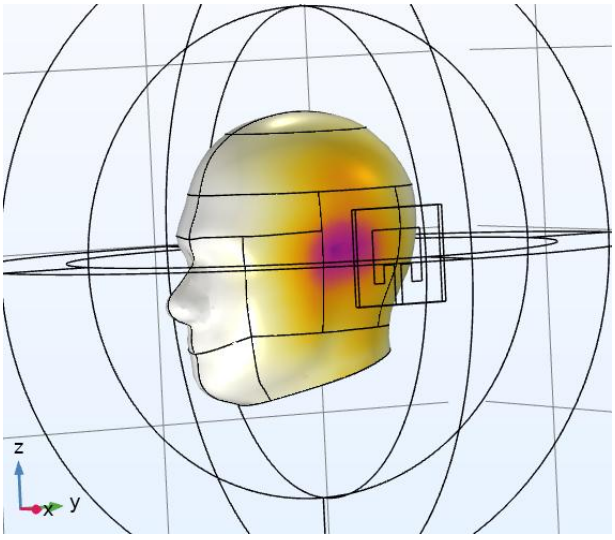

Fig. 3. *Human head SAR model*

The created computer model calculates only the local value of the SAR parameter. The maximum value of the local SAR is always higher than the maximum value of the average SAR value.

The propagation of electromagnetic waves in biological tissues takes the form of absorbed energy. Most of the absorbed energy is converted into heat, which leads to an increase in temperature in biological tissues. The thermal effect, obtained from electromagnetic radiation of a mobile phone, is most pronounced on the surface of the head skin (most often the area of a person's ear) [2]. The increase in temperature depends on the physiological properties of the tissues (blood perfusion) and can be calculated using a biothermal equation that takes into account heat loss due to blood circulation in the human body. The thermal effect on and in the human head for a frequency of 900 MHz is shown in Fig. 4.

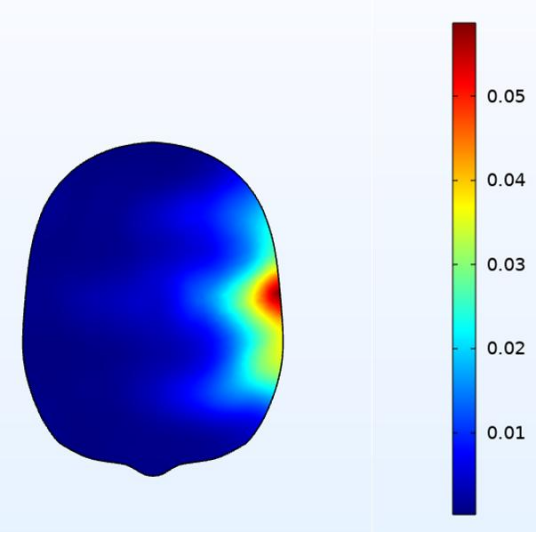

Fig. 4. *Thermal effect in the depth of the head*

It can be seen that the temperature is highest in the area near the source of electromagnetic radiation, where the mobile phone is positioned. The temperature of the brain tissue rises about 0.6°C and decreases inside the head. The validity of this computer model was experimentally confirmed using a thermal imaging camera and EEG. The results of the experiment for the distribution of the temperature on the surface of the head after using a mobile phone are outlined in Fig. 5.

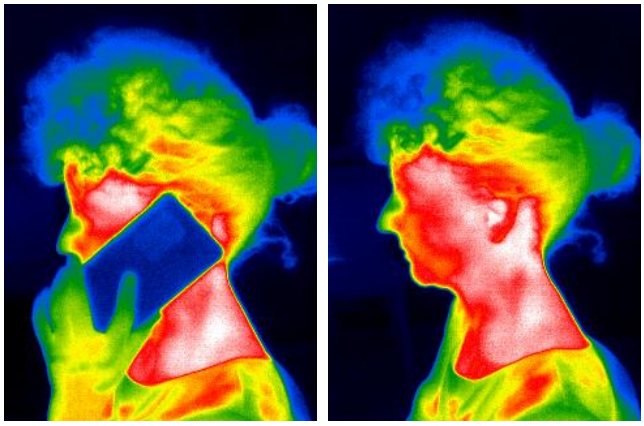

Fig. 5. *Temperature distribution at the surface after 15-minute phone call*

Temperature distribution at the surface of human head is in correlation with ambient temperature while the temperature inside biological tissues does not depend on it. It is interesting to know that the microwave change in the temperature of the human head can lead to an increase in the temperature of the hypothalamus (Fig. 6) by about 0.2-0.3°C, which may cause health problems [7].

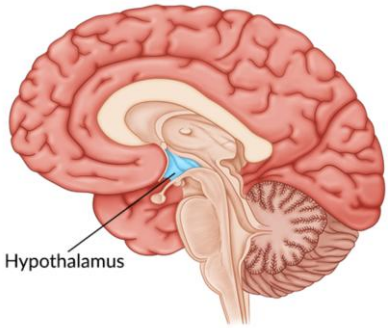

Fig. 6. *Hypothalamus*

The hypothalamus has some basic functions such as controlling body temperature, hunger, thirst, libido, heart rate, releasing hormones from the pituitary gland, producing digestive juices, balancing body fluids, etc. As the body's various systems send signals to the brain, they alert the hypothalamus to any imbalances. As a result, the hypothalamus responds by releasing the right hormones to balance the body.

The influence of mobile phone exposure on the nervous response was studied in [8], [9] by analysing electrophysiological measurements of brain wave activity. EEG test measurements were taken in two situations when the participant was not using and when using a mobile phone (Fig. 7).

A series of paired samples t-test analysis on spectral power, conducted over the EEG spectral band delta – δ (2-4 Hz), theta – θ (4-8 Hz), alpha – α (8-13 Hz), and beta – β (13-32 Hz) for all points was applied. The results with p-values less than 0.05 indicate statistically significant differences in EEG power in T3 (θ, α, and β), T5 (θ and α), and F7 (θ and α) points as shown in Fig. 8.

In the points, which are in the immediate vicinity of the GSM device with highest absorption of the electromagnetic field, a significant change of the signal spectrum is observed (Fig. 8), as revealed our previous research [8], [9], [10].

Fig. 7. *A participant during the experimental procedure*

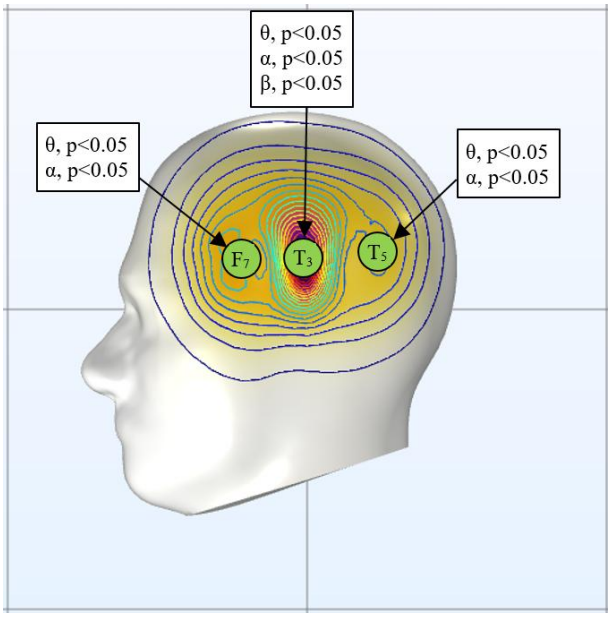

Fig. 8. *SAR model and points of change in human brain activity*

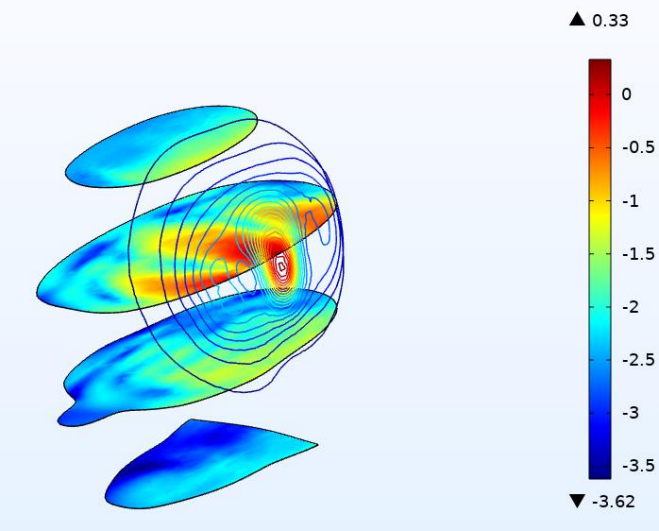

Fig. 9. *Distribution of SAR in the human head*

A section of the head at the level of maximum absorption (Fig. 9) shows coincidence of the sites of change in brain activity with the maximum SAR levels. The change in brain activity due to prolonged use of a mobile phone is a prerequisite for loss of concentration, memory problems, feelings of fatigue, anxiety, and intense affective states [11], [12].

5. Conclusion

This article examines the Specific Absorption Rate (SAR), as well as the thermal effect, caused by the use of a mobile phone. The study is conducted using a computer model via COMSOL Multiphysics software, which takes into account the specific characteristics of the human head and the parameters of a mobile phone. The advantage of the simulation compared to the thermal imaging camera is possibility to analyse temperature distribution through head and inside biological tissues. The validity of the created computer model is confirmed by a series of experimental studies using thermal images and EEG.

The results of research show that the temperature to which the tissues of the head are heated depends on the amount of energy, absorbed by the human head. The resulting high SAR values on the skin surface are not biologically hazardous, as peripheral blood circulation and thermal conductivity to the environment effectively cool the skin. More worrying is the fact that prolonged use of a mobile phone leads to a change in the brain activity of the user. Our future research efforts are oriented towards creating a comprehensive model for studying the risk factors of excessive use of smart technologies among children and adults.

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