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Temperature distribution and Specific Absorption Rate inside a child's head

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ABSTRACT

This paper represents the numerical analysis of Specific Absorption Rate (SAR) and temperature distribution within a real child head model exposed to mobile phone radiation at the frequency of $f = 900$ MHz. In this research the SAR and temperature distribution are obtained by numerical solutions of the equation of electromagnetic waves propagation and by bioheat equation, respectively, and are shown inside different biological tissues and organs during exposure to electromagnetic radiation from a mobile phone. As electromagnetic properties of tissues depend on the electromagnetic waves frequency, the value of SAR and temperature will be different for different tissues and organs. The maximum absorption of electromagnetic energy is in the surface layers of the model, whereby this value is greater than the maximum allowed value defined by standards. Furthermore, the increase in temperature is the highest in those biological tissues and organs that are closest to the source of radiation i.e. a mobile phone. Moving away from a mobile phone, the temperature decreases, but more slowly than the SAR values. In the analysis of the temperature rise resulting from tissues and organs heating due to the effects of electromagnetic fields on a child's head, special attention will be given to the maximum temperature increase in the brain.

1. Introduction

It is fair to say that we are currently living in a world of technology. The need for mobility and the accessibility of different content ranging from information to entertainment created a new world, the world of mobile communications. In order to respond to the needs of today's users, manufacturers of mobile devices combined the requirements of communication with the sharing of different content offering all that in a single device. Mobile phones have progressed significantly, from ordinary devices, which were used only for voice transfer, to smartphones, which have become a part of our everyday life because of their capabilities. The expansion of social networks and the availability of video and audio material brought mobile phones closer to the youngest population.

This massive use of mobile phones has aroused significant public concern about possible health consequences due to the impact of electromagnetic radiation from mobile phones. Based on numerous studies, the safety measures that prescribe the maximum allowable levels for exposure to electromagnetic fields embedded in safety standards have been adopted [1,2]. Even the International Agency for Cancer Research (IARC) has characterized the electromagnetic field as potentially carcinogenic to humans and classified it as a group 2B carcinogen [3].

However, most studies dealing with the influence of electromagnetic radiation from mobile phones are focused on determining the absorbed energy in the standard models of adult head [4,5]. Likewise, the international security standards and guidelines about the limits of exposure to electromagnetic fields are developed based on research conducted only on adults. Regardless of the fact that each standard contains specific safety limits, it should be determined whether they are also sufficiently valid in case of children.

Therefore, this study includes the comparison of the results obtained in the case of adults with the results obtained in the case of children, because of the differences in their anatomy. The essential difference between the different effect of electromagnetic radiation on adults and children is the difference in size and shape of the head as well as the dimensions of the tissue. The dimensions of a child head are smaller compared with an adult's head, so the biological tissues are thinner. It can therefore be expected that the penetration depth of electromagnetic waves will be more pronounced in the case of a child [6–14].

Assessment of the effects of exposure to mobile phone radiation is based on the determination of the internal induced electromagnetic fields and absorption of electromagnetic energy, which

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results in an increase of temperature in the human head. In addition to the operating frequency and the distance between the electromagnetic source and the exposed object, the shape of the anatomical human head model and its features also play an important role in the absorption of electromagnetic energy.

Probably the best way to understand the electromagnetic effects on the body is to study thermal interaction with the body. Assessment of exposure to mobile phone radiation is based on determining the electromagnetic field penetration within the head and its distribution, as well as the energy absorbed, which results in an increase of temperature of biological tissues and organs within the human head.

The aim of this study is the determination of the absorbed energy distribution and the temperature of the anatomical child head model exposed to mobile phone radiation at the frequency of $f = 900$ MHz.

2. Numerical method and modeling

2.1. Model

In order to determine the impact of mobile phone radiation on the user's head, we developed a real model of the child head. Anatomical characteristics of this model correspond to a child aged 7 (Fig. 1) [15–17]. The cross-section of the child head model with biological tissues and organs (Table 1) is shown in Fig. 2. Numerical designations for tissues and organs from Fig. 2 correspond to the numerical designations of tissues and organs shown in Table 1.

Each biological organ and tissue in the child head model should be defined by appropriate electromagnetic characteristics. Detailed knowledge of the electromagnetic characteristics of biological tissues and organs (permittivity, conductivity, and permeability) is essential for the understanding of the interaction between electromagnetic radiation and the body because the effects of propagation, reflection, and attenuation of electromagnetic waves in the body depend on these electromagnetic characteristics. The main electromagnetic parameters of biological tissues and organs are given in Table 1 [18].

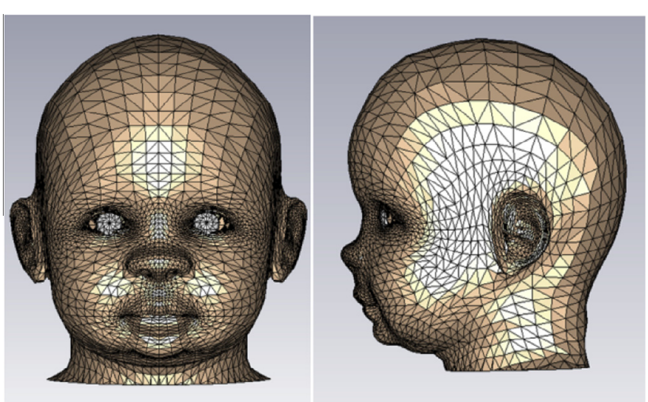

Fig. 1. External appearance of the child head model.

In order to create a detailed numerical model of the child head with the correct associated electromagnetic properties of biological tissues and organs and to determine the spatial distribution of the electromagnetic field within the model, which originates from a mobile phone, we used the CST software package [19], which is based on the FIT (Finite Integration Theory) method [20].

When using CST analysis software, the key step before any computation is to create the mesh of elements. A finer mesh means a greater number of elements and, consequently, more accurate results. On the other hand, a finer mesh demands more powerful hardware and more computational time. Therefore, it can be concluded that it is essential to find the proper balance between result accuracy and time. For the analysis presented in this paper, we selected a hexahedral type of mesh. The model consists of 1,500,000 mesh cells, while fine adjustments in maximum and minimum element dimensions were necessary for each domain (biological organs and tissues).

In order to define the independence of the appropriate number of required mesh elements, it is necessary to perform the test of convergence. In Fig. 3, the curve of convergence process is shown. Based on the illustration shown in Fig. 3, it can be seen that a sufficient number of mesh cells is 1,500,000. It can be assumed that with this number of elements the accuracy of the numerical results is independent of the number of mesh elements, which is why the 3D child head model contains this many mesh cells.

For the electromagnetic field source, we designed a mobile phone, whose features correspond to an actual smartphone model (Fig. 4). The mobile phone is designed to contain the following parts: planar inverted F antenna (PIFA), the display, and the mobile housing. The planar inverted F antenna (PIFA), as a source of electromagnetic radiation, was modeled for the frequency of $f = 900$ MHz, with output power of $P = 1$ W [21] and impedance of $Z = 50\ \Omega$.

2.2. SAR calculation

When the electromagnetic wave spreads through the human tissue, the tissue absorbs the energy of electromagnetic waves. The interaction of electromagnetic waves with biological tissues can be defined as the Specific Absorption Rate (SAR). SAR is defined as the speed of power dissipation normalized by density of the material, and it can be described by the following equation [22]:

$$\mathrm{SAR} = \frac{\sigma}{\rho}|E|^2, \tag{1}$$

Table 1
Electromagnetic properties of tissues and organs at $f = 900$ MHz.

900 MHZ		ε_r	σ (S m^{-1})	ρ (kg m^{-3})
1.	Cortical bones	12.45	0.143	1908
2.	Brain	45.805	0.7665	1046
3.	Cerebrospinal fluid	68.60	2.410	1007
4.	Fat	11.30	0.109	911
5.	Cartilage	42.70	0.782	1100
6.	Pituitary gland	59.70	1.040	1053
7.	spinal cord	32.50	0.574	1075
8.	Muscle	55.00	0.943	1090
9.	Eyes	49.60	0.994	1052
10.	Skin	41.40	0.867	1109
11.	Tongue	55.30	0.936	1090
12.	Teeth	12.50	0.143	2180