EXPERIMENTAL AND NUMERICAL ASSESSMENT OF TISSUE TEMPERATURE ELEVATION DUE TO MOBILE PHONE USE

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Abstract

The electromagnetic and thermal exposure of users to commercially available mobile phones, operating at GSM 900 MHz and DCS 1800 MHz are studied. Simulated data, using Finite Difference Time Domain Method and Bio-heat Equation, are combined with non invasive temperature elevation measurements in healthy adult volunteers, using a prototype Microwave Radiometry-based Imaging System (MiRaIS). Specific Absorption Rate (SAR) and temperature elevation (ΔT) are computed in a three layered spherical head model, radiated by a linear dipole and a generic phone, at both frequencies. The maximum peak temperature increase due to electromagnetic power absorption is 0.402^{0}C, computed in skin for the case of linear dipole operated at 1800 MHz, placed at d_1 = 2 mm, in room temperature of 30^{0}C. Radiometry measurements concluded to temperature increase of 0.8-1^{0}C.

1. INTRODUCTION

Mobile phone use has dramatically increased over the last decade, but doubts remain over its safety. One of the many electromagnetic field induced effects on tissues is the tangible temperature elevation. According to epidemiological investigations, mobile phone users report symptoms of discomfort feeling, warmth behind/around or on the ear and heat sensation of the cheek [1]. The heat sensation may be due to power absorption by the tissues, thermal insulation and phone battery currents. Obviously, the symptoms become intense, as the duration of mobile phone use increases.

This study assesses numerically and experimentally the tissue temperature elevation, combined with the electromagnetic absorbed power, due to mobile phone usage. A preliminary numerical computation of the electromagnetic absorbed power and the thermal distribution in tissues is combined with measurements of temperature elevation in healthy adult volunteers, using a radiometry experimental set-up.

2. MATERIALS AND METHODS

2.1. Simulation

In order to numerically assess the absorbed power and the temperature elevation in biological tissue, electromagnetic [2] and thermodynamic [3] computations are respectively conducted. A three layered spherical adult head model is considered, consisting of skin, skull (cortical bone) and brain (grey matter) tissue. Head diameter is 20 cm, while the thicknesses of the skin and skull layers are both assumed to be 0.5 cm [4]. Head model is radiated by (a) a $\lambda_0/2$ linear dipole and (b) a generic phone [5] operating at GSM f_0 = 900 MHz and DCS f_0 = 1800 MHz. The linear dipole is placed at distance d_1 = 2 mm (feed point at (3,0,0)) and d_2 = 10.5 mm from the spherical surface, while the plastic cover of the generic phone is placed in touch with the sphere resulting to distance d = 10.5 mm between antenna feed point and head surface. The Finite Difference Time Domain (FDTD)-based platform SEMCAD-X (SPEAG, Zurich) is used. Both electromagnetic and thermodynamic computations are carried out with the same FDTD grid (up to ~20 million FDTD cells). Tissue dielectric properties are assigned according to [6], while the thermal properties are derived by literature (e.g. [7]). At the thermal boundary between the head model and the ambient, a heat transfer of 5 W/(m^{2}K) at a nominal ambient temperature of 25^{0}C is assumed. Room temperature of 30^{0}C is also taken into consideration. Initial temperature of all tissues is set to 37^{0}C.

2.2. Measurement

2.2.1. System Description

Based on the focused microwave radiometry method, a prototype system (MiRaIS), including an ellipsoidal conductive wall cavity, which provides the required beamforming and focusing, has been developed for the imaging of biological tissues via remote passive contactless measurements. The measurement is realized by placing the human head in the region of the first focus and collecting the radiation converged at the second by an almost isotropic dipole antenna connected to a sensitive total power radiometer operating at the range 1-4 GHz. The system has already shown in previously performed research work [8] the capability to provide temperature and/or conductivity variations in phantoms and biological tissue. Theoretical and experimental results conclude that with the appropriate combination of operation frequencies and dielectric matching layers placed around the human head, it is possible to monitor areas of interest with a variety of detection depths and spatial resolutions [9].

2.2.2. Participants and Measurement procedure

Initial measurements were performed with the participation of five healthy volunteers. The measurements were performed using MiRaIs at 3.5 GHz operation frequency before and after usage of commercial mobile phones, three at 1800 MHz and two at 900 MHz, in sessions of 30 min duration. Each one of the participants was appropriately placed with the area of the ear lateral to the mobile phone at the ellipsoid's focus point and steady state measurements were acquired before and after mobile usage. In all cases of mobile use, all participants were instructed to keep the phone in normal usage ("cheek") position.

3. RESULTS

3.1. Numerical

Tissue peak temperature elevation (ΔT) is related to the peak spatial average Specific Absorption Rate ($psSAR_{1g/10g}$ = 2 W/kg) with reference tissue mass of 1g and 10g, as defined by [10] and [11] respectively. Additionally, ΔT is scaled to average emitted power of 0.25 W (900 MHz) and 0.125 W (1800 MHz) for typical commercial equipment. Thermal steady state is achieved in less than 20 min. Numerical results are presented in Table 1.

Table 1. Peak temperature elevation ΔT (^{0}C) in tissue for 900 MHz and (1800 MHz)

EM source	distance (mm)	Pin = 0.25 W (0.125 W) at room temperature		psSAR = 2 W/kg	
		25^{0}C	30^{0}C	$psSAR_{1g}$ [10]	$psSAR_{10g}$ [11]
linear dipole	d_1 = 2	0.173 (0.173)	0.210 (0.402)	0.159 (0.153)	0.171 (0.161)
	d_2 = 10.5	0.165 (0.162)	0.168 (0.168)	0.167 (0.160)	0.179 (0.168)
generic phone	d =10.5	0.162 (0.158)	0.164 (0.161)	0.170 (0.161)	0.184 (0.170)

The maximum peak temperature elevation is 0.402^{0}C and it is computed in skin for the case of linear dipole operated at 1800 MHz, placed at d_1 = 2 mm, in room temperature of 30^{0}C. The corresponding peak temperature elevation in brain tissue is 0.375^{0}C. Temperature distribution is indicatively illustrated in Figure 1 for the case of linear dipole operated at 900 MHz, placed at d_1 = 2 mm, in room temperature of 30^{0}C. Temperature distribution has been extracted for xz plane (y = -0.45 mm) where the peak temperature elevation has been calculated (0.210^{0}C).

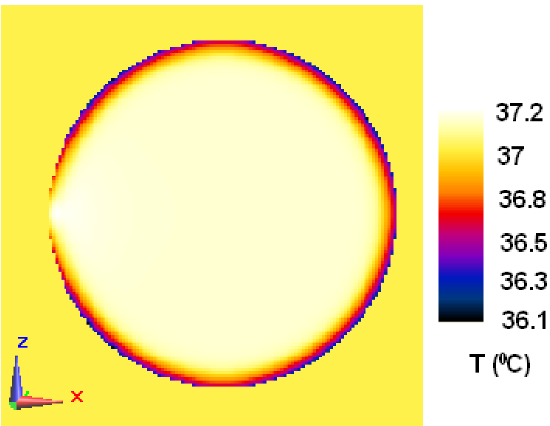

Fig. 1. Temperature distribution in (^{0}C) for the case of linear dipole operated at 900 MHz, placed at d_1 = 2 mm, in room temperature of 30^{0}C. xz plane (y = -0.45 mm) where peak ΔT is illustrated.

Figure 2 illustrates temperature values along the x-axis, for (y,z) = (-0.45, 0) mm. The peak ΔT is computed in skin at x = 9.6 mm, i.e. in depth 4.6 mm from the surface.

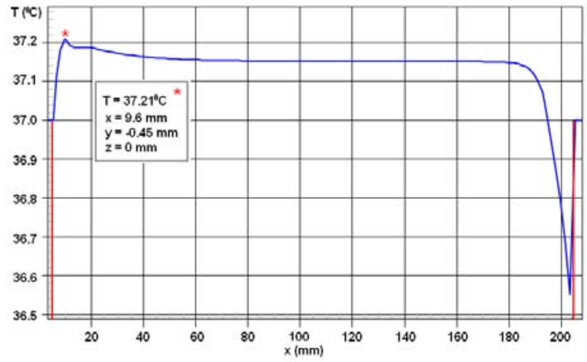

Fig. 2. Temperature in (ºC) for the case of Figure 1 along the x-axis for (y,z) = (-0.45, 0) mm. Red vertical lines indicate the sphere diameter

3.2. Experimental

Radiometric output voltage differences before phone usage compared to measurements made after using the mobile phones were in the order of 1.5 mV-2 mV which according to the system's temperature resolution with the receiver setup described above corresponds to a temperature difference of 0.8-1ºC [8]. The spatial resolution is less than 1 cm and detection depth inside the human head up to 2 cm.

4. DISCUSSION

Due to electromagnetic power absorption, the peak temperature increase is 0.402ºC and 0.375ºC in skin and brain, respectively at 1800 MHz, scaled to average emitted power of 0.125 W, for 30ºC room temperature. The values of temperature elevation are in good agreement with already published simulated data (e.g. [12]). Radiometry measurements concluded to additional temperature increase, which is probably due to i) the contact between the phone and the skin (thermal insulation) and ii) conduction of the heat produced in the phone by the battery currents and running of the radiofrequency electronic circuits transmitted to the tissue.

Future investigations will include the use of several anatomically correct head models in order to take into consideration i) the efficient heat transfer mechanisms taking place in the tissues and ii) the computation uncertainty and inter-subject variability.

5. CONCLUSION

Nowadays the number of cell phone users is increasing rapidly while the technology is constantly evolving. Numerous studies are carried out to investigate the effects of RF energy from cell phones on the human body. In the present paper an effort to numerically and experimentally assess the tissue temperature elevation due to mobile phone usage is made. The maximum peak temperature increase in brain tissue theoretically computed is in the order of 0.4ºC whereas preliminary radiometry measurements concluded to temperature increase of 0.8-1ºC.

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